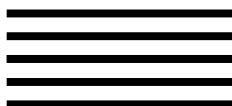


PROGRAMME FOR
HARMONISED AIR TRAFFIC
MANAGEMENT RESEARCH
IN EUROCONTROL



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PHARE

EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION, EUROCONTROL



PD/1 FINAL REPORT
Annex F
Lessons Learnt from PD/1

PHARE/NATS/PD1-10.2/SSR;1.1



EUROCONTROL

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1. INTRODUCTION

This annex has been produced by the PD/1 team to provide an insight into the running of PD/1 and will address issues associated with developing the facility, preparing and executing the trials and interpreting the results. Its primary objectives are to record the lessons learnt during the lifecycle of PD/1 and to provide an interpretation of the results. It is hoped that this document will provide useful input to not only PD/2 and PD/3 but future large scale real-time simulations.

1.1 OVERVIEW

It should be emphasised that PD/1 was not a pre-operational system. It was an experimental system that was used to evaluate the PHARE tools in a full simulation of a future ATC system. The aim was to gain knowledge on the interaction of the tools in support of a specific operational concept and also to obtain the controllers' views on the use of the tools. A programme of this nature will not and should not produce a single simple result. Even if the result was that workload decreased for the controllers with the introduction of the advanced computer assistance tools and concepts, this on its own would be of little use without knowing which aspects of the system contributed to this reduction (was it a particular tool, a procedure or some aspect of the airspace) or what was the benefit to airlines. The programme was a collaborative effort between a number of different projects each contributing elements to the system, including the following:-

- the specification of the GHMI from the PHARE GHMI group;
- the computer assistance tools from the PHARE Advanced Tools (PATs) group;
- the datalink and EFMS elements from the EFMS group.

Each of these groups requires detailed information on their aspects of the system to assist them with their on-going work programmes. Therefore, to support these groups, an extensive database of controller actions, system state and aircraft state data was recorded for each of the trials. It is hoped that from the results described here the individual groups will identify issues or aspects of the system where they require further detailed information. In response to specific questions the database can be interrogated for information.

A number of subjective and objective measures, which are described in Annex C: Results were selected by the PHARE Validation group to assess the controllers' perceived workload and performance with the PD/1 concept. The data analysed to support these measures is only a very small subset of the data recorded during the PD/1 trials. The complete PD/1 database includes data on all the inputs and selections made by the controllers during the runs together with the status of all the aircraft at that time. These data can be used to determine in detail specific aspects of controller tasks (e.g. Which tool was most used by a specific controller? How long did it take to plan an aircraft trajectory?) or aspects of a specific aircraft's flight (e.g. How many instructions was it given? How many of these were climbs, headings, speed

changes etc.?). It can also be used to assist in the interpretation of high level results, for example in the advanced organisations the number of ATC instructions given to the aircraft by the Tactical Controller can be checked against the number which would have resulted from simply implementing the plan generated by the Planning Controller. A mismatch could indicate that the Tactical Controller was not following the plan generated by the Planning Controller and the reasons would require further analysis e.g. was the plan wrong, so that the aircraft were in conflict, did the controller forget to give the instructions, as a result of misunderstanding the system or was there time pressure. This type of investigative analysis of the recorded data could be performed by PHARE teams interested in very specific aspects of the system.

It is important that the output of the PD/1 work programme must not only be based on the results of the measured trials but also on the lessons learnt during the complete PD/1 programme. For example, a great deal of information on the technical aspects of realising the operational concept was gained during the preparation of the facility. Also, during the training periods the controllers tended to be more relaxed than during the actual trials, and in this period useful information was gained on the initial views of the controllers relating to the system, concepts and ATC procedures. Throughout the trials weeks the PD/1 team were able to observe the use of the system by the subject controllers both directly and indirectly. Through performing the role of feed sector controller, members of the PD/1 team were able to indirectly observe how the traffic was being controlled by the subject controllers.

This unique knowledge comprises views, impressions and observations of the PD/1 team and resides collectively with the PD/1 team members, including those involved in the system design, the system integration, the training programme and those operating as feed sector controllers. It has been used to interpret and qualify the results obtained from the basic analysis, presented in Annex C: Results, and provides the basis for the discussion in this Annex.

This annex will also address the areas where problems arose during the development and integration and relate them to specific items such as operational aspects, GHMI development, PATs integration and simulator development. The issue of controller subjects and their training was considered to have been a major issue in PD/1, and a description of the issues relating to controller participation and training are covered in Annex B: Controller Subjects and Training.

2. SYSTEM SET UP

The following sections describe the configuration of the system at the time of the PD/1 Main Phase trials. Performance and discussion of the various elements of the facility are presented in Section 5.0 of this document.

2.1 GHMI

Two GHMI configurations were developed for PD/1, one to support the Reference System (Organisation 0) and the other to support the Advanced System (Organisations 1 and 2). The Organisations are described in Section 2.4 of this annex. The primary difference between the Reference System GHMI and that developed for the Advanced System was the introduction of facilities to support the PATs in the Advanced System. The GHMIs were implemented using X Window and MOTIF in a UNIX environment and have been coded in C. The GHMI was built as a client within the context of the client/server architecture of the PD/1 platform.

The GHMI configuration for the trials comprised two sector suites, one for NERC sector 10 and the other for sector 11. Each sector suite comprised two large screen displays, a 27" diagonal Intergraph Display for the Tactical Controller (TC) and a 20" square (2k×2k pixels) Sony Display for the Planning Controller (PC). In addition a 21" diagonal Sun display was provided for each of the two Feed sector positions. The information and data display facilities available to the TC, PC and Feed sector positions were functionally identical. Each controller was permitted to select whichever display windows they considered necessary or desirable to execute their respective tasks. All interaction with the displayed information was performed using a screen cursor driven by a three button mouse, but only two buttons were used. Control of the voice facility (i.e. intra-, inter-sector and to the pseudo pilots) was via a separate touch panel.

In addition to the GHMI provided for the trials a stand-alone version was available for training purposes. This comprised the same display and interaction facilities as for the integrated trial facility but with simulated feedback from other sectors and from the pseudo pilots. This training facility could be implemented on a variety of UNIX platforms but for the training period this was either the 27" diagonal Intergraph Displays, 20" square (2k×2k pixels) Sony Displays or 21" diagonal Sun monitors.

2.2 GROUND SYSTEM (TOOLS)

The tools available for the Main Phase Demonstration were dependent on the Organisations being simulated. By definition the PATs were only used in the Advanced System to support Organisations 1 and 2. The following sections contain information on the tools available in the Reference and Advanced Systems.

2.2.1 Reference System

The Reference System did not contain any of the PATs but it did contain a Vertical Assistance Window (VAW), Horizontal Assistance Window (HAW) and a Conflict Risk Display (CRD). The information displayed in these windows was derived from system state data and potential conflicts at waypoints.

2.2.2 Advanced System

The PD/1 platform was developed by modifying and enhancing the UK NATS Research Facility (NRF). This facility uses a client/server architecture and provides the basic building blocks required for the PD/1 platform. The following PATs were integrated into this platform:-

- the Trajectory Predictor (TP);
- the Conflict Probe (CP);
- the Flight Path Monitor (FPM);
- the Highly Interactive Problem Solver (HIPS).

The integration was performed using the PHARE CMS API interfaces developed for these tools. A “bridge” was designed and implemented between the CMS API structures and the existing NRF API set to enable the two API structures to co-exist on the same platform.

2.3 TRAFFIC SAMPLES

The traffic samples used during the Main Phase Demonstrations were mixed populations of aircraft (eg including military) selected to give low, medium and high traffic loads to the controllers. Two categories of aircraft were used: 3-D FMS equipped and 4-D FMS equipped. The 4-D FMS equipped aircraft had a full duplex datalink and were only present in Organisation 2 either as 30% or 70% of the sample. The distribution of aircraft in these samples was verified during the two Pilot Phases.

2.4 OPERATIONAL PROCEDURES

The PD/1 Operational Scenarios document, reference 1, and the PD/1 Training Manual, reference 2, both contain information on the operational procedures devised to support the three PD/1 Organisations. The salient points of the operational procedures developed for each Organisation are given in the following sub-sections.

2.4.1 Reference System (ORG 0)

The Reference System has the following characteristics:

- planning anticipation as in current systems;
- mixed aircraft population (as foreseen for year 2000) with 3 flow rates (low, medium and high);
- current controller roles of Planner and Tactical have been retained;
- derived from ODID which operates without paper flight strips and with simple aids (e.g. Conflict Risk Display, Entry/Exit Aids);
- airspace is NERC sectors 10 and 11 with adjacent feed sectors.

The procedures used for Organisation 0 were based on those to be used in the UK NERC. In this environment the overall control task is shared between a Planning Controller (PC) and a Tactical Controller (TC). The PC is in an advisory role and the TC retains full executive control of the aircraft.

