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PHARE Advanced Tools Tactical Load Smoother

Final Report

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EUROCONTROL

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EXECUTIVE SUMMARY

PHARE introduced the concept of layered planning based on aircraft flying known 4 dimensional trajectories. Aircraft are expected to be accurate in 4D although there may be uncertainties in time due, for example, to delays at take-off. The first layer of planning is the Multi-Sector Planner controller who assesses the load on sectors in a Multi-Sector Area. The task of the Multi-Sector Planner is to reduce the complexity of the planning task for the planner controllers in the Multi-Sector Area. To carry out this task the Multi-Sector Planner requires information on the forecast traffic complexity in the sectors. The Tactical Load Smoother tool supplies this complexity information. Initially intended to provide functionality to the Multi-Sector Planner to allow intervention to amend traffic flows, the Tactical Load Smoother in PHARE is a tool that displays the forecast complexity of the traffic in the Multi-Sector Area up to 40 minutes in the future.

The forecast complexity is not only based on the numbers of aircraft in the Multi-Sector Area but also on the number of conflicts and the numbers of changes of vector in the area. For each sector graphs are generated and displayed showing traffic load, problem load and complexity load. Each of these values is given a threshold warning level above which the controllers may become overloaded.

A Complexity map display of the sectors shows the areas within the sectors which are exceeding threshold levels as a ‘contour map’ showing hot spots. The Multi-Sector Planner can interrogate the map to obtain a display of the aircraft that are within the hot spots. This allows the Multi-Sector Planner to amend the trajectories of aircraft using tools such as the Problem Solver to reduce the complexity of the area. The Multi-Sector Planner can alter the time of the forecast to investigate peaks in the loading levels.

The Tactical Load Smoother core software calculates the probability of aircraft being in particular positions in a sector and of their being in conflict. The probability densities are then mapped and displayed to the Multi-Sector Planner. The Tactical Load Smoother processing is intensive and recalculation is required whenever a trajectory is modified. The entire complexity map requires reprocessing when the look ahead time is changed. The processing overhead was a problem until it was solved with a more streamlined algorithm.

The Tactical Load Smoother was exercised in an Internal Operational Clarification Project at EEC in preparation for PD/3. Controllers found the displays useful and developed differing but successful methods of working. One based on classic deconfliction or simplification of forecast conflicts by separating a small number of aircraft. The other was simply spreading traffic horizontally where it was forecast to pass through a high complexity area. Both methods achieved the end result of simplifying the forecast traffic to a level that was within the capability of the Planner Controllers.

The task of Multi-Sector Planning is complex. The Tactical Load Smoother tool provides the information required by the Multi-Sector Planner to carry out the task. Further research is needed to improve the algorithms and the performance of the tool and to quantify the benefits of the layered planning approach.

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1 INTRODUCTION

1.1 SCOPE

This document is the Final Report for the Tactical Load Smoother (TLS). The TLS was developed during the Programme for Harmonised Air-Traffic Management Research in Eurocontrol (PHARE).

This document deals primarily with the development of the TLS software. This software provides the functionality of the tool. The information generated by the TLS software is of use to a relevant air-traffic controller[1] only if is displayed by means of a suitable human-machine interface (HMI). A controller can only interact with the TLS software by means of the HMI. Although the HMI is an integral part of the TLS tool, it is not dealt with in this document. The reason for this is that it is intended that the HMI of the TLS be integrated into the HMI of a Controller Working Position (CWP). Figure 1 shows the relationship between the TLS software, the HMI system, and the rest of the system.

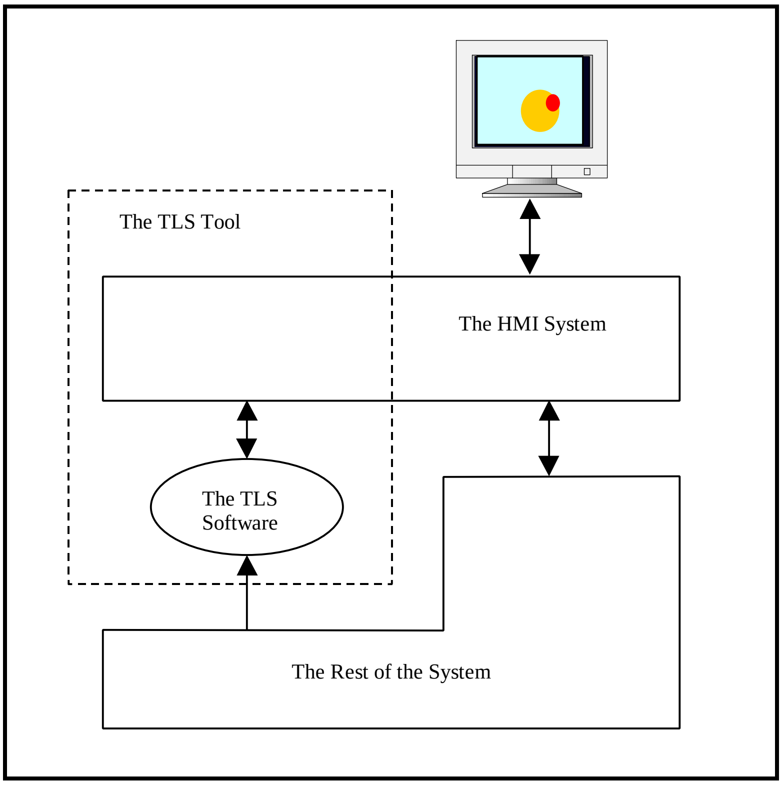

Figure 1 : The context of the TLS tool.

The purpose of this document is:

- to describe the TLS software;
- to describe the development of the TLS software;
- to describe how the TLS software has been integrated into other systems and how it has been used experimentally;
- to describe the results of those experiments; and
- to make recommendations for further work.

This document should be comprehensible to anyone with a basic understanding of air-

1 From now on, the term "controller" will be used in place of the term "air-traffic controller".

traffic control (ATC) systems. It is not necessary to have knowledge of the PHARE programme.

1.2 DOCUMENT CONTEXT

The TLS is one of nine tools that are known collectively as the PHARE Advanced Tools (PATs). The other tools are:

- the Arrival Manager [1];
- the Conflict Probe [2];
- the Co-operative Tools [3];
- the Departure Manager [4];
- the Flight-Path Monitor [5];
- the Negotiation Manager [6];
- the Problem Solver [7]; and
- the Trajectory Predictor [8].

As well as the Final Reports, an "umbrella" document [9] provides all the additional and background information that is needed. Further information about the PATs can be found in [10-11].

1.3 OVERVIEW

The TLS was developed to be an aid to controllers with the multi-sector-planning rôle known as Multi-Sector Planners (MSPs). Following the multi-sector concept, an MSP is responsible for the medium-term planning of the trajectories of the aircraft that enter the region of airspace, called a Multi-Sector Area (MSA), with which he is associated. Currently, this role does not exist in any operational ATC system.

As its name suggests, a Multi-Sector Area (MSA) comprises a number of “traditional” sectors. A different team of controllers is responsible for providing the ATC service in each sector. The purpose of the MSP is to ensure that the controllers of the individual sectors are never subjected to a workload that is so high that safety is jeopardised.

An MSP will be able to use a TLS to help him perform his tasks. The main purpose of a TLS is to predict and then analyse the air-traffic situation that will evolve some tens of minutes later in the Multi-Sector Area (MSA) with which it is associated. The purpose of the analysis is to determine the "complexity" of the predicted air-traffic situation, resulting in the generation of relevant indicators for the MSP. The MSP has to monitor the indicators to determine the times and places where the complexity of the air-traffic situation is predicted to be so high that the associated sector controllers would have an excessively difficult task. The MSP must then do something to ensure that the predicted high-complexity air-traffic situation does not occur.

There are 3 main indicators of future complexity in the MSA: the total number of aircraft; the number of conflicts; the complexity of the trajectories as assessed by number of vector changes. The look-ahead time, the length of time into the future for which the complexity prediction is made, ranges from 10 to 40 minutes.

The simplest type of indicator that is generated by the TLS software is the total number of aircraft that is predicted to be in each sector as a function of look-ahead time. The number of conflict situations that is predicted to occur in each sector as a function of look-ahead time is used as another complexity indicator. The aircraft forecast to be flying in the MSA are then broken down into the number of climbing aircraft, the number of descending aircraft, and the number of aircraft flying level.

The three types of indicator mentioned above can be displayed to the MSP for each sector in the form of a Traffic Load Graph, a Problem Load Graph, and a Complexity

Graph respectively. For each of these, a threshold level can be set. When every one of the plotted values for a particular sector is below its respective threshold, the controllers responsible for that sector should have no problem performing their tasks. If one (or more) of the values passes the threshold level, an alarm can be generated to indicate to the MSP that the air-traffic situation in that sector is predicted to becoming complex.

Before the MSP can take action information would be needed that is more precise about the predicted air-traffic situation. For this reason, the TLS software can also generate information about the level of complexity of the predicted air-traffic situation at a particular moment of time as a function of ground position. This information can be displayed on a Complexity Map. A Complexity Map is generated for the whole of the Multi-Sector Area (MSA). The main purpose of the Complexity Map is to indicate regions where the local complexity of the predicted air-traffic situation is too high. Such a localised region of high complexity is known as a hot spot.