The PC is responsible for co-ordination of traffic offered into his sector and co-ordination of traffic leaving his sector. He or she will continuously compare the information available on sector inbound traffic with the traffic situation within the sector to determine whether any potential conflicts exist. This includes sector entry, sector exit and sector transit conflicts. If a potential conflict is identified then attempt will be made to negotiate new entry/exit conditions with the requisite sector. Co-ordination is on flight level or position only.

The TC is responsible for ensuring conflict-free passage of aircraft through the airspace and achieving co-ordinated levels. The TC performs all direct communication with the aircraft in the sector and is responsible for all transfers. The offering TC will be responsible for ensuring that co-ordination takes place before an aircraft reaches the adjacent sector's airspace.

2.4.2 Advanced System (ORG 1)

ORG 1 has the following characteristics:

- advanced conflict-free planning based on a sector by sector lookahead time;

- mixed aircraft population (as foreseen for year 2000) with 3 flow rates (low, medium and high);
- computer assistance tools, as listed in Section 2.2.2;
- controller methods reflect the extended look ahead and conflict-free planning;
- airspace as in the Reference System.

Organisation 1 differs from Organisation 0 by the quality of information provided to the TC from the PC. In ORG 1 the PC is equipped with computer assistance tools which enable him to provide additional support information to his TC through the mechanism of advanced planning. The PC attempts to produce a complete conflict-free sector transit plan for each aircraft which is then displayed to the TC in the Communications List Window (CLW) as a set of instructions which the TC will subsequently verbally communicate to the aircraft at the indicated times.

The TC also has available the same tools as the PC; however, given the time horizon in which the TC operates, these are of little practical use. The TC's major tasks are as for ORG 0, but he also has the additional task of monitoring the deviation alerts generated by the Flight Path Monitor (FPM) and taking the necessary corrective action.

2.4.3 Advanced System (ORG 2)

ORG 2 has the following characteristics:

- advanced conflict-free planning based on a sector by sector lookahead time;
- mixed aircraft population (as foreseen for year 2000) with 3 flow rates (low, medium and high), 4-D FMS equipped aircraft with full-two way datalink introduced in the traffic samples in varying proportions 30% and 70%;
- computer assistance tools, as listed in Section 2.2.2;
- controller methods reflect the extended look ahead, conflict-free planning and handling of 4-D FMS equipped aircraft;
- airspace as in the Reference System.

Organisation 2 differs from Organisation 1 by the inclusion of 4-D FMS equipped aircraft and a two-way datalink for communication with these aircraft. In Organisation 1 the TC is provided with a list of instructions, describing the planned trajectory, which is passed verbally to the aircraft at the time indicated. In Organisation 2 the planned trajectory for a 4-D FMS equipped aircraft is communicated to the aircraft via the datalink as a series of constraints. Non-equipped aircraft are handled in the same way as in Organisation 1.

2.5 MEASUREMENT METHODS

The measurement methods and analysis applied in PD/1 were defined by the PHARE Validation Tools group. This group worked closely with the GHMI group during the specification phase so that a cross over of ideas could occur. The Validation Tools group were tasked to identify the analysis to be carried out on data collected from the trials and to assist with the subsequent analysis task.

The Validation Group established a set of parameters and data to be recorded during the execution of the trials. This included data relating to the PATs, interaction with the GHMI, and voice communications, these are detailed in reference 3.

The techniques to be used to collect the data comprised the following:

- computer recording of data from the PD/1 platform;
- Instantaneous Self Assessment (ISA);
- video recording of the controllers during the exercises;
- recording of all voice traffic (inter-sector, intra-sector and to the pseudo pilots);
- debriefing of controllers using questionnaires.

2.6 PSEUDO PILOTS

Six pseudo pilots were used for each trial run, two for each measured sector and one per feed sector. All pseudo pilots had been fully trained on their facility and were fully conversant with the R/T procedures and dialogue expected by the controllers for aircraft traversing the selected airspace. They are employed on a casual basis whenever required for a trial but come from a pool of such people which has been established to support a range of national trials as well as PD/1.

3. TRIAL

3.1 TRIAL PLAN

The second Pilot Phase trials (September - October 1995) used the same set of controllers as the first Pilot Phase (March - April 1995). These controllers also took part in the Main Phase trials along with a further twenty four controllers. During the period of the Main Trial two controllers had to drop out. One was replaced by a new British controller who was given intensive training over two days and then took the tactical controller role. The other controller was replaced by an ex-LATCC controller from the EUROCONTROL Experimental Centre who was helping with training. Although there were reservations about using someone who was so closely connected with the trials, there was little choice other than to re-use one of the retired British controllers who had already taken part in the trial.

The following table identifies when the various groups took part in the training and the trials. The groups that took part in the second Pilot Phase had been trained prior to the first Pilot Phase and hence did not undergo a second formal training period.

Week Group	Training			Second Pilot Phase				Main Phase							
	36 04/09	37 11/09	38 18/09	39 25/09	40 02/10	41 09/10	42 16/10	43 23/10	44 30/10	45 06/11	46 13/11	47 20/11	48 27/11	49 04/12	50 11/12
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4															

A number of different assessment and data collection methods, as described below, were applied at specific times during the phase.

Start of the Trials Weeks

Each controller was asked to fill out a personal information record sheet to provide background information such as their previous ATC experience and validations.

During Each Trial

Three methods of data collection were used.

First, since this was only a Pilot Phase, there were experimental scientists, training and software staff standing by in the simulation room to instantly discuss points raised during the runs and to help controllers over difficulties.

Second, controllers were provided with a two page proforma. The first page of this was for them to record during and immediately after the runs any notable occurrences, problems or other points for later discussion and the second page was a self-assessment rating scale for skill level. These notes were collected after each run. Specific comments relating to traffic samples, software and tool functionality were fed back on a daily basis to the system design team.

Third, video and audio recordings were made of the controllers and their workstations.

After Each Major Run or At the End of a Significant Series of Runs

The controllers were debriefed in a guided group session. During these debrief sessions programmer and other experimental staff were present to deal instantly and in the most appropriate way with points raised and agree modifications where these were fully justified.

End of Trial Week

The controllers were asked to fill out a questionnaire detailing in general terms their reactions to the simulation in any of its aspects including training, scenarios, tools and HMI.

3.2.1.2 Second Pilot Phase

As with the first Pilot Phase the data collection during the second Pilot Phase was not assessed against the specific objectives of the PD/1 Main Phase. The objectives of the data collection during this phase were as follows:

- refinement of the assessment and data collection methodology to be applied to the Main Phase of PD/1;
- practice for all experimental staff in the business and techniques of a large scale simulation;
- practice for the assessment team in the various aspects of debriefing and questionnaire application to trials.

These were basically the same as for the first pilot phase. However, there was very little time to make modifications to the system and so any changes were limited to correcting errors.

The same methods of data collection were used as for the first pilot phase. In addition, towards the end of the second Pilot Phase the ISA (Instantaneous Self Assessment) boxes

were integrated into the system and were tested during some of the trials. This testing showed that there were problems with the software which collected the input from the boxes and this was notified to DLR who provided updated software. Earlier delivery of the items to be integrated would have made it much easier for the PD/1 team to fully test the system prior to trials periods and hence identify any problems.

3.2.1.3 Main Phase

During the Main Phase the aim was to collect data which would be used to test the specific objectives of PD/1. The same methods of data collection were used as had been tested during the Pilot Phases. However, some problems were encountered during the trials with collection of data. The PD/1 development team were not supposed to be involved in debriefing controllers as it was thought that they might lead the questioning. The Validation team however did not have sufficient personnel or adequate experience of the system to fully debrief the controllers and in addition many of the comments made by the controllers were over coffee and lunch breaks and were therefore not formally recorded.

It is important that the controllers are made fully aware of the fact that they are taking part in a trial and not the evaluation of a pre-operational system. If possible this briefing should be given by a controller who is fully familiar with both the facility and the objectives of the trial, since controllers tend to accept information more readily from another controller rather than from a non-controller. In addition, the controllers must not regard the trials as a test of their personal abilities but as an evaluation of a concept; this should be stressed during the training course and repeated during the trials.

The number of runs necessary during each week of the trial was determined by the need to gather data for analysis. Some of the controllers found that the four runs a day were very tiring and quite stressful.

The controllers that took part in the Pilot Phases were again used as subjects during the Main Phase which, with hindsight, proved not to be a good idea. Some of the suggestions made by these controllers were not incorporated into PD/1 for a number of reasons: the ideas were not unanimous or they could not be implemented in the time available, others would have changed the underlying operational concept, and some would have been useful in a pre-operational evaluation but were inappropriate for an experimental system. Despite the PD/1 team's efforts to explain that all their suggestions had been considered fully, these controllers could not always comprehend why their ideas had been 'ignored' and were therefore were frustrated at being asked to work with a system that they felt to be incorrect.

4. PD/1 PROGRAMME EXECUTION

Throughout this section one issue will continuously re-occur and that is the need for a full time Project Leader and team who on a day-to-day basis organise and undertake the programme of work. Early in the project, NATS indeed recognised this need and appointed a PD/1 Project Leader and a full time, core, team. This is particularly important for a large scale collaborative project, such as PD/1, where the different components were developed by diverse teams whose objectives and timescales were not necessarily directly related to those of the PD/1 programme. There has to be a single person who can maintain an overview of the programme, the deliverables from the other groups, and be in a position to react and address problems as they occur.

In addition, the project team have to be able to provide the software “glue” which is necessary to integrate the individual components (the PATs, GHMI, EFMS and the host platform) to provide a complete and consistent simulation package. They also have to organise the training and the general logistics for the trials (hotels, transport for the participating controllers and visitors).

The following sections will address the experiences gained and observations made during the development of the programme and the execution of the trials.

4.1 GHMI

The method of working established to develop the GHMI to support PD/1 was that the specification would be produced by the PHARE GHMI group and the implementation performed by the PD/1 team at DRA Malvern. Whilst this strategy was followed fairly rigorously during the development of the Reference System (ORG 0) it proved necessary to adopt a much more interactive approach for the development of the Advanced System (ORG 1 and ORG 2). The development of the PD/1 GHMI through the project development and Pilot Phases is discussed in the following sub-sections.

With respect to the GHMI a careful balance has to be achieved between the extra effort required in seeking to develop the ultimate GHMI versus one that is able to provide an adequate interface for the controllers to perform the demonstration successfully. In the context of PD/1, ‘successful’ means that the interface should not frustrate the controllers or preclude them from carrying out tasks they deem to be essential.

4.1.1 Reference System

The specification of the PD/1 Reference System GHMI was based on the interface developed to support the ODID trials performed at EEC Brétigny and hence the concepts had already had a degree of controller exposure and comment. Using the information and controller comments from the ODID exercise enabled the GHMI specification team to produce a detailed specification with a considerable degree of confidence, even without a prototyping phase.

Following the delivery of the GHMI specification, the PD/1 team implemented it and distributed stand-alone interactive versions of the facility to the PHARE partners. There was sufficient simulator functionality built into the stand-alone facility to enable the GHMI to be fully exercised. Several improvements/modifications were identified via this path and were fed back into the specification.

4.1.2 Advanced System

The development of the Advanced System was complicated by the fact that there was no existing system which could be used as a starting point for the operational procedures. Hence the data interaction and presentation features necessary to support the ORG 1/2 concepts needed to be developed from first principles. Therefore, the initial GHMI specification could not be as precise or complete as had been produced for the Reference System. This resulted in the interface being developed from a series of working papers and discussions between the PD/1 team and the PHARE GHMI group. The net result of this approach was that the PD/1 team was implementing and prototyping the GHMI at the same time as the GHMI group was updating and reworking their specification.

The production of working papers and new ideas continued up to the start of the Main Phase demonstrations and no complete specification of the Advanced System was produced. In practice this meant that some of the latest thinking of the GHMI group could not be implemented and, in addition, some ideas developed by the PD/1 team which were necessary to produce a coherent working facility were implemented without formal consideration by the GHMI group.

It was not always appreciated that although the visible part of the GHMI, namely the windows, buttons, menus etc., could quickly be developed, the determination and implementation of the underlying logic to enable the required interactions to take place took significantly longer.

4.1.3 Observations

As the controllers' only view of the system is through the GHMI, it is inevitable that problems which actually relate to deficiencies in other elements of the facility but which manifest themselves in the GHMI (e.g. PATs, system performance etc.) will be considered by the controllers together with those of the GHMI itself. It is for this reason that it is essential to have staff fully conversant with all elements of the facility available during the debriefing, in order to explain and attempt, by further questioning if necessary, to determine the root cause of a specific problem or comment. The comments received and observations made have been categorised into the following groups to facilitate the discussions:-

- those relating to the "look and feel" of the GHMI;
- those relating to deficiencies in other elements of the system but which become visible through the GHMI;
- those relating to GHMI functionality;
- those relating to errors or inconsistencies in the GHMI.

4.1.3.1 Look and Feel

The results of both the first and second Pilot Phase showed that, whilst not formally measured during the trial, the response time of the interface strongly influenced the controllers perception of the system. This was most apparent in the operations which required intensive on screen manipulation of features e.g. track data block repositioning or trajectory manipulation in the HIPS. The two Intergraph workstations used for the Planning Controller positions were replaced for the Main Phase trials with Sony large screen displays with Metheus drivers. This combination provided acceptable response times for the Planning Controllers. The Tactical Controllers continued to use the Intergraph workstations in the Main Phase demonstrations, but some reported high frustration levels on their TLX questionnaires after heavy traffic samples in part as a result of graphics response time. The argument put forward that PD/1 was evaluating concepts rather than GHMIs and hence that providing the response time of the GHMI was reasonable it was not of primary importance to the results was therefore not valid. The controllers were being asked to perform a novel role with new tools and anything which distracted them from this task had a detrimental effect on their assessment of the facility. Some controllers stated that their responses to ISA prompts were not influenced by how busy they felt but by how frustrated they were with the system.

The controllers' impression of the presentation of the information, the colours and the input mechanism, was generally favourable. Naturally, as was expected, certain controllers had suggestions for change either based on the experience of their own systems or as a result of using the PD/1 interface. Some of these will be discussed in subsequent sections, but as stated previously care has to be taken in distinguishing between GHMI specific issues and

topics which relate to other elements of the system but only become apparent to the controllers via the GHMI.

The best commentary on the look and feel of the GHMI was that very little comment or discussion was had on what colour should be used for specific items, whether the right input device was used etc.. This allowed more time for discussion of the objectives of the demonstration.

4.1.3.2 Outside Dependencies

These outside dependencies concern components and functionality of the system that are not directly related to the GHMI but which resulted in comments about the GHMI. The majority of comments in this category concerned the interaction between the Trajectory Predictor and the HIPS. The PATs issues associated with each of these tools will be discussed in Section 5.2. The HIPS provides an approximate planned trajectory which then has to be submitted to the Trajectory Predictor for validation. The subsequent validated trajectory is then re-displayed in the HIPS window. The two trajectories, as expected, can differ in detail as the HIPS is based on a simple graphical solution of merely joining constraint points whereas the Trajectory Predictor takes into account such factors as aircraft performance, weather etc.. These differences could sometimes result in a 'trajectory' produced using the HIPS subsequently being 'failed' by the Trajectory Predictor as there were still conflicts with other aircraft. For some controllers it proved very difficult to explain these differences and the tendency was to criticise the GHMI. This problem was compounded by the fact that some of the outputs from the Trajectory Predictor were 'strange', see Section 4.2.2. (Note. The requirement for rapid responses when using the HIPS meant that the full TP could not be used at all stages of the trajectory design process.)

4.1.3.3 GHMI Functionality

With respect to the GHMI functionality a careful balance has to be achieved between the extra effort required in seeking to develop the ultimate GHMI versus one that is able to provide an adequate interface for the controllers to perform the demonstration successfully. In the context of PD/1 'successful' means that the interface should not frustrate the controllers or preclude them from carrying out tasks they deem to be essential.

Understandably controllers views of what features are necessary varied. This was dependent on their background and the ATC systems they had already been exposed to. There were also considerable differences in the way controllers viewed the GHMI. Some viewed it as a tool for operating the simulation and, providing that basic mechanisms were available, were willing to accept that they may not be optimal, e.g. the algorithms for avoiding label overlap, others wanted everything optimised. The latter group of controllers were those who had the greatest difficulty in accepting the trials as an evaluation of a concept rather than the evaluation of a pre-operational system.

The degree of experience with an interface has a direct effect on the mechanisms required; for example when the controller is unfamiliar with an interface then more guidance and support is required from the system. With greater exposure, additional flexibility may be required, e.g. provision of short cut mechanisms for regularly executed operations. The controllers only had two weeks to learn the system and take part in the trials and hence were not at the stage where short-cut mechanisms are required. There were numerous mechanisms that were implemented in the PD/1 GHMI that were not used during the trials. An example was the extensive shape coding and annotation of constraint points in the HIPS windows. A simple distinction between altitude and non-altitude constraints was all the controllers used and understood. PD/3 should be very cautious in this area, as considerable amounts of time

can be used up in specifying, discussing, implementing and testing mechanisms that will not be used during the trials.

It should be emphasised that the PHARE Demonstrations are designed to demonstrate and evaluate a specific concept against a set of objectives. They are not intended to be a development of a pre-operational system. Therefore, the aim should be to provide an interface that is as simple as possible whilst able to meet the requirements of the trials.

4.1.3.4 Errors or Inconsistencies in the GHMI

There were a group of errors or inconsistencies in the GHMI which gave rise to comments from the controllers. These were either as a result of inconsistencies in the specification, errors in the implementation or a lack of operational procedures to address the specific item.