The MSP can interrogate the TLS software to determine the identity of the aircraft whose planned trajectories are predicted to generate a particular hot spot. Having identified the relevant aircraft, the MSP can formulate a plan of action with the aim of eliminating the predicted hot spot. The MSP would have to modify the planned trajectory of either single aircraft or, perhaps, "flows" of aircraft to have an effect.

1.4 DOCUMENT STRUCTURE

This document contains nine sections.

Section 1 is this section.

Section 2 contains a description of the concept of multi-sector planning and the reason why such a concept is deemed useful. The need for a tool, the TLS, to help MSPs is stated. The context of a TLS tool is described, as is an idea of how to define the complexity of an air-traffic situation. Finally, the process of the development of the TLS software is described.

Section 3 contains a description of the requirements that the TLS tool had to meet.

Section 4 contains a description of how the TLS software was implemented.

Section 5 contains a description of how the TLS tool has been used in experiments, most notably for the third PHARE Demonstration.

Section 6 describes the results of the experiments mentioned in Section 5.

Section 7 contains the conclusions and recommendations for future work.

Section 8 contains a list of abbreviations and acronyms.

Finally, Section 9 contains a list of references.

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2 OPERATIONAL CONCEPTS

2.1 OPERATIONAL CONCEPT

2.1.1 Background

An ATC system is responsible for ensuring the "safe, orderly, and expeditious" flow of air-traffic in a specific region of airspace. Typically, this airspace is divided up into sub-regions called sectors. With a controller team assigned to each sector. The maximum size of a particular sector is limited by the requirement that its team of controllers has to be able to maintain control over all the aircraft that are in at any one time using a single radio frequency.

A team of controllers consists of at least a Planning Controller (PC) and a Tactical Controller (TC). The PC of a sector is responsible for

- monitoring the progress of the aircraft that are planned to enter the sector;
- assessing the likelihood that any particular one of those aircraft will be involved in a conflict situation in the sector;
- organising (if possible) the planned aircraft trajectories so as to prevent any predicted conflict situations from occurring; and
- determining the remaining problems that the Tactical Controller will have to deal with.

A PC should start taking account of an aircraft approximately ten minutes before it is planned to enter the sector.

The tasks of the TC of a sector include:

- monitoring the aircraft that are in the sector;
- maintaining the safe separation of all those aircraft from each other;
- ensuring that each aircraft remains in the airspace that is allotted to it (i.e. ensuring that no aircraft enters an out-of-bounds region);
- ensuring (where possible) that each aircraft leaves the sector at the expected time and at the expected place;
- negotiating new sector exit conditions with the PCs of the adjacent sectors when an aircraft cannot meet its planned sector exit conditions; and
- updating the flight plan of each aircraft, especially when it has deviated, either accidentally or because of a controller intervention, from its planned trajectory.

Normally, a sector controller looks for potential problems in the future by estimating how the air-traffic situation will evolve in the future from the current situation. To perform these sorts of tasks, a controller needs to expend a certain amount of mental effort. The amount of mental effort required is a function of the "complexity" of the air-traffic situation that has to be controlled. As an air-traffic situation becomes more and more complex, it becomes harder and harder for the relevant controllers to maintain the safe, orderly and expeditious flow of the aircraft involved. If the complexity of the air-traffic situation were to become too great, the controllers would not be able to assure the safety of the aircraft involved.

As the team of controllers for a sector must always be able to perform their tasks correctly, it is important that the complexity of the air-traffic situation in a sector is never allowed to become too great. To ensure this, the maximum number of aircraft that a particular sector can contain simultaneously is limited.

If the demand for flights requires that the maximum number of aircraft that a particular region of airspace can simultaneously contain has to be augmented, the “normal” solution is to throw more bodies at the problem. Either more controllers are assigned to the sectors concerned or single sectors can be split into two or more sectors, each of which is assigned its own team of controllers. However, a given volume of airspace cannot be continually sub-divided to reduce workload as the co-ordination workload increases with the number of sectors and eventually a point of diminishing returns is reached.

The complexity of any air-traffic situation is dependent on, amongst other things, the number of aircraft that make it up. If there are too many aircraft in a sector, the sector is said to be over-loaded. The task of the EUROCONTROL Central Flow Management Unit (CFMU) is to protect sectors from being overloaded to the extent that safety is compromised.

The CFMU processes filed flight plans to predict the number of aircraft that will be simultaneously in each sector at every instant assuming that every flight progresses as planned. The maximum number of aircraft that a particular sector can safely contain at any one time has been determined. The predicted number of aircraft in a sector at any one moment is compared with the maximum number. If too many aircraft are predicted to be in a sector at any one time, the CFMU acts to prevent the situation from arising.

The CFMU has no control over aircraft that are already airborne and cannot modify their planned trajectories. Thus, the CFMU has to act on the aircraft that are still on the ground. The CFMU is responsible for assigning take-off slots to aircraft. Usually, the CFMU assigns take-off slots about three hours before the filed requested departure time. If the CFMU predicts that a sector will be overloaded, it acts by denying the requested take-off slot to as many aircraft as is necessary to eliminate the overloading.

The (long-term) planning by the CFMU ensures that no sector should ever have too many aircraft in it simultaneously if flight plans are followed perfectly. Flight plans, however, are rarely followed perfectly. Thus, occasionally, a sector will contain too many aircraft to be handled easily. In addition, it is possible for the local air-traffic situation in a part of a sector to be too complex. If a hot spot forms in a sector, the workload of the sector TC can greatly increase.

In PHARE, the concept of exception management meant that the controller workload is linked more to the exceptions such as conflicts than directly to the number of aircraft. If the number of exceptions is high then the PC workload will be high.

There is a need to forecast complexity and identify sectors that will become too complex with, potentially, too many exceptions for the PC/TC team to handle. Once identified there needs to be a method for timely reduction of this complexity.

2.1.2 The Multi-Sector Planning Concept

One of the solutions proposed to eliminate localised traffic hot-spots in a sector is to add an additional layer of planning between the long-term planning performed by the CFMU and the short-term planning performed by the sector PCs. The role of the MSP was "invented" for the controller who would perform this medium-term planning function.

According to the multi-sector-planning concept, an MSP is responsible for the medium-term planning in a region of airspace known as a Multi-Sector Area (MSA). The sorts of sectors that can be included in a Multi-Sector Area (MSA) are en-route sectors, extended terminal control area (ETMA) sectors, and approach sectors.

The principal task of an MSP is to ensure that the PCs and TCs of the individual sectors that are included in his MSA are not subject to air-traffic situations that give them excessive workloads. To do this, an MSP has to be able to do three things. First, he has to be able to predict accurately the actual air-traffic situation that will evolve some 30 or 40 minutes later in the MSA. Second, he has to be able to determine the level of complexity of the predicted air-traffic situation. Third, he has to be able to prevent any predicted hot spots from occurring.

The task of predicting air-traffic situations for an MSP is significantly different from that of the sector PCs. First, an MSP has to deal simultaneously with many more aircraft than a sector PC does. As several sectors can comprise an MSA, an MSP could be responsible for several hundreds of aircraft per hour. Second, an MSP has to predict the air-traffic situation some tens of minutes into the future in comparison with a sector PC who has to predict air-traffic situations some 10 minutes ahead. This is necessary because, at the instant that the prediction is made, every aircraft involved in it needs to be outside the Multi-Sector Area (MSA) and expected to enter it between 10 and 30 minutes later. The location of an aircraft 10 minutes time into the future can be predicted more accurately than its location 40 minutes into the future.

It is evident that an MSP could not do his job in the same way as the sector controllers do their jobs today. An MSP could not perform all the required calculations in his head. Thus, he needs some form of help. The TLS was developed to provide this help.

2.1.3 Measures Of Complexity

As mentioned above, one of the tasks of an MSP would be to ensure that, in the Multi-Sector Area (MSA) (MSA), the sector controllers could always safely control the aircraft in their respective sectors. It would be useful if a TLS could determine the ease, or difficulty, with which a given air-traffic situation could be controlled.

The ease with which a given air-traffic situation can be controlled is called the "controllability" of that air-traffic situation. The controllability of an air-traffic situation in a sector can be defined as

$$Controllability = \frac{RequiredMentalEffort}{MaximumMentalEffort}$$

where *RequiredMentalEffort* is a measure of the mental effort required to control the air-traffic situation and *MaximumMentalEffort* is a measure of the maximum mental effort that should ever be required to control an air-traffic situation.

The mental effort required to perform a set of tasks is dependent on the number of tasks that have to be performed, their complexity (however that is defined), and the way that they are performed. Thus, the mental effort required to perform a set of tasks can, and does, vary from one person to another. As such, the controllability of a sector is dependent on the controllers that are doing the controlling.