The 'solution' to the problems of errors and inconsistencies is obvious; more time is needed for specification, implementation and testing, but again there is a balance to be struck between the effort required and the benefits of achieving a more nearly perfect system. It is the solution to the lack of consistent operational procedures that needs addressing. The easy answer would be to say that a person with a recent operational background should be available at all stages of the project. However, there are practical difficulties associated with this approach and these are discussed in Section 4.3.

4.1.4 Conclusions

There were several things that became apparent during the specification and development of the GHMI that are worth addressing in this document.

For the Reference System (ORG 0) the operational procedures were well understood and the GHMI specification could build on the experience gained from ODID. This was not the case for the Advanced Organisations where both the operational procedures and the functionality were new. In this situation there was a need for a high degree of interaction with operational staff and the PATs developers during the specification of the GHMI.

The necessary degree of interaction did not take place fully, as operational staff with an understanding of the concepts were not available and the eventual delivery dates for the PATs were not sympathetic to the needs of GHMI development. Hence, the GHMI team had to make a large number of assumptions as to operational procedures and the type of data available from the PATs during development of the Advanced System specification. The result of this was that, in the absence of a detailed requirement, the GHMI team attempted to provide for all eventualities, thus delaying the specification and also seeking functionality which was not actually required by the PATs. Again there is a trade-off here; waiting for a complete specification to be available could extend the project timescales.

Following receipt of the specification the PD/1 core team was required to design and build both the GHMI and the software necessary to integrate the GHMI with the rest of the system. This emphasises the need to have a core team that is fully conversant with all aspects of the simulation who can act as brokers between the various groups in order to produce a coherent system.

4.2 GROUND SYSTEM (TOOLS)

The PATs were central to the PD/1 concept and as such their correct operation was essential to the system. Whilst considerable re-working was performed by the individual PATs teams

on their respective tools following the first integration test, it was evident during the final integration that there had still been little consideration of the interaction between the tools. One example is the definition of error tubes around the aircraft's forecast trajectory; each tool had an error tube defined, but their definitions and use were not consistent. Again the core team had to develop a significant amount of software to manipulate the data passing between tools to ensure consistency and interoperability.

When considering the integration of the PATs into the simulator, it is important to note that it is only necessary for individual tools to operate according to their own requirements; they cannot be expected to know about the operational concept under which they will operate. For example the Trajectory Predictor is expected to attempt to generate a trajectory from a series of constraints. It cannot be expected to know where the constraints came from or where the output trajectory needs to be sent (i.e. the GHMI, the Conflict Probe or HIPS etc.).

It is the responsibility of the core team to integrate the individual tools and to develop the software to co-ordinate the operation of the tools within the simulator as a whole. In the case of PD/1 this 'glue' software, amongst other things, provided the mechanisms for scheduling the tools, passing data between the tools, negotiating trajectories with the simulated and live aircraft and providing the data output from the tools in a format suitable to drive the GHMI. This meant that the PD/1 core team were required to develop a detailed understanding of the operation of the different tools. This further emphasises the need to have a single dedicated team responsible for the execution of the simulation.

The following sections will address some of the controller comments and identify some problems that were noted with individual PATs. When addressing the comments relating to the PATs it is necessary to consider each of the tools used in PD/1 individually and to be careful to attribute the comments to the correct tool. The PD/1 toolset was centred around the Trajectory Predictor and hence its operation was critical to the controllers' perception of the tools in general. The Highly Interactive Problem Solver (HIPS) provided a mechanism for editing and viewing trajectories, the Conflict Probe provided information about potential conflicts between trajectories, with the Flight Path Monitor signalling any deviation of the aircraft from the trajectory.

The comments relating to the tools operation were split into two categories as follows:-

- perceived incorrect operation due to misunderstanding;
- suggested improvements.

The first category is dealt with in Section 5 and the second category is addressed in the following sub-sections.

4.2.1 Highly Interactive Problem Solver

The HIPS met with a high degree of approval from the Planning Controllers (see Annex D) and a number of constructive comments were made suggesting modifications and enhancements which, according to various controllers, would improve the usability of the tool. The main ones are presented below:-

- when aircraft are potentially in conflict, the controllers consider that it is more desirable to climb one aircraft behind another, once the potential conflict has passed, rather than in front, as the consequences of a late or slow climb are less critical. Therefore, they considered that the conflict zones in the HIPS profile (height) window should provide differing indications of errors when an aircraft was planned to climb in front or behind other aircraft. The results of the simple geometric calculation of separation currently presented in the HIPS caused

concern to the controllers. Although the separation was within the specified criteria, their perception of what constituted safe criteria was different;

- the speed profile window was considered difficult to use and interpret. This was due in part to the fact that the speed was not displayed directly within the window. Instead, it was represented indirectly as the time at a point relative to an average speed. The controller is then able to propose an earlier or later time at that given point;
- when manipulating the trajectory within the HIPS windows it was not possible to see very far into the previous or next sector. This resulted in some, apparently valid, trajectory proposals failing due to unseen manoeuvre planned for the aircraft in adjacent sectors;
- it was generally considered that the ability to set up parallel routing using the HIPS lateral display would be an advantage.

4.2.2 Trajectory Predictor

The Trajectory Predictor was central to the operation of the Advanced Organisations and hence it is not surprising that the majority of comments on the tools were related to its operation. The major problems with the Trajectory Predictor were related to the unexpected outputs generated from the sets of constraints. Some of these were erroneous, non-flyable trajectories, but the majority were acceptable trajectories although not necessarily what was expected by the controllers.

4.2.3 Conflict Probe

Most discussion concerning the Conflict Probe related to the differences in conflicts detected by it and the HIPS, which were especially noticeable in the climb phase of flight. This was due to differences in the algorithms used by the two tools for detecting conflicts. These differences highlight the problem of interoperability of the tools as both tools met their individual requirement specifications.

4.2.4 Flight Path Monitor

The controllers requested more information on the nature of, and reason for, the deviations signalled by this tool. In addition, an indication of the priority of the deviation, i.e. was there a risk of a conflict with another aircraft developing, and possible solution was required.

4.3 AIRSPACE AND TRAFFIC SAMPLES

The choice of airspace may be a significant factor in the design of the trials and in the interpretation of the results. Two opposing views have been expressed on the selection of airspace. One school of thought suggests that a fictitious airspace should be selected whilst the other is in favour of a recognised airspace being used. PD/1 took the latter approach.

The main arguments in favour of a fictitious airspace and associated traffic patterns are those against using real airspace and vice versa.

The main arguments in favour of simulating an existing airspace and associated traffic patterns, and hence against the use of fictitious airspace and traffic are as follows:-

- a level of credibility is given to the simulation;

- the risk of carefully tailoring the airspace to suit the tools and thus getting better results is removed (however, note that in the real world a radically different ATC concept might require the airspace to be redesigned);
- the criticism “...it works in this simulation but what about the real world etc...” is reduced.

The drawbacks of using an existing airspace and traffic patterns is that controllers familiar with it will tend to attempt to use the techniques they currently employ in that airspace. This is not always conducive to introducing new tools and concepts. They can also become very concerned about details of the traffic sample e.g. when increasing the traffic density during the trials, comments such as “...that airline would not fly that number of 737s on that route...” were common. Both of these points could have an adverse effect on the evaluation of the tools. The use of a fictitious airspace also means that all controllers would have a common starting point and are not influenced by existing knowledge of the airspace.

It is therefore apparent that careful consideration has to be given to both approaches. It is the PD/1 team’s feeling that on balance the simulation of a real region of airspace and its associated traffic patterns is preferable for the reasons given above and the following additional reasons. A considerable amount of information was obtained on the PD/1 concept of advanced planning as a result of having to work within the physical confines of NERC sector 11. The effects of the very narrow East/West dimension of sector 11 were particularly apparent during the development of the simulation facility, raising problems associated with the availability of advanced data for planning for Westbound traffic into sector 10, ownership of data etc.. These issues had knock-on effects with respect to the GHMI facilities and associated operational procedures. Additionally the airspace limitations stimulated a lot of useful discussions with the controllers during the trials. All of the above information would have, inadvertently, been lost had a fictitious airspace with large sectors more suitable to the advanced planning concept been adopted for PD/1.

An interesting point concerning traffic samples was raised by one of the controllers involved in the PD/1 trials. PD/1 had adopted the accepted view that traffic samples used for training the controllers should be different from those used for the trials to prevent the controllers from becoming familiar with the samples. The view advanced by the controller was that in the “real world” a controller becomes very familiar with the day-to-day hour-by-hour distribution of traffic in his sector and hence the mental picture of the traffic in the sector is not formed solely from the actions being taken at the time but also from a knowledge of the expected traffic and its requirements. As a result of this the controllers opinion was that a more optimum use of the tools could have been made had the controllers been more familiar with the traffic samples and hence the aircrafts’ likely requirements.

4.4 OPERATIONAL CONSIDERATIONS

In all simulations of this nature there is a requirement for operational personnel to support the simulation from its planning stage, through development, trials and the final analysis. In common with most simulations, the complete requirement was not met for PD/1.

The requirement for operational support was not solely for the PD/1 core team but was a common request from the PHARE groups supporting PD/1, specifically the GHMI and PATs groups.

It is appreciated that this problem is a difficult one to address as nobody disputes the need for operational support but the limited availability of such staff makes it extremely difficult to commit them to long term projects of this nature.

Experience during PD/1 shows that having access to such staff on an ad-hoc basis to answer a specific point, whilst better than no access, does not work effectively when trying to address new concepts or procedures. It is necessary that these people are fully versed with the objectives of the project, the work that has already been done and are available to participate in the meetings and discussions so that they can build up an awareness of all aspects of the project. Having been fully involved in the development of the operational aspects, as well as having an understanding of the complete system, they are then in a position to assist with the training of the controllers for the trials and the debriefing and assimilation of the controllers reactions to and comments on the system.

As stated above the PD/1 project did not have this type of dedicated operational support in the development stages. However the provision, by EEC, of an experienced ex-civil controller following the first Pilot Phase proved invaluable. He was available almost continuously throughout the second Pilot Phase, the training and the 8 weeks of Main Phase. The major benefit to PD/1 was that because he had a full time involvement, rather than being just an observer or adviser, he was able to participate fully in the project. During the preparation he was able to assist with fine tuning the facility and modifying the operational aspects of the training course. Throughout the running of the trials he acted as a feed sector controller and through this role was able to assess the controllers reaction during a trial, be in a position to assist with the formal debriefing and to participate in the equally important ad-hoc general discussions.

It is strongly urged that PD/2, PD/3 and future simulations take steps to secure this type of operational support.

4.5 MEASUREMENT METHODS

Experience during the execution of the Pilot Phases and the Main Phase demonstrations have shown that all debriefing personnel need to be fully trained in the operation of the system. This is mainly so that they do not misinterpret controller observations and are also able to pursue a specific item to elicit whether a problem actually exists or there is a misunderstanding. The availability of a controller during the trials and the debriefing is also considered to be essential, see Section 4.4.

In addition representatives of the Validation group need to be present during the whole trial run, recording accurately any information and observations about specific runs. The knowledge that they have gained during the trials can then be used to guide analysis of the data collected. The personnel carrying out the analysis also need to have first-hand knowledge of the operation of the system to prevent them reaching erroneous conclusions. As with all analysis it is important to have a feel for the expected results to guard against mistakes being made during the extraction of data.

4.6 FEED SECTOR CONTROLLERS

The role of the feed sectors in the simulation needs to be carefully considered. The initial idea behind manning the feed sector was to provide co-ordination for aircraft entering and exiting the measured sectors in a more realistic manner than could be achieved automatically. However, this raises some questions about how much “controlling” the feed sector should do, if an aircraft would be in conflict a short distance inside the measured sector, should the feed sector try to resolve it or send advanced information and wait for a proposal from the measured sector? If an inbound aircraft is not planned to descend should the feed sector send a proposal to do so?

The main concern is that there needs to be consistency in the way that the feed sectors behave during the trials so that the same quality of control is applied throughout, otherwise it may reflect in the results gathered for the measured sectors.

5. PD/1 TEAMS DISCUSSION OF RESULTS

The subjective and objective results, provided by the PHARE Validation team, are presented in Annex C and Annex D to this report. This section will discuss and interpret the results obtained. The results presented in these annexes will have been influenced by a number of factors, some of which are inherent to such a simulation and some of which could be the subject of further experiments and/or analyses. These will be discussed in this section.

It quickly became apparent during the PD/1 programme that the analysis phase was going to require very careful interpretation of interdependent data to evaluate the concept fully and to avoid erroneous conclusions on the impact of the introduction of computer assistance tools.

In order to interpret the results of the analysis, it is essential not only to have a detailed knowledge of all the areas comprising the PD/1 system which includes the operational concept and individual PATs operation but also of how the individual controllers approached the trials and operated the system. It is important, in the context of establishing useful information for future trials, to attempt to establish whether a controller's view of the performance of specific elements of the system is a direct result of that element or a consequence of other actions he or she has performed. This is equally important for measured parameters or sets of parameters. For example, is the actual number of separation infringements that occurred a result of the tools failing, the controller misusing the tool through lack of familiarity, the controller being overworked and thus unable to use the tool correctly, or the controller misunderstanding the operational concept. The discussion presented in this section of the analysed results will provide the PD/1 team's interpretation of those results. The aim is to provide an insight both into the controllers' operation of the system and areas where further research and development could be beneficial.

It should be emphasised that the discussions are based on the collective knowledge of the PD/1 team which comprises views, impressions and observations gathered throughout the PD/1 programme. This knowledge has resulted from participation in the system design and integration, the training, the pilot phases and support to the main demonstrations. Whilst all of these views, impressions and observations can not be substantiated by documented evidence, they provide an insight into where further investigation and analysis of the data set, including the video recordings of the trials, could be performed.

5.1 SUBJECTIVE WORKLOAD

The results presented in Annex C indicate the following:

- that both the Tactical and Planning Controllers perceived their workload to increase for the first of the advanced organisations, ORG 1 i.e. moving from ORG 0 to ORG 1;
- the TC did not significantly distinguish between the perceived workload for ORG 0 and ORG 2 with 70% 4-D FMS and datalink equipped aircraft, but reported an increase in perceived workload between ORG 0 and ORG 1;
- the PC perceived a significant workload increase when moving from ORG 0 to the advanced ORGs but no significant difference between ORG 1 and ORG 2.

When the results were broken down into the factors which contribute to the workload, as measured using TLX, (effort expended, mental demand, time pressure, physical demand and frustration experienced) the following was identified:

- the PCs did not identify any significant change in mental demand between any of the organisations, but between the ORG 0 and ORG 2 with 70% 4-D FMS and datalink equipped aircraft all the other elements of perceived workload showed a significant increase. The PCs also reported that ORG 1 was significantly more frustrating than ORG 0;
- The TCs reported a significant increase in mental demand from ORG 0 to ORG 1, a significant decrease from ORG 2 30% 4-D FMS and datalink-equipped aircraft to ORG 2 70% 4-D FMS and datalink-equipped aircraft, with a trend for a decrease between ORG 0 and ORG 2 70% 4-D FMS and datalink-equipped aircraft. When going from ORG 0 to ORG 2 70% 4-D FMS and datalink-equipped aircraft the TCs showed a significant reduction in physical demand. In terms of frustration the TCs reported a significant difference between ORG 0 and ORG 1 with no significant difference between ORG 0 and ORG 2 70% 4-D FMS and datalink-equipped aircraft.

It was to be expected that the controllers perceived workload would increase with the introduction of computer assistance tools, given the novel concepts, the new procedures and the length of the training period. The important aspects to be discussed are “What contributed to the perceived workload increase?”

- Was it related to the specific operational concept?
- Was it related to the tools in general or to the behaviour of specific tools?
- Was it related to the fidelity or performance of the facility?
- Was it related to unfamiliarity with the system?
- Was it related to the controller’s experience or willingness to participate in experiments?

The following discussion will address the above topics with reference to the views of the PD/1 team, controller comments and objective measures.

5.2 THE ADVANCED ORGANISATIONS

The PD/1 concept for the Advanced Organisations was based on providing an accurate prediction (from the trajectory prediction tool) of the position of all aircraft in the simulated en-route airspace. Using this information, together with the other computer assistance tools, the Planning Controller was able to plan a conflict-free trajectory for an aircraft through his sector prior to the aircraft entering his sector. This was the “Advanced Planning Concept”. The mechanism for conveying the trajectory to the aircraft was dependent on the aircraft fit. In the case of the 3-D FMS equipped aircraft the description of the trajectory was provided to the Tactical Controller as a series of timed instructions (e.g. climb, descend, turn on to a heading) to be passed to the aircraft via R/T, whereas in the case of 4-D FMS and datalink-equipped aircraft the trajectory was sent to the aircraft as a series of 4-D constraint points (x, y, z and t).

In response to a specific question “What are your views on the advanced planning concept” the majority of the controllers thought the concept of advanced planning, with computer assistance and air-ground integration, would be beneficial. They considered that it would improve capacity through more efficient use of the airspace and a reduced controller

workload, and would provide a better service to the user. In particular, they thought it would be very useful for oceanic control, regions with many overflights, and when there was a substantial number of 4-D FMS/datalink-equipped aircraft. However, a number of reservations were also expressed. The comments provided by the controllers together with the PD/1 teams interpretation are discussed below.