As mentioned above, the mental effort required to perform a set of tasks is dependent on the number and complexity of those tasks. The complexity of an air-traffic situation can be defined in such a way that the greater its value, the greater the mental effort required to control that situation. Then, the *RequiredMentalEffort* is dependent on the complexity of the air-traffic situation and on the working practices i.e.

$$Complexity + WorkingPractices => RequiredMentalEffort$$

When asked about the sorts of factors that add to the complexity of a particular air-traffic situation, controllers mention:

- the number of aircraft that have to be to monitored;
- the number of conflict situations that have to be prevented;
- the types of those conflict situations (such as two aircraft approaching head-to-head, one aircraft catching up a second aircraft, one aircraft crossing the

trajectory of a second aircraft, etc)

- the speeds of the aircraft;
- the climb/descent rates of the aircraft;
- the levels of equipment of the aircraft;
- the distances of the aircraft from the sector boundary;
- the sector transit times of the aircraft; and
- the compatibility between the direction of flight of each aircraft and the normal direction of flight (as determined, for example, by the semi-circular rule) for an aircraft at the same altitude.

In this list, we have factors that are dependent on three types of relationships. Some of the factors depend on the relationships between pairs of aircraft (such as the number of conflict situations to be avoided and their types). Other factors depend on the characteristics of individual aircraft (such as their ground speed, vertical speed, and levels of equipment). Still other factors depend on the relationships of individual aircraft with the sector (such as the sector transit times, the flight level correspondence, and the proximity of the aircraft to the sector boundary).

2.2 CONTEXT DESCRIPTION

2.2.1 Overview

The TLS software has to be integrated into a system that can:

- provide the information that the TLS software requires;
- handle the information that the TLS software generates, displaying it as appropriate; and
- enable a controller to modify planned aircraft trajectories.

Figure 2 shows the relationship of the TLS with other clients and servers.

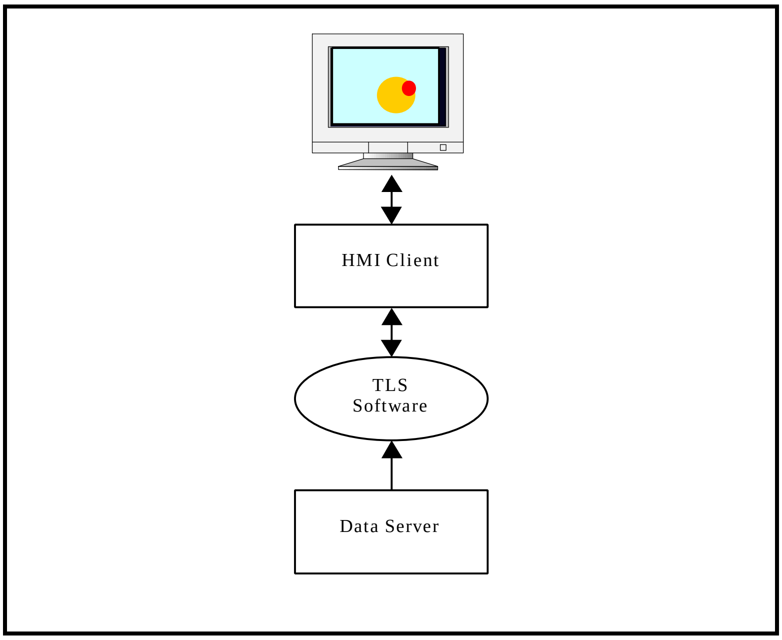

Figure 2: The context of the TLS software.

The basic purpose of the TLS software is to generate information that characterises predicted air-traffic situations and that can be displayed to an MSP. The TLS software requires various types of information to be able to perform this function correctly.

2.2.2 Required Information

The information required by the TLS software is provided by the data server. The provided information can be categorised as:

- airspace information;
- planned flight information; or
- aircraft information.

The airspace information that is required includes:

- the form of the volume of airspace associated with each sector that is in the muti-sector area;
- the location of each airport that is in the Multi-Sector Area (MSA); and
- the location of each navigation point and beacon that is in the Multi-Sector Area (MSA);

The required planned flight information is the planned 4D trajectory of each aircraft that is planned to enter the Multi-Sector Area (MSA).

The required aircraft information is the level of equipment for each aircraft that is planned to enter the Multi-Sector Area (MSA).

2.2.3 Generated Outputs

For each sector in the Multi-Sector Area (MSA), the TLS software generates:

- the total number of aircraft predicted to be in the sector as a function of look-ahead time;
- the number of climbing aircraft predicted to be in the sector as a function of look-ahead time;
- the number of descending aircraft predicted to be in the sector as a function of look-ahead time;
- the number of aircraft in level flight predicted to be in the sector as a function of look-ahead time;
- the number of conflict situations occurring in the sector as a function of look-ahead time; and
- the overall complexity of the predicted air-traffic situation in the sector as a function of look-ahead time;

The information generated by the TLS software is provided to the HMI client for displaying.

The TLS software can also generate the information to produce a map of the complexity of the predicted air-traffic situation at some particular look-ahead time as a function of ground position.

2.2.4 Events

The TLS needs to be notified of the current time at regular intervals. Thus, the TLS needs to be informed whenever the current interval has finished and the next interval is beginning.

The TLS software also needs to be informed whenever an aircraft that is of interest to it takes off or lands. If the planned trajectory of an aircraft of interest changes, the TLS software needs to be informed.

Lastly, the TLS software needs to be informed of the events generated by the display clients.

2.3 DEVELOPMENT PROCESS

2.3.1 History Of Tool Development

The ideas behind the TLS were defined in 1992. However, development of the TLS software was not started until September 1995. As no platform was available at that time, a simple ATC simulator was developed and the TLS software was integrated into it. This stand-alone system was used for all the development work.

Later, in October 1996, another version of the TLS software was integrated into the Rapid Prototyping platform at the Eurocontrol Experimental Centre (EEC). This version of the TLS software behaved as a "black box" that generated, on demand, both the Complexity Map information and the overall level of complexity for each sector in the Multi-Sector Area (MSA) as a function of look-ahead time. The zones were displayed on the radar display of the Look-Ahead Display and the graphs were displayed in separate windows. This configuration was used for an IOCP (Internal Operational Clarification Project).

Finally, in 1998, another version of the TLS software was integrated into the ESCAPE platform at the EEC. This version of the TLS software was used during that part of the third PHARE Demonstration (PD/3) that was performed at the EEC.

2.3.2 Why It Was Developed That Way

The two most important constraints that determined the architecture that was selected for the TLS software were that:

- the TLS software had to be consistent with the client-server paradigm; and
- the TLS software had to be independent of the actual platform on which it was to be integrated.

To meet these requirements, a layered architecture was selected for the TLS software. This is indicated in Figure 3.

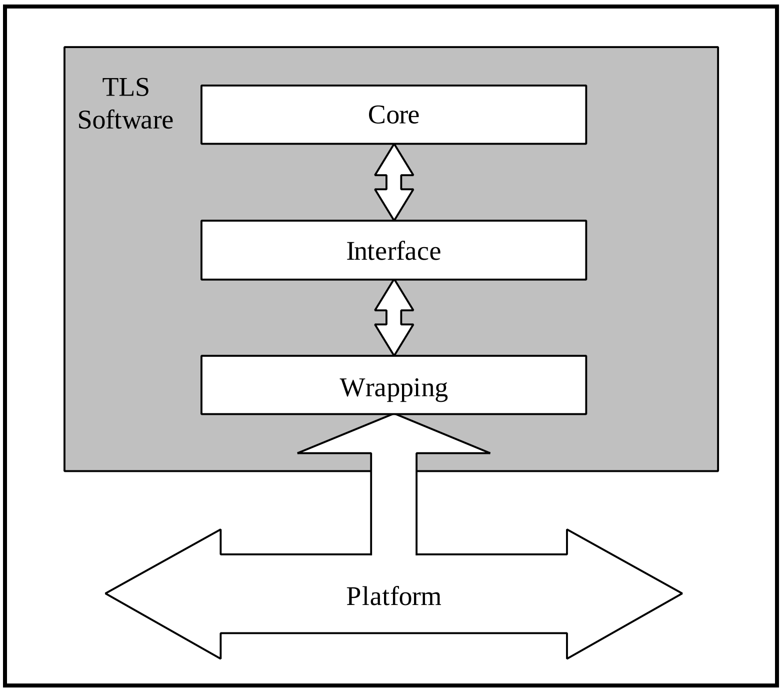

Figure 3 : The architecture of the TLS software.

All the calculations that are associated with the functionality of the TLS software are performed in the core. The interface layer behaves as an internal platform to the core; it is independent of the actual platform on which the TLS software is integrated. The wrapping layer is responsible for the communications between the interface layer and the actual platform. As the wrapping layer is highly dependent on the platform, only the core and the interface layer are intrinsic parts of the TLS software.

2.3.3 Dropped Ideas And Concepts

The TLS analyses air-traffic situations in its associated Multi-Sector Area (MSA) and then displays the results of those analyses to the MSP. However, the current version of the TLS does not provide any services to enable the MSP to solve the displayed problems.

Originally, it was thought that the TLS could be provided with some sort of "flow" editing system. Such a system would have enabled the MSP to select a set of flights that had the same or similar characteristics and then to modify their trajectories en masse. For example, the MSP could have been able to select the trajectories of all aircraft whose altitude was greater than, say FL310, and then edit those trajectories as a block so as to, for example, descend every aircraft by 4000 feet. It was decided to not develop such a flow editing system.

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3 REQUIREMENT DESCRIPTION

3.1 USER REQUIREMENTS

3.1.1 Overview

The TLS software will be associated with every MSP Controller Working Position (CWP). Such a CWP will provide the tools that an MSP requires to do his job. In the following sections, the information that should be displayed by the CWP is listed. The possible requests of an MSP are also listed.