The PD/1 team noted that the controllers expressed concerns about the role of the Tactical Controller. The Tactical Controllers considered that they were under involved in the control strategy and that their role had been deskilled, since in many cases it involved merely passing clearances according to the Planner's plans and in other cases it merely involved monitoring the progress of flights. They considered that this could have safety implications. There were three main issues contributing to this view, namely the TC:-

- had to trust his Planner;
- had to trust the output of the system;
- would be unable to cope with an emergency situation.

As the plans were generated by the Planner, the Tactical Controller usually had no part in developing them and often could not understand why a certain manoeuvre had been chosen. Some Tactical Controllers were therefore unhappy with the plans, and blamed either the system or the Planning Controller. These controllers often tactically intervened and manoeuvred an aircraft differently from that planned. This resulted in the aircraft's agreed trajectory, or contract, with the ground being broken and therefore an increase in workload occurred due to the aircraft needing to be re-planned. Other controllers accepted that the Planner had developed the plans for valid reasons and followed them even though they could not appreciate the reason for some of the planned manoeuvres. Tactical Controllers seemed happiest when the two controllers worked as a team, with the Planner discussing the plans for certain aircraft so that the Tactical Controller was aware of the reasons for these plans, and the Tactical Controller making suggestions in the light of the evolving traffic situation such that the Planner might replan an aircraft more efficiently. Several pairs of controllers were observed to work well as teams, but others rarely spoke to one another and some commented that they felt that they were working in different timeframes so couldn't communicate.

Many Tactical Controllers were unhappy about the output of the computer assistance tools; this was apparent both from discussions and responses to the debriefing questionnaires (see Annex D). For example, they were often unwilling to accept the planned conflict resolution derived using the tools as, based on their own predictive capabilities, they considered the aircraft would not maintain separation without further manoeuvres. Quite often the comment was made that "the aircraft involved will violate separation criteria if they continue along this path."

The mistrust of the tools output was compounded by the HIPS not distinguishing between an aircraft climbing in front or behind another aircraft, see Section 4.2.1, and Planners often planning to climb an aircraft in front of another. Similarly, if a Planner had planned an aircraft to climb after one at a higher flight level had overflown, the Tactical Controller was unhappy at the time delay that was present before the climb could be started. This delay was due to the error bounds around the aircraft's forecast position that had to be included in deciding when it would be safe to climb. The result was that the aircraft was planned to climb later than it could have done if under purely tactical control. (Note that this is an apparent anomaly of the advanced planning concept which is generally considered to make more efficient use of airspace - error bounds have to be included in any prediction of an aircraft's position and these will grow with look-ahead time for 3-D FMS aircraft. Aircraft may therefore be planned to manoeuvre at less optimum times than if they were under purely tactical control.)

A lot of time was spent by the controllers monitoring aircraft as they progressed along their planned trajectories and explicitly checking the separation when they crossed or passed, although this monitoring facility was provided by the tools. It is the PD/1 team's view that it was this mistrust of the tools, and therefore the continual checking of their output, which resulted in a backlog of other aircraft needing attention and which was a major contributory factor to the workload reported by the controllers.

There was also a general consensus that the Tactical Controller was not able to build a mental picture of the traffic situation and was consequently not adequately in control. This was deemed to be a problem if an emergency arose. Although actual emergencies were not simulated in PD/1, an emergency situation could arise when aircraft were deviating and immediate action was required to resolve a near-term conflict. The Tactical Controllers felt that they would be unable to cope in many of these situations, since they did not have a mental picture of the aircraft in their sector. Tactical Controllers reported particular problems with datalink-equipped aircraft, since these would execute their planned manoeuvres without any input from the Tactical Controller. The only way a Tactical Controller could discover the intended trajectory was by displaying the aircraft's flight leg.

With the current concept, it was felt that further advisory tools to help in such emergency situations would be needed, and that some indication of the future intentions of datalink-equipped aircraft was necessary. However, the comment by one controller that mental pictures of the situation are built-up by being familiar with the airspace and traffic flows, and not purely by viewing the current traffic, mean that it would be unreasonable within the PD/1 trials to expect a good mental picture to be established.

Several controllers noted that there were problems with using the concept in the airspace simulated since sector 11 had very short east-west routes, but thought that it would be better in larger sectors. A number of discussions centred around whether fictitious or real airspace should be used for the measured sectors, see Section 4.3. Part of the problem being that one of the sectors chosen, NERC sector 11, was too narrow to give sufficient time for the Planning Controller of sector 10 to perform his tasks for Westbound traffic before they arrived at the boundary between sectors 10 and 11. Therefore, would it be better to use larger sectors that would be more suited to the tools? While this would undoubtedly make it easier to use the tools, the disadvantage is the criticism that "it works in the simulation but what about the real world".

One recurring problem, with the Advanced Organisations in particular, was the difficulty that some controllers had in appreciating that they were taking part in a trial of new concepts rather than a pre-operational evaluation. This led to the common comment "this is not how we do it today".

The following section will discuss the implications of the above observations and comments. It will also assess their impact on the PD/1 results reported.

5.3 ADVANCED ORGANISATION (DISCUSSION)

5.3.1 Unfamiliarity With Interface/System/Concept

The controllers only had a week of training to learn new operational concepts, new interfaces etc.. This was insufficient time to be familiar enough to operate the system efficiently, particularly for the Advanced Organisations. There was considerable variation in the controllers' ability to interact with the interface, which was evident from observations during the trials and from studying the video recordings of their actions during the trials. Those

controllers who had difficulty in operating the interface tended to become frustrated, and reported this on their questionnaires. Conversely, some of the other controllers showed no difficulties at all in performing the graphical manipulations required. This makes it very difficult to draw simple conclusions from controllers perceptions of general system aspects; it is essential to determine the reasons for their comments.

It was observed that most of the controllers were much slower at manipulating the interface than members of the project team who had considerable experience of it. This slowness resulted from three main factors: being unsure of how to do something; not being aware of the quickest way of achieving a certain result; or speed of interaction with the tools. These are expanded on below:-

Unsure of how to do something:

Controllers were observed trying to carry out actions currently disallowed by the system, for example they were attempting to interact with fields in a label or menu when they were intentionally not available due to that controller not having control authority for that aircraft.

Understanding of appropriate tool for task:

An example of this in the Advanced System was that two tools were available to the controller for editing, validating and registering trajectories. These were the Augmented Dynamic Flight Leg (ADFL) and the Highly Interactive Problem Solver (HIPS); both were used in conjunction with the Trajectory Support Tool (TST). The ADFL was particularly useful for registering a trajectory that required no editing (i.e. aircraft that did not need climb or descent manoeuvres inserted, or trajectories that were conflict-free). If the trajectory needed editing, the HIPS was generally the optimum tool to use since it showed possible conflict regions, although the ADFL used in conjunction with the HIPS provided a faster means of putting aircraft on parallel routes. Controllers who were using the system efficiently would choose the tool most appropriate to the task required, and usage was divided between the two tools.

Speed of interaction with the tools:

Some controllers were observed to take a long time over certain actions. On occasions this would be justifiable since they may have been thinking over the traffic situation. However, it was apparent that they sometimes forgot to complete a sequence of related inputs, for example they would edit and validate a trajectory but would forget to complete the registration process and therefore the trajectory was not input into the system.

Additionally, with the Advanced Organisations, some controllers were not fully familiar with using the system or concept to control the traffic. This resulted in them not using the system optimally, although this could also have been the result of controllers not accepting the concept and therefore not using the system as intended.

Some controllers had difficulty in fully understanding the concept of trajectories and their error bounds. This manifested itself in a lack of understanding of why trajectories had to be re-coordinated with the next sector if they had only changed the sector exit time, and not the exit flight level or position. Also, they did not fully appreciate the meaning of potential conflicts identified by the PATs Conflict Probe - this did not just indicate aircraft that would definitely lose separation, but those that might lost separation dependent on what their actual positions within the trajectory error bounds turned out to be. One particular situation which

arose quite often was where an aircraft wanted to climb but was prevented by another aircraft above it. The error bounds around the predicted trajectory were often such that although the Planner had planned the aircraft to climb as soon as it was apparently safe to do so in the HIPS, in the event, the actual traffic positions made it safe to do so at an earlier time. Some TCs understood the reasons for the climb being when it was while others did not, and then blamed either their Planner or the system and tactically intervened to climb the aircraft earlier than planned.

Another situation in which it was apparent that some controllers understood well the information the tools were presenting was in the use of the HIPS. These controllers often manipulated trajectories in such a way that they clipped the error zones displayed in the HIPS, resulting in an aircraft trajectory which was apparently in potential conflict with other flights, on the assumption that the probability of a loss of separation was small.

5.3.2 Discussion of Objective Measurements

The factors discussed in the previous section would have contributed greatly to the controllers' responses to the ISA, TLX and questionnaires. A number of objective measures were selected in order to provide an insight into the controllers' use of, and the performance of, PD/1.

The first of these measures was the number of ATC instructions issued by the Tactical Controllers. Care has to be exercised, following the above discussions and observations, in directly associating the number of ATC instructions actually issued during a run with those it was necessary to issue and from this deriving estimates of the workload associated with the advanced organisations.