3.1.2 Display Requirements

For each sector that is a member of the Multi-Sector Area (MSA), it should be possible to get displayed:

- the number of aircraft that is predicted to be in the sector as a function of look-ahead time;
- the number of climbing aircraft that is predicted to be in the sector as a function of look-ahead time;
- the number of descending aircraft that is predicted to be in the sector as a function of look-ahead time;
- the number of aircraft flying level that is predicted to be in the sector as a function of look-ahead time;
- the number of conflict situations that is predicted to be occurring in the sector as a function of look-ahead time;
- the overall complexity of the air-traffic situation that is predicted to occur in the sector as a function of look-ahead time;
- the maximum number of aircraft that can be in the sector simultaneously if the sector is not to be overloaded; and
- the maximum value of overall complexity of the air-traffic situation in the sector if the sector is not to be overloaded.

It should also be possible to get displayed the complexity of the predicted air-traffic situation as a function of ground position for a particular look-ahead time.

3.1.3 Input Requirements

It should be possible for an MSP to select the look-ahead time for which the complexity of the predicted air-traffic situation as a function of ground position is displayed.

It should be possible for the MSP to get displayed the identities of the aircraft that are the cause of a hot spot.

3.2 FUNCTIONAL REQUIREMENTS

The information that has to be displayed dictates the functions that the TLS software has to perform. Consequently, the TLS software should be capable of predicting accurately the air-traffic situation that will occur in the Multi-Sector Area (MSA) for look-ahead times ranging from 10 to 40 minutes.

The TLS software should be capable of analysing the predicted air-traffic situations to determine:

- the number of aircraft;
- the number of climbing aircraft;
- the number of descending aircraft;
- the number of aircraft in level flight; and
- the number of conflict situations;

in each sector of the Multi-Sector Area (MSA) as a function of look-ahead time.

The TLS software should also be capable of determining the overall complexity of the predicted air-traffic situation in each sector of the Multi-Sector Area (MSA) as a function of look-ahead time. The algorithm used to calculate a value for the overall complexity of a sector should take account of the opinions of controllers.

The TLS software should be capable of generating an alarm whenever the number of aircraft predicted to be simultaneously in a sector exceeds the pre-set threshold for that sector.

The TLS software should be capable of generating an alarm whenever the overall complexity of the predicted air-traffic situation in a sector exceeds the pre-set threshold for that sector.

The TLS software should be capable of determining the complexity of the predicted air-traffic situation in the Multi-Sector Area (MSA) as a function of ground position for a look-ahead time specified by the MSP.

3.3 IMPLEMENTATION DEPENDENT REQUIREMENTS

The TLS software has to be capable of being integrated into a number of different ATC system platforms, such as the PD/3 simulation platform at the EEC (which is called ESCAPE).

The TLS software should be implemented in accordance with the client/server concept.

4 IMPLEMENTATION

4.1 HOW DEVELOPED

4.1.1 The Architecture

The TLS software was implemented in a layered manner, as indicated earlier in this document in Figure 3. The three layers of the TLS software are:

- the core;
- the interface; and
- the wrapping.

As previously mentioned, the wrapping layer is highly dependent on the platform. For this reason, only the implementation of the core and the interface software is now described in more detail.

4.1.2 The Core

The main purpose of the core of the TLS software is to:

- predict accurately the air-traffic situation that will occur in the Multi-Sector Area (MSA) as a function of look-ahead time; and
- calculate the value of indicators that characterise the complexity of the predicted air-traffic situation.

The core of the TLS software generates information at two levels of granularity. Firstly, it generates the values of indicators that characterise the overall air-traffic situation in each sector that is a member of the Multi-Sector Area (MSA). Secondly, it generates the values of indicators that are characteristic of much smaller regions of airspace. The values of the first type of indicator can be displayed as a function of time for each sector. The values of the second type of indicator can be displayed in the form of a map.

The calculations performed by the TLS software can only have a real purpose if the results they provide bear some resemblance to reality. Thus, if the TLS software predicts that a certain air-traffic situation will occur at a certain time in the future, the actual air-traffic situation at that time must resemble the one predicted (if nothing too unexpected happens).

All the work that was carried out in PHARE was based on the definition of the PHARE Medium-Term Scenario. This scenario is based on predictions of the way the typical air-traffic situations in Europe will be from the year 2000 up to the year 2015. The medium-term scenario document [12] specifies the assumptions that were made in developing the Medium-Term Scenario. The document also lists possible options for dealing with the predicted increase in the number of flights being made.

In the PHARE concept, the path through space (otherwise known as the 3D trajectory) that an aircraft is planned to follow is described by specifying some of the positions along that path. The specified positions have to be sufficiently close together that it is possible to interpolate non-specified positions along the path without a significant loss of accuracy. Each position is specified by a set of three spatial co-ordinates (such as its latitude, longitude, and altitude). If each position is associated with a time, a 4D trajectory has been specified.

The actual 4D trajectory followed by a particular aircraft can be significantly different its planned 4D trajectory especially if the planning was done a long time before. In general, aircraft can follow their planned 3D trajectories quite accurately (in the absence of controller interactions) but to pass each specified point at the time specified is more difficult. Now, an MSP is supposed to plan aircraft trajectories 40 minutes or so ahead. In 40 minutes, a number of factors can contribute to ensure that the actual 4D trajectory followed by an aircraft is significantly different from the planned trajectory. When predicting the future trajectory of an aircraft based on its planned trajectory, therefore, there is always an element of uncertainty associated. This uncertainty increases as the look-ahead time increases.

Consider an aircraft that has a certain planned 4D trajectory. Now, because an aircraft does not usually follow exactly its planned trajectory, there will usually be a difference between the planned position, $P_{p,}$ of the aircraft at a certain time and its actual position, P_a., at that time, This difference is referred to as a position error.

If we compare many actual aircraft positions with the corresponding planned positions, we can determine the probability with which the position error (P_p - P_a) will have a certain value. We would expect the position error with the highest probability of occurring (the expected position error) to be zero as the planned trajectory is the expected trajectory.

It is useful to split the position error into an along-track component, an across-track component, and a vertical component. If this is done, the probability that a particular actual position will have a certain error component is independent of the route of the planned trajectory. See Figure 4.

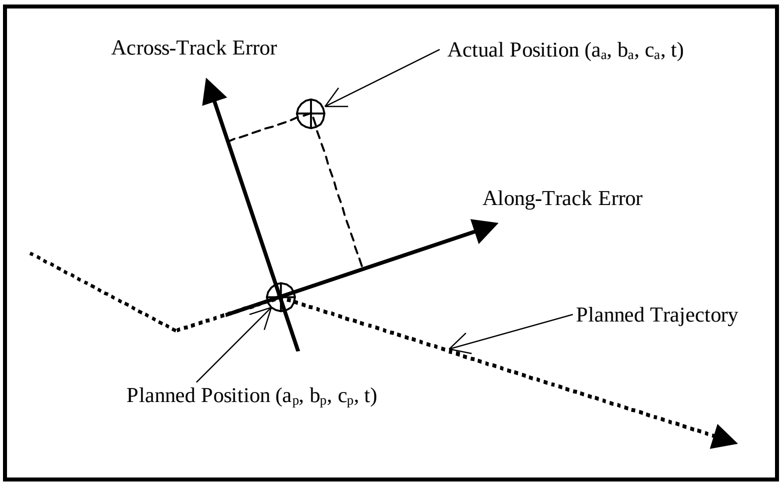

Figure 4: Along- and across-track errors.

Instead of comparing the actual and planned positions of an aircraft at the same time after take-off, we can compare the actual and planned positions of that aircraft at the same along-track distance after take-off. Clearly, if this is done, there is no longer any along-track error. However, in place of the along-track error, there can now be an error in the time at which the given along-track distance was reached with respect to the planned time. Thus, the 4D-position error can be expressed in terms of an across-track error, a vertical error, and a time error.

In the PHARE concept, each specified position of a planned 4D trajectory is associated with a small volume of uncertainty. It is as if the planned trajectory is surrounded by a tube. This tube is called a contract tube in PHARE. It defines the volume of airspace in which the aircraft has contracted to remain.

As far as the calculations that are made by the core of the TLS software are concerned, the dimensions of the PHARE contract tube around a planned trajectory are considered to be sufficient to define the uncertainties in the across-track and vertical directions. The reason why this is believed is that an aircraft usually closely follows the path planned for it. Indeed, if it appears that an aircraft will cross the boundary of its contract tube, a re-planning process is initiated.

For the temporal uncertainties, it is considered that the dimensions of the PHARE contract tube are insufficient because the look-ahead times used by the TLS software are significantly larger than the look-ahead times used by the sector controllers. In particular, at the instant that an air-traffic situation is being predicted 40 minutes ahead, a significant number of the aircraft in that situation can be still on the ground. As predicted trajectories in PHARE are calculated with respect to the take-off time, it is necessary to augment the temporal uncertainties to take account of the uncertainty in the time of departure for those aircraft. For aircraft already airborne, it is necessary to augment the temporal uncertainties to take account of possible interventions by controllers in sectors that are outside the Multi-Sector Area (MSA).

The level of equipment onboard an aircraft can also have an effect on the temporal uncertainties. An aircraft that is equipped with a 4D-flight management system (FMS) may be able to reduce the discrepancies between the planned and actual times that the aircraft passes a particular point better than a lesser equipped aircraft.

The temporal uncertainties may have different probability distributions for early and late times (as an aircraft is more likely to arrive at a given point late than early). Thus, in the TLS software, the temporal uncertainties take account of the uncertainties in the take-off time, the uncertainties in the estimated time of entry into the Multi-Sector Area (MSA), and the level of the onboard FMS equipment. In short, the TLS software defines its own version of a tube, being the PHARE contract tube with extended along-track uncertainties to account for the larger temporal uncertainties.

As stated above, in the PHARE concept, it is assumed that an aircraft in flight will always be found within the volume of airspace defined by its contract tube. This assumption is supported by the fact that if an aircraft is detected to be about to leave its contract tube, a re-planning activity is triggered resulting in a new planned trajectory and contract tube.

As far as the TLS software is concerned, an aircraft will always be found somewhere in its extended contract tube; consequently, outside the tube, there is zero probability of finding the aircraft. It is assumed that the most likely location of an aircraft is somewhere along its planned trajectory. This is because the planned trajectory, which will have been negotiated with the aircraft, should have been generated taking account of such things as the performance of the aircraft and the meteorological conditions. Away from the planned trajectory, there is a decreasing probability of finding the aircraft until this probability reaches zero at the boundary of the contract tube. The actual probability density function for aircraft in a contract tube is not known. Having no information that indicates the contrary, it is assumed that the probability of finding an aircraft at a position with a given across-track deviation in the contract tube is described by a truncated Normal (Gaussian) distribution about the predicted trajectory. The same assumption is made for the vertical deviations. The boundary of the contract tube corresponds to a certain number of standard deviations from the predicted trajectory. The along-track deviations are calculated on the assumption that if a certain planned along-track distance is reached late or early with respect to the planned time, this is equivalent to an along-track deviation at the planned time.

As the distribution of the along-track uncertainties about a point can be asymmetrical, the TLS software models the along-track probability density as a non-continuous Normal distribution. There is a 50 percent probability of finding the aircraft on either side (ahead or behind) of the predicted position but with the standard deviation being greater on one side of the point than on the other.

Given the maximum look-ahead times used by the TLS software, the uncertainties associated with the predictions become so large that it is not particularly useful to make predictions on an aircraft by aircraft basis. Thus, the core of the TLS software calculates the values of its indicators statistically.

At any particular moment of time, *t*, the probability, P_t, that an aircraft will be found in a particular elemental volume of airspace (in the contract tube) can be represented by

$$P_t = \iiint_{\text{volume}} D_t(\Delta\text{across}, \Delta\text{along}, \Delta\text{vert})\, d\Delta\text{across} \cdot d\Delta\text{along} \cdot d\Delta\text{vert}$$

where

$$D_t(\Delta\text{across}, \Delta\text{along}, \Delta\text{vert}) = f_{\text{left,right}}(\Delta\text{across}) \times f_{\text{ahead,behind}}(\Delta\text{along}) \times f_{\text{top,bottom}}(\Delta\text{vert})$$

In this equation:

- Δacross is the across-track deviation;
- Δalong is the along-track deviation calculated from the temporal deviation; and
- Δvert is the vertical deviation.

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

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

where

$$K = \left[\int_{-s}^{s} \frac{e^{-\frac{x^2}{2}}}{\sqrt{2p}}\, dx\right]$$

which is the Normal probability density multiplied by a factor, K, that compensates for the fact that the distribution is truncated at the tube boundary. s is the number of standard deviations to the tube boundary from the predicted trajectory. The TLS software uses a value of three for s; resulting in a value of K that is very close to one.

The size of the volume over which the integral mentioned above is performed should be made as small as possible. This volume is referred to as the elementary volume in this document. The limit on its size is imposed by the time taken to perform the calculations. Smaller volumes, with their better granularity, will yield a better accuracy but will require more computing power than larger volumes.

The result of all the calculations is a set of values that give the probability of finding a particular aircraft in a particular volume of airspace. These results are then mapped onto an arbitrary airspace structure. For the TLS, airspace is divided up into a series of boxes that are several nautical miles square by 1000 feet high. The probability that each aircraft occupies each box is calculated as follows. If an elementary volume is contained in a box, the probability of finding that aircraft in that box is augmented by the probability of finding it in that elementary volume. In this way, the probability of finding each aircraft in each box can be calculated.

To determine the conflict probability density in a particular box, it is necessary to calculate and sum the probability that any pair of aircraft is in conflict in the box. A conflict is said to have occurred if one aircraft approaches too close to another aircraft. Another way of seeing this is that a conflict situation arises if one aircraft is found in the exclusion volume that surrounds another aircraft. The exclusion volume is defined by the separation standards. Consequently, if a particular aircraft has a probability, P_a, of being found in a box, it could be in conflict with any other aircraft whose exclusion volume intersects that box. Assume that a second aircraft has a probability, P_v, of being found in a certain elemental volume. If the exclusion volume about this elemental volume intersects the box, there is a probability of a conflict situation occurring involving these two aircraft of P_aP_v. The probability of a conflict situation occurring in the box is augmented by P_aP_v. See Figure 5.

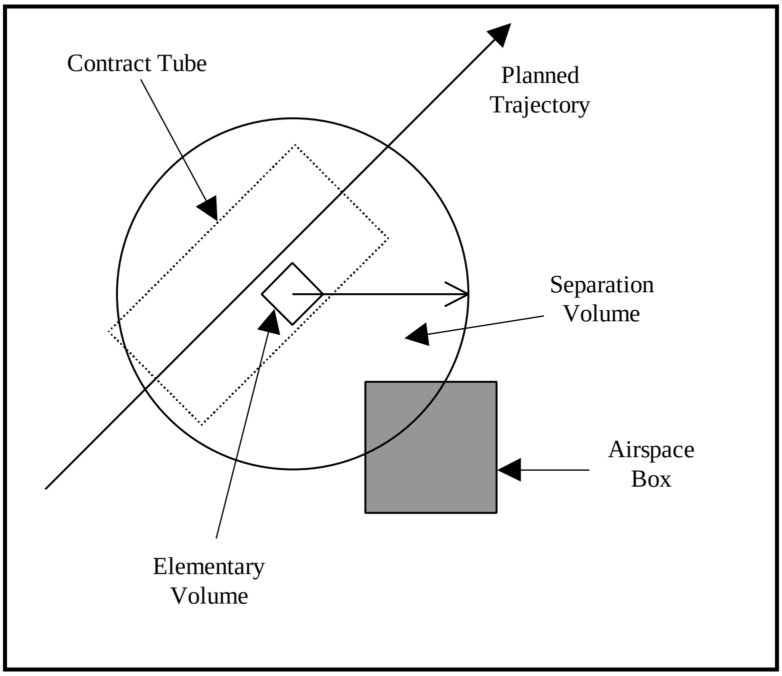

Figure 5: The conflict-density calculation

The calculation of the complexity of the air-traffic situation adds some new information to the information already gained. This new information includes information about the position of the box in the sector, the characteristics of each aircraft, the aircraft relative to its position in the sector and information related to one aircraft to another.

As mentioned above, controllers have a feeling, gained through experience, that the complexity of an air-traffic situation is affected by a number of factors.

If an aircraft is in a box that is close to the edge of a sector, the possible interventions are limited and may require additional co-ordination work (thus increasing workload). Therefore, a complexity factor has been defined to take account of the nearness of a box to the sector boundary. In the current implementation of the TLS software, this factor, S(Sector), can take one of three values, dependent on whether the box is in the centre of the sector, close to the sector boundary, or very close to the sector boundary. Intuitively, the factor increases as the box's position approaches the sector boundary.

$$S(Sector) = \begin{Bmatrix} in\_centre \\ close\_to\_edge \\ very\_close\_to\_edge \end{Bmatrix}$$

with

$$in\_centre <= close\_to\_edge <= very\_close\_to\_edge$$

This factor is calculated as a function of the distances in the vertical and the horizontal planes of the centre of the box from the edge of the sector. These two distances are compared with the respective vertical and horizontal separation standards. If at least one of the distances is less than the corresponding separation standard, the box is said to be very close to the edge of the sector. If the previous criterion is not met but at least one of these distances is between one and two times the corresponding separation standard, the box is said to be close to the edge of the sector. In all other cases, the box is said to be in the centre of the sector.

Complexity is also affected by the characteristics of the aircraft. An aircraft that has a 4D FMS may be easier to "manipulate" than a lesser-equipped aircraft. In addition, an aircraft that is in level flight is easier to manipulate than one that is climbing or descending. Furthermore, a slow aircraft is easier to deal with than a fast one. A factor, A(Aircraft), has been defined to take account of this.

$$A(Aircraft) = \begin{Bmatrix} 4D\_FMS \\ 3D\_FMS \\ No\_FMS \end{Bmatrix} \times \begin{Bmatrix} level \\ climbing \\ descending \end{Bmatrix} \times \begin{Bmatrix} slow \\ medium \\ fast \end{Bmatrix}$$

Again, intuitively,

$$\begin{array}{lllll} 4D\_FMS & <= & 3D\_FMS & <= & No\_FMS \\ level & <= & climbing & & \\ level & <= & descending & & \\ slow & <= & medium & <= & fast \end{array}$$

For the TLS, an aircraft is considered to be in level flight if its vertical speed is less than or equal to 100 feet per minute. If its speed is greater than 100 feet per minute upwards, the aircraft is considered to be climbing. If its speed is greater than 100 feet per minute downwards, the aircraft is considered to be descending.