All the aircraft present in every PD/1 scenario, i.e. ORG 0, ORG 1 and ORG 2, possess a flight plan. In ORG 1 and ORG 2 the flight plan is enhanced by profile information supplied by the PATs Trajectory Predictor, the combination of the flight plan and the profile information is termed the trajectory for the aircraft.

In ORG 0 the Planning Controller examines the flight plan of the aircraft before it enters the sector and either accepts the plan or modifies the entry and/or exit conditions. In ORG 0 it is not part of the PC's role to plan manoeuvres within the sector, only the entry/exit conditions. Any proposed modifications are conveyed to the aircraft by the Tactical Controller using the standard R/T procedures. This is the classical ATC task for the Tactical Controller and the number of ATC instructions issued can be considered as a contributory factor to the controller's perceived workload.

In ORG 1 the PATs were introduced with all aircraft having 3-D FMS without datalink. Each aircraft now had an associated trajectory and it is this that the Planning Controller examines before the aircraft enters the sector. Through examination of this trajectory, using the PATs, the Planning Controller is able not only to plan the entry and/or exit conditions for his sector but also designs conflict-free trajectories through the sector. This is because the planning controller is able to plan the timings of aircraft manoeuvres within his sector (climbs, descents, headings etc.). As a result of the planning task, a list of timed instructions is produced and these have to be conveyed to the aircraft by the Tactical Controller using R/T so that the aircraft can follow the planned trajectory. As in ORG 0, the number of ATC instructions issued by the Tactical Controller can be considered as a contributory factor to the controllers' perceived workload. However, the nature of the Tactical Controller's task has changed with respect to ORG 0. In this case the manoeuvres and times for the manoeuvres have been decided as part of the planning activity. The Tactical Controller's task is to relay the instructions to the aircraft, monitor the tactical picture for conformance to the plans and

also for any unusual activity, and issue any tactical instructions necessary to rectify problems. Therefore whilst the number of ATC instructions issued is a contributory factor in assessing the controllers' workload compared to ORG 0 the nature of the work has changed.

In ORG 2 varying percentages of 4-D FMS and datalink-equipped aircraft are introduced into the traffic samples. The planning activity for these aircraft is similar to that described for ORG 1 with the exception of an additional task of negotiating the planned trajectory with the aircraft via datalink. The Tactical Controller's role is changed significantly in that for the 4-D FMS and datalink-equipped aircraft he or she no longer has to convey the manoeuvres to the aircraft, and instead only has to perform the hello/goodbye R/T activity. In this organisation the Tactical Controller still has to perform the activity as described for ORG 1 on the non datalink-equipped aircraft. In addition the Tactical Controller has to monitor the tactical situation for conformance to planned trajectories and tactically intervene to solve any problems which might occur.

Therefore whilst the number of ATC instructions issued can be considered as a contributing to the Tactical Controller's workload in all the organisations, it is not sufficient to directly compare the total number of instructions for the different organisation as the nature of the task has changed considerably. To address this issue of the changing task, further analysis beyond the basic comparison of the number of ATC instructions has been performed and this, together with observations made during the trials, will be used to provide an insight into the link between the controllers' perceived workload and the number of ATC instructions issued.

The data shows that there is considerable variation between Tactical Controllers in the mean number of instructions issued per aircraft for both sectors. Whilst this is to be expected for ORG 0 where control is of the classical form, i.e. there are no tools to provide the controller with manoeuvre advisories, it is less evident why it should be so variable for the other organisations where the Planning Controller and the tools are attempting to provide a stabilised conflict free traffic flow for the sector.

For sector 10 in week 1 it is noticeable that the number of ATC instructions issued in ORG 1 is low compared to other weeks. Further analysis has shown the following:-

- the number of instructions generated as a result of the Planning Controller's task is comparable to those for other weeks;
- the Communications List Window is approximately the same size as for the other weeks.

Therefore it is evident that, for some reason, the controller has not issued the R/T instructions to the aircraft although he has clicked the message off in the CLW, hence updating the plan within the ground system but not instructing the aircraft to follow the new plan. The outcome of this would be that aircraft which had not been given instructions would deviate from their planned trajectories and if not subject to corrective tactical control could come into conflict with other aircraft. In this event the Planning Controller would be insistent that although the tools indicated no potential conflict when he produced the plan, he can now see a conflict (which has occurred as a result of the Tactical Controller not issuing the instructions to the aircraft). Both controllers would blame the tools for not detecting the conflict and hence frustration levels would increase. This indicates that the drop in the number of ATC instructions is not, in this case, contributing to a reduction in perceived workload.

On further examination it is evident that the sector 10 Tactical Controller in week 3 was giving a large number of ATC instructions. Investigation of the nature of the instructions shows that a large proportion of these were heading changes. From examination of the video recordings of these runs it can be seen that the Planning Controller has decided to put a

number of aircraft on parallel tracks for a particular route in this sector, thereby generating a number of heading instructions to be subsequently issued by the Tactical Controller in the case of non datalink-equipped aircraft. This illustrates the fact that the required number of ATC instructions can vary greatly depending on the control strategies adopted.

When investigating the type of the ATC instructions issued during the trial runs it was found that the majority were flight level changes, which was consistent with the traffic patterns expected for the chosen airspace. When just the level changes are examined it can be seen that there is a degree of consistency throughout the weeks for the Advanced Organisations. One possible explanation for this is that the tools are providing a consistent traffic flow through the sectors and are guiding the Planning Controller's choice of plan.

The type of analysis performed on the ATC instructions illustrates both the scope of analysis that is possible using the data that was recorded and also the different ways in which the system was operated by different controllers. The analysis has identified some useful avenues for further investigation. It has also illustrated that the number of ATC instructions issued by the Tactical Controller is very dependent on his understanding of the system and the Planning Controller's actions.

5.3.3 Discussion of the Minimum Separation Infringements

This section discusses the number of minimum separation infringements, an objective measure selected by the PHARE Validation Group, and indicates how their occurrence could be unattributable to both the introduction of the computer assistance tools and 4-D FMS equipped aircraft.

Aircraft which deviated from their planned trajectory were notified to the controller by displaying a yellow circle around the aircraft symbol. Hence, as the aircraft was not conforming to its planned trajectory, the trajectory that the aircraft was following was not being checked for possible conflicts by the PATs Conflict Probe. The safety of such aircraft was therefore dependent on monitoring by the controllers, and, as a final measure, by the Short Term Conflict Alert (STCA). The operational concept required that the trajectory of a deviating aircraft be replanned as early as possible (unless they were only going to deviate for a short time, e.g. if climbing slightly too slowly) so that they were again on a planned trajectory which was subject to checking by the Conflict Probe. In many cases it was observed that deviating aircraft were not being replanned. Experience gained from observation of the trials suggests that uncorrected deviations were the major contributory factor to the minimum separation infringements for the advanced organisations.

The main reason observed for aircraft deviating was as follows. Tactical Controllers were supposed to pass clearances to 3-D FMS aircraft over the R/T in accordance with the plans generated by the Planning Controller. The instructions and times at which they should be sent were listed in the Communications List Window. On many occasions it was observed that the Tactical Controllers forgot that they were supposed to send the instructions from this list and gave aircraft instructions when they decided it was appropriate. It was also observed that they sometimes forgot the mechanism for informing the system that the clearance had been given via R/T (clicking on the message in the CLW) and interacted with the track data block (as in the reference system), thereby inputting a tactical intervention. The result of these actions was that aircraft were no longer following their planned trajectories. As the tools were working on the planned trajectories and not the actual flight paths of the aircraft loss of separation occurred which could only be detected by the STCA.

The distribution of number of infringements per sector for the individual weeks (see Annex C) shows marked differences. It is likely that a major contributory factor to this was

the shape of sector 11. The aircraft travelling East-West had a very short transit time in sector 11 and hence loss of separation in sector 10 could be due to a deviation which commenced in sector 11. Even if this deviation is correctly noted by the sector 11 controllers it is likely, in some cases, that the necessary replanning cannot be executed before the aircraft reached the sector boundary. Therefore the sector 10 tactical controller has to take control of an aircraft that is already deviating from its plan.

5.4 CONTRIBUTIONS TO PERCEIVED WORKLOAD

Four main areas have been highlighted as contributing to the controllers' perceived increase in workload.

First, unnecessary tactical interventions were made on aircraft that were correctly planned. Second, aircraft were not following their plans as a result of failure to issue instructions to the non-datalinked aircraft. In both these cases extra work is required as the aircraft has to be re-planned. Third, lack of familiarity with the interface was evident. This was seen during the analysis which showed that attempts were being made to interact with aircraft at the wrong time, which caused frustration when the system prevented input. Finally, unexpected outputs from the tools or system limitations caused frustration and delay to the controllers.