An aircraft with a ground speed of less than 150 knots is considered as a slow aircraft whereas an aircraft with a ground speed of greater than 400 knots is considered as a fast aircraft. All other aircraft are classified as medium aircraft.

The complexity of an air-traffic situation is also thought to be a function of the length of time that each aircraft is planned to spend in the sector. If the anticipated sector transit time for an aircraft is small, there is limited scope for modifying the trajectory of that aircraft. Another factor that adds to the complexity is the flight level for each aircraft in level flight. If an aircraft is at a flight level that is not in accordance with the general direction/flight level rule, this adds to the complexity of the situation. A factor, AS(Aircraft, Sector) takes account of these factors.

$$AS(Aircraft,Sector) = \begin{Bmatrix} appropriate\_level \\ inappropriate\_level \end{Bmatrix} \times \begin{Bmatrix} long\_transit\_time \\ average\_transit\_time \\ short\_transit\_time \end{Bmatrix}$$

Once again, intuitively,

$$\begin{array}{lll} appropriate\_level & <= & inappropriate\_level \\ long\_transit\_time & <= & average\_transit\_time \\ & <= & short\_transit\_time \end{array}$$

For the TLS, an aircraft is considered to be at an appropriate level if its heading is less than 90° different from the normal heading of aircraft at that flight level and at an inappropriate level otherwise.

An aircraft is considered to have a long transit time if it remains for more than 20 minutes in the sector, an average transit time if it remains for between 5 and 20 minutes in the sector, and a short transit time if it remains for less than 5 minutes in the sector.

Finally, the relationship between pairs of aircraft has an affect on the complexity of the air-traffic situation. Aircraft that are following each other are easier to deal with than aircraft that are approaching each other head on, for example. A factor, AA(Aircraft, Aircraft) has been defined to take account of this.

$$AA(Aircraft, Aircraft) = \begin{Bmatrix} in\_line \\ crossing \\ head\_on \end{Bmatrix} \times \begin{Bmatrix} both\_level \\ both\_climbing \\ both\_descending \\ one\_level\_one\_climbing \\ one\_level\_one\_descending \\ one\_climbing\_one\_descending \end{Bmatrix}$$

Intuitively,

$$\begin{array}{l} in\_line <= crossing <= head\_on \\ both\_level <= both\_climbing \\ both\_level <= both\_descending \\ both\_climbing <= one\_level\_one\_climbing \\ both\_climbing <= one\_level\_one\_descending \\ both\_descending <= one\_level\_one\_climbing \\ both\_descending <= one\_level\_one\_descending \\ one\_level\_one\_climbing <= one\_climbing\_one\_descending \\ one\_level\_one\_descending <= one\_climbing\_one\_descending \end{array}$$

For the TLS, a pair of aircraft are considered in-line if their headings are the same to within 20°, crossing if their headings are different by more than 20° and less than 160°, and head-on if their headings are different by more than 160°.

The global complexity is calculated as

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

AA($Aircraft_i$ $Aircraft_j$) is a function of the geometry of the potential conflict situation (if any) involving the two aircraft. If there is no risk of a conflict involving the two aircraft, it has the value 1. If there is a risk of a conflict situation, it has a value of greater than one. If i = j, AA($Aircraft_I$, $Aircraft_j$) has the value 1.

A($Aircraft_j$) is a function of the level of equipment onboard the aircraft, the speed of the aircraft, and whether the aircraft is climbing/descending or flying level.

AS($Aircraft_i$, Sector) is a function of the position of the aircraft with respect to the sector boundary, the time required by the aircraft to cross the sector, and the compatibility between the flight level of the aircraft and its trajectory.

All the factors in this computation have a value that is greater than or equal to one. Some factors have the value 1, such as the factor for 4D-equipped aircraft. The values of the other constants were fixed based on the orderings of a typical set of air-traffic situations. In increasing order of complexity, for PD/3, are a single aircraft, a simple two-aircraft conflict, a complex two-aircraft conflict and multiple aircraft conflict.

4.1.3 The Interface

The interface layer of the TLS software is partitioned as shown in Figure 6.

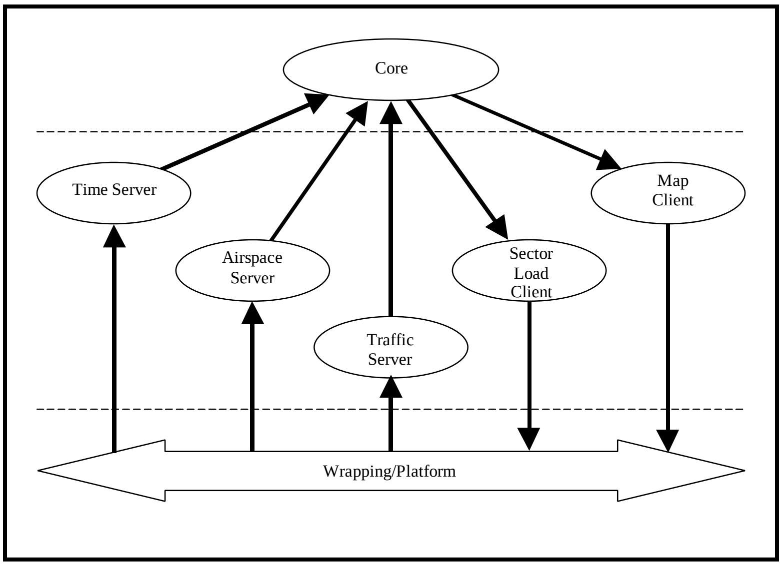

Figure 6: The TLS software interface layer.

Figure 6 indicates that the TLS software is also a client/server system. The Time Server, Airspace Server, and Traffic Server receive data and events from the rest of the system. The Sector Load Client and Map Client receive the data that is generated by the TLS core.

4.2 TECHNICAL ENVIRONMENT

The TLS software is written in C++. The TLS core and the TLS interface are independent of the platform in which the TLS is integrated. These two parts constitute the deliverable software for the TLS.

4.3 PERFORMANCE ISSUES

The calculations of the complexity require a lot of processing capability. The calculations of global sector complexity are done whenever the Sector Load Windows need to be updated. These windows need to be updated whenever a planned trajectory is modified. If no changes are made to the planned trajectories, these windows have to be updated once every minute. This ensures that the range of look-ahead times remains constant.

The calculations that are made for the Complexity Map need to be performed very rapidly once the look-ahead time has been selected.

4.4 PROBLEMS FOUND AND SOLVED

The main problem that was found with the initial versions of the TLS software was the length of time needed to perform the necessary calculations. The algorithm described in Section 4 was the solution.

4.5 UNSOLVED PROBLEMS

Controllers would like the relative significance of conflict situations to be reduced as far as the calculation of complexity is concerned. The controllers would like a "broader" view of complexity. They would like to see smaller hot spots combined to give larger hot spots. The controllers would like to see fewer problems but with more aircraft per problem.

The initial concept of the TLS was that the Multi-Sector Planner would be able to access the information on the flights within the MSA and then using that information have the ability to select and modify certain flights if required. This initial concept was dropped in favour of using the editing capability of the Problem Solver. In the longer term a multiple edit capability could be useful for Multi-Sector Planners.

4.6 LESSONS LEARNT

One of the problems that the TLS team had initially was that there was not a platform on which to integrate the TLS software. This fact lead to the TLS software being given a layered structure (which, in fact, is a bonus). Nevertheless, two versions of the wrapping software had to be written - one for the ESCAPE platform, the other for the Rapid Prototyping platform.

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5 USAGE OF TOOL

5.1 IOCP

An IOCP was performed at the EEC between October 1996 and March 1997 [13]. The controllers involved in the earlier tests did not provide too many comments about either the concept of the MSP role in general or the TLS tool in particular. The main reason for this is that the controllers were faced with too many new concepts and tools. Comments that were more useful were received after the later experiments.

5.1.1 The Displays

Figure 7 is a screen capture that was made during a run of the IOCP on the Rapid Prototyping platform. This shows the Complexity Map as well as a couple of Sector Load Windows.