6. SUMMARY OF LESSONS LEARNT AND RECOMMENDATIONS

6.1 PROJECT TEAM

One of the most important lessons learnt from the PD/1 project is that there is the need for a full-time Project Leader and team who are directly concerned with the project and who accept ownership for the programme. This is particularly important for a large-scale collaborative project, such as PD/1, where the components are developed by diverse teams whose objectives and timescales are not necessarily those required by the PD/1 programme. There needs to be an individual who can maintain an overview of the programme, the deliverables from the other groups, and be in a position to react and address problems as they occur.

A project as complex as PD/1 requires a dedicated core project team, focused on the development of the system throughout the project and having knowledge of all areas of the system. This project team has to be able to provide the software "glue" which is necessary to integrate the individual components (the PATs, GHMI, EFMS and the host platform) to provide a complete and consistent simulation package. This is essential in order that interoperability problems and those areas of the system that would otherwise "belong" to no-one, can be dealt with.

In addition the team has to organise the training and the general logistics for the trials (hotels, transport for the participating controllers and visitors).

6.2 OPERATIONAL SUPPORT

There is a requirement for operational personnel to support these complex simulation from the planning stage, through development, trials and the final analysis. Experience gained during PD/1 shows that having access to such staff on an ad-hoc basis to answer specific points, whilst better than no access, does not work effectively when trying to address new

concepts or procedures. It is necessary that these people are fully versed with the objectives of the project and the work that has already been done, and are available to participate in the meetings and discussions so that they can build up an operational awareness of all aspects of the project. Having been fully involved in the project they are then in a position to assist with the training and debriefing of controllers. They can then help to assimilate the controllers' reactions to and comments on the system.

The provision of an experienced ex-civil controller following the first Pilot Phase proved invaluable. He was available almost continuously throughout the second Pilot Phase, the training and the 8 weeks of trials. With this level of commitment he was able to participate fully in the project.

It is strongly urged that PD/2, PD/3 and future simulations of the nature of PD/1 take steps to secure this type of operational support.

6.3 OPERATIONAL CONCEPT

In general the concept of advanced planning and datalink exchange of trajectory planning data was appreciated by the Planning Controllers. However, there were reservations expressed by a number of controllers relating to the role of the Tactical Controller in the PD/1 Advanced Organisations. The controllers considered that they were under involved in the control strategy and their role was becoming that of a monitor of a situation jointly decided by the Planner and the aircraft. This in turn resulted in them feeling that they had to expend a great deal of effort in maintaining situational awareness in order to cope with emergencies.

Tactical controllers seemed happiest when the two controllers worked as a team, with the Planner discussing his plans for certain aircraft so that the Tactical Controller was aware of the reasons for these plans. In some cases the Tactical Controller made suggestions in the light of the evolving traffic situation such that the Planner could replan an aircraft more efficiently. Several pairs of controllers were observed to work well as teams, but others rarely spoke to one another and some commented that they felt that they were working in different timeframes so couldn't communicate.

6.4 SELECTION OF CONTROLLERS

The aim when carrying out the PHARE Demonstrations is to use novel concepts. It is therefore vital when selecting controllers to participate in the trials that they are receptive to new ideas. The experiments require considerable effort from the controllers, as they must be willing to provide feedback on all aspects of the system. There is a need to emphasise to those responsible for supplying the controllers that they will be taking part in a concept development trial, not an evaluation of a pre-operational system. The controllers selected need to be made aware of this, and asked if they are happy to participate in such an experiment. This is particularly important for controllers who may be involved in the various Pilot Phases of the programme as they may suggest changes to the system which are then not incorporated. There could be a number of valid reasons for not incorporating the suggestions, e.g. lack of time, inconsistency with other system aspects, different controller opinions etc. but if their suggestions are not incorporated these controllers might reject the system when asked to operate it again. For this reason the controllers need to commit themselves to operating the system as they are asked, even if they do not totally agree with the operation.

6.5 CONTROLLER TRAINING

During the execution of the PD/1 trials it became apparent that there were problems associated with the use of validated controllers when investigating new concepts, new tools and new procedures with a new interface. It was difficult to separate the performance of various elements of the system from the controllers' performance. For example were the loss of separations measured in certain of the Advanced Organisations a result of the tools or the controllers' use of the information provided by the tools? A major factor contributing to this problem was the short time available for training and hence the controllers' lack of familiarity with the interface. The other major factor was the difficulty experienced by several controllers in accepting that they were taking part in an experiment and not a pre-operational evaluation. The result of this was that they tended not to accept the output of the tools and hence expended considerable effort in checking that aircraft would remain conflict free if they followed the trajectory planned. This gave them extra tasks over and above the control task envisaged and hence contributed to their perceived workload. However, there are many issues concerning operating procedures and practices which only experienced controllers can address.

The recommendation of the PD/1 team is that the trials should involve not only experienced controllers but also technical staff who are fully conversant with the interface, the concept and the control procedures that have been developed for the system. Using these technical staff would give a benchmark performance for the system as they could be expected to operate in an optimal manner for the interface.

The topic of controller training is addressed fully in Annex B: Controller Subjects and Training.

6.6 CONTROLLER BRIEFING

It is important that the controllers are made fully aware of the fact that they are taking part in a trial and not the evaluation of a pre-operational system. If possible this briefing should be given by a controller who is fully familiar with both the facility and the objectives as controllers accept information more readily from a controller than from a non-controller.

Similarly, it is vital that the controllers taking part in the trials do not regard it as a test of their personal abilities but as an evaluation of a concept; this should be stressed during the training course and repeated during the trials. Once the controllers are under the stress of a trial, there is a tendency for them to forget this fact and revert to controlling the traffic in any way that they can rather than allow problems to occur.

6.7 CONTROLLER DEBRIEFING

Experience gained during the execution of the Pilot Phases and the Main Phase demonstrations have shown that all debriefing personnel need to be fully trained in the operation of the system so that they do not misinterpret observations made by the controllers. Their level of understanding should be such that they are able to pursue a specific comment to elicit whether a real problem exists or there is a misunderstanding of the concept or system. The availability of a controller during the trials and the debriefing is essential as they more easily understand controllers concerns.

The questions asked during the debrief should be structured towards enhancing the required analyses. For example, one measure is of perceived workload. It is known that a controller may comment that system A is easier to use than system B, but that his ISA scores show the

opposite. Also, the use a controller makes of the system clearly significantly influences workload: examples observed during the trial were TCs checking the details of the PCs' plans or PCs being very slow at using the HIPS. As many of the factors influencing workload etc. should be identified during the structured debriefing: to be able to do this successfully the validation personnel need to be fully familiar with all aspects of the simulation.

6.8 MEASUREMENTS AND ANALYSIS

It is the authors' view that the reliance on classical analysis techniques applied to controller derived data as the basis for the majority of the results of a demonstration such as PD/1 has to be questioned. The main reason for this is the variation between controllers with respect to operating and assessing the system. Therefore the actions of one set of controllers who were seen to operate the system as planned provided valuable information on system aspects. Whereas other controllers who had difficulty in performing the graphical manipulations, or accepting the tools output did not attempt to use the system as planned and hence their comments address the operation of a system that was not under control.

6.9 SELECTION OF REFERENCE SYSTEM

In PD/1 ORG 0 was designed to be a baseline system with no computer assistance tools or datalink. The aim was to use this ORG with all the traffic samples in order to provide a benchmark from which to evaluate the effect of the tools. This was necessary as the controller's backgrounds and exposure to automation in their current systems varied considerably. However, whilst it met this objective it was evident that the controllers were treating this ORG as another system requiring evaluation. They considered the Reference System to have potential for implementation in the near term and provided numerous ideas for slight improvements. Whilst this in itself was not a problem, it did distract the controllers from the main objectives of PD/1 and further highlights the problem that controllers consider their role as assessing pre-operational systems rather than testing concepts.

7. ABBREVIATIONS

API	application programme interface
ATC	air traffic control
CMS	common modular simulator
CP	conflict probe
CRD	conflict risk display
DLR	Deutsche Forschungsanstalt für Luft und Raumfahrt
EEC	EUROCONTROL Experimental Centre
EFMS	experimental flight management system
FMS	flight management system
FPM	flight path monitor
GHMI	ground human machine interface
HAW	horizontal aid window
HIPS	highly interactive problem solver

ISA	instantaneous self assessment
LATCC	London Air Traffic Control Centre
NATS	National Air Traffic Services
NERC	New En Route Centre
NRF	NATS Research Facility
ODID	Operational Displays and Input Devices
ORG	organisation
PATs	PHARE advanced tools
PC	planning controller
PD/1	PHARE Demonstration 1
PD/2	PHARE Demonstration 2
PD/3	PHARE Demonstration 3
PHARE	Programme for Harmonised ATM Research in EUROCONTROL
R/T	radio/telephony
TC	tactical controller
TP	trajectory predictor
VAW	vertical aid window

8. REFERENCES

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