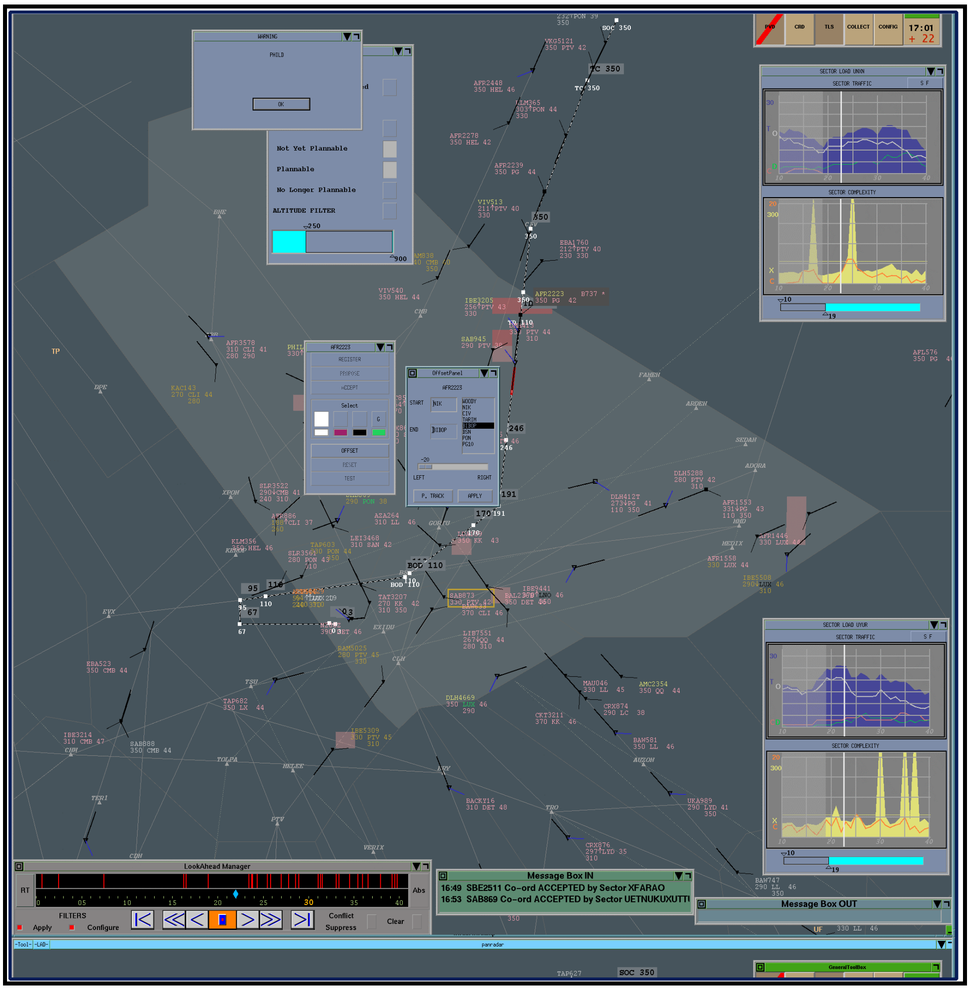

Figure 7: A screen capture from the IOCP.

5.2 PHARE DEMONSTRATIONS

The first PHARE Demonstration (PD1) was run in 1995 [14]. It was hosted by DERA and addressed a number of en-route issues. The second PHARE Demonstration (PD2) was run in 1996 [15]. It was hosted by DLR and addressed several terminal approach issues. A TLS was not required for either the first or the second PHARE Demonstrations.

The third PHARE Demonstration (PD/3) was run in 1998 [16, 17]. It was hosted by three separate sites, namely EEC, NLR, and CENA. Each of these sites performed a different experiment so that different aspects of ATC, including en-route control, Extended TMA control, and the integration of en-route and ETMA concepts could be studied.

The main aim of the experiment that was performed at the EEC was to demonstrate an air-ground integrated system in all phases of flight. PD/3 was required to show the potential for both air-space capacity and controller "productivity" improvements in a full "gate-to-gate" environment using:

- layered planning techniques to operate at scales greater than the traditional sector scale;
- the introduction of advanced computer-based tools and associated GHMI to assist controllers with their organisation and planning tasks;
- the introduction of both an arrival- and a departure-management tool; and
- the introduction of 4D trajectory negotiation and editing.

The layered planning concept in PD/3 gave responsibility to the MSP for the planning of air-traffic between 10 ad 30 minutes ahead. The sector planning controllers worked up to 10 minutes ahead before an aircraft entered the sector. Both planners were tasked with either solving predicted conflict situations (for 4D-equipped aircraft) or preparing solutions (for 3D-equipped aircraft). The sector tactical controller was responsible for implementing the solutions prepared by the sector planner, solved and implemented any other problems that arose tactically, and maintained radio contact with the aircraft.

5.2.1 The Displays

The results of the traffic density and conflict density calculations were displayed in the Sector Load Window. One window was available for each sector of the MSA. Figure 8 shows one such window.

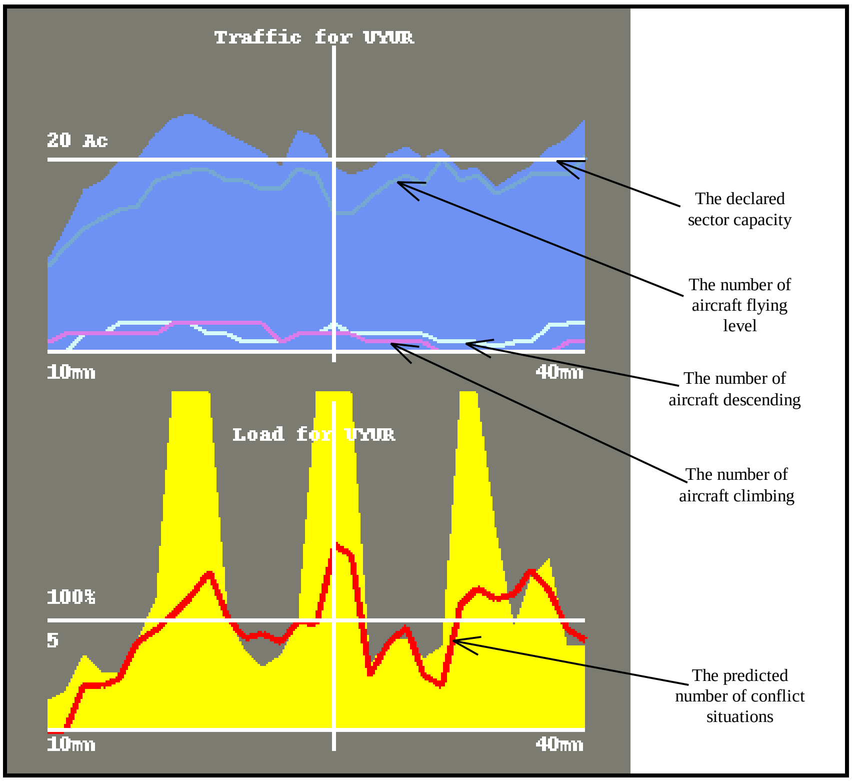

Figure 8: A Sector Load Window

The upper graph in Figure 8 is a plot of predicted traffic load as a function of time.

The time ranges from 10 to 40 minutes into the future. The traffic load is represented by the number of aircraft climbing, descending, and flying level together with the total number of aircraft. The horizontal line indicates the declared sector capacity, which is 20 aircraft here.

The lower graph in Figure 8 plots both the predicted number of conflict situations (the dark (red) line) and the sector complexity figure (the envelope of the light filled area) as a function of time. Again, the time values range from 10 to 40 minutes into the future. The horizontal reference line indicates the limit of allowed complexity under the operating conditions in force.

These graphs provide an idea of the future air-traffic situation in the sectors of the Multi-Sector Area (MSA). They are useful for indicating situations that could possibly overload the sector controllers.

To gain further information on a possible overloaded sector, the MSP could get another display shown - the Complexity Map. The Complexity Map is drawn for a particular moment of time, which is selected by the MSP. Figure 9 shows a Complexity Map.

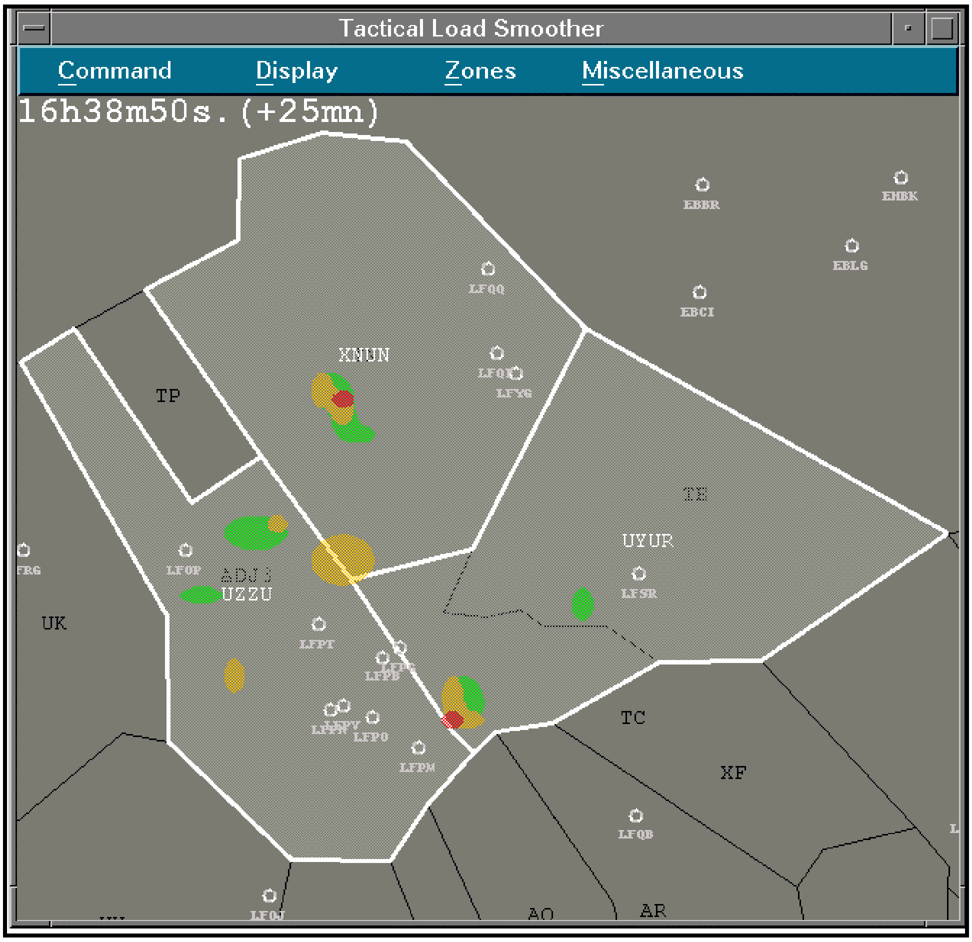

Figure 9: A Complexity Map

The Complexity Map provides a plan view of the whole Multi-Sector Area (MSA), showing predicted complexity as a function of ground position. The picture is constructed by projecting all the complexity values for a given column of airspace cubes onto the ground plane. The colour assigned to each square is determined by the worst case (greatest) complexity value that is found in the column.

This process results in a set of coloured squares on the map. For purely aesthetic reasons (i.e. the controllers prefer it that way), the squares were rounded using a Bezier function. The result is a Complexity Map as shown in Figure 9. The rounding does not appear to cause any problems as the exact locations of the boundaries of the different complexity zones is not that important.

5.2.2 Usage Of The TLS In PD/3

In the PD/3 experiments, the MSP used the Sector Load Windows as his entry point into the TLS. If the Sector Load Windows indicated a high traffic loading or a high traffic complexity at a given time, the MSP was supposed to investigate the predictions further by calling up the Complexity Map. To do this, the MSP had to click on one of the graphs displayed in one of the Sector Load Windows at a position whose time co-ordinate was at the instant when the problem was predicted to occur. The vertical line that can be seen in Figure 7 indicates the look-ahead time selected (which is 25 minutes in this case).

Once the Complexity Map had been called up, the MSP could get further information displayed. It was possible to zoom into a hot spot to obtain the identities of the aircraft that had been predicted to contribute to the problem. A close-up view of a Complexity Map is shown in Figure 10.

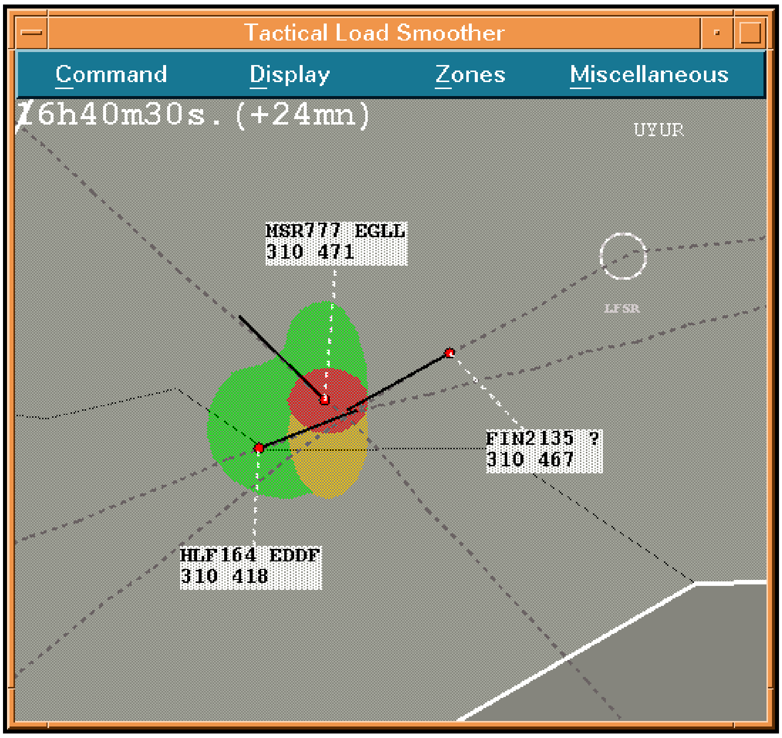

Figure 10: A Zoomed-In Complexity Map

In Figure 10, the three aircraft that contribute to the predicted hot spot are identified.

With the PD/3 HMI, it was possible to have the Complexity Map drawn for look-ahead times a few minutes earlier or later than the look-ahead time selected. This enabled the MSP to gain an appreciation of the exact circumstances leading up to the formation of a hot spot.

After analysing the predicted air-traffic situation, the MSP was supposed to use his experience to decide whether to intervene or not in some way to simplify that situation. He could do this by "editing" a trajectory.

6 RESULTS

6.1 IOCP TRIALS AND TEST RUNS

According to the controllers, most of the areas of high complexity appeared where expected, given a good knowledge of the airspace, route structure, and air traffic. The main interest for the controllers was in those regions of high complexity that were not expected.

The controllers tended to use the Sector Load Windows to gain feedback after modifying planned trajectories. They expected to see, and usually did see, the predicted complexity decrease after having re-planned.

Given the way in which complexity is calculated, conflict situations have a lot of weight. Consequently, the elimination of predicted conflict situations from an air-traffic situation lead to a decrease in the complexity of that situation. It was wondered, however, if a situation could be made less complex without the resolution of conflict situations. This was seen on two occasions. On the first occasion, a controller had to deal with a predicted conflict situation involving five aircraft. The controller (who had the MSP role) split this into two conflict situations, one involving two of the aircraft, the other involving the other three. The complexity of the situation was reduced by this. From a very complex conflict, the controller had managed to create two much simpler conflicts. On the second occasion, the controller used a lot of offset routing to spread out horizontally a flow of traffic. As he did this, he took no account of existing or generated predicted conflict situations. The complexity of the situation decreased.

6.2 PHARE DEMONSTRATIONS

The PD/3 experiment did not run sufficiently to exercise the TLS. However, a few indications were obtained. The concept of layered working was deemed useful enough to be further investigated.

Remarks made by controllers gave indications of possible developments to the TLS software. The most general feeling was that the problem zones should be larger, and so include more aircraft, but that there should be fewer areas. The problem now is that the calculation of complexity gives too much weight to the occurrence of conflict situations.

Another idea that was mentioned was to indicate the aircraft that contributed the most to a hot spot. Often, the removal of a "troublesome" aircraft could significantly simplify a seemingly difficult problem.

The final comments were relevant to how to modify the planned air-traffic situations. In PD/3, individual trajectories were re-planned by the MSP. In the future, it might be possible to manipulate a number of trajectories with a single action.

6.3 ACHIEVEMENT OF CONCEPT

Insofar as there was a multi-sector-planning concept, the PD/3 IOCP has shown that it is feasible. The TLS software, embedded in a simulation system, was able to provide an MSP with sufficient information to be able to analyse traffic over an MSA.

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7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

Because the operational scenario in which the TLS will be used was not very well defined, the TLS was developed to be as flexible as possible. The computations of air traffic complexity use information about predicted trajectories with errors. These computations do not rely on any assumptions about controllers' working methods, route structures, prediction accuracy, or aircraft equipment levels.

The experiments that have been carried out using a TLS tool have shown that it can be of use to an MSP.

7.2 RECOMMENDATIONS

Further studies should be made to try to validate the multi-sector-planning concept. It is important to refine the algorithms that are used by the TLS software in the calculation of the complexity of an air-traffic situation.

The TLS tool was developed with a particular future operational concept (the PHARE concept) in mind. This concept is based on the assumption that a proportion of the aircraft being controlled will be equipped with a 4D FMS system. However, the TLS tool could be useful in the nearer future, with its functionality similar to that that was tested during the PD/3 experiment.

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8 ABBREVIATIONS AND ACRONYMS

3D	3-Dimensional
4D	4-Dimensional
ATC	Air-Traffic Control
ATM	Air-Traffic Management
CENA	Centre d'Etudes de la Navigation Aérienne
CFMU	Central Flight Management Unit
CWP	Controller Working Position
DERA	Defence Evaluation and Research Agency
DLR	Deutsche Forschungsanstalt für Luft- und Raumfahrt
EEC	Eurocontrol Experimental Centre
ESCAPE	Eurocontrol Simulation Capability And Platform for Experimentation
ETMA	Extended TMA
Eurocontrol	The European Organisation for the Safety of Air Navigation
FL	Flight Level
FMS	Flight Management System
GUI	Graphical User Interface
HMI	Human-Machine Interface
IOCP	Internal Operational Clarification Project
MSA	Multi-Sector Area
MSP	Multi-Sector Planner
NLR	Nationaal Lucht- enRuimtevaartlaboratorium
PAT	PHARE Advanced Tool
PC	Planning Controller
PD/3	PHARE Demonstration #3
PHARE	Programme for the Harmonised ATM Research in Eurocontrol
TC	Tactical Controller
TLS	Tactical Load Smoother
TMA	Terminal Manoeuvring Area

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