PRESENTING UNCERTAINTY TO CONTROLLERS AND PILOTS

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Abstract

Much of the information used in air traffic management (ATM) is inherently uncertain, most obviously where it involves predictions of future system states. The main approach to this uncertainty has been to reduce it at source, by developing more accurate and reliable tools and by standardizing operating procedures. However, this approach may not be sustainable or optimal as new ATM concepts, with increased reliance on predicted information, are introduced - there may be situations in which presenting the uncertainty to users provides greater safety and operational benefits.

This paper describes the findings, to the end of 2002, of a study performed under the CARE Innovative Action initiative of Eurocontrol [1]. The study asks where, and if so how uncertainty could usefully be presented. To provide a practical context for these questions, three controller tools have been considered as case studies: the Tactical Load Smoother (TLS), Medium Term Conflict Detection (MTCD) and the Conflict Resolution Adviser (CORA). The study has identified a number of scenarios in which presentation of uncertainty could be helpful, and has envisioned, at a high level, some solutions by which this could be achieved. The next stage of work will develop more concrete visualizations for further evaluation.

The paper also discusses lessons learned with regard to the design process that could have applications beyond the case study tools, and so point towards guidance on the topic of uncertainty presentation in general.

Introduction

Why consider uncertainty?

If there were no uncertainty in air traffic, such that all flights could be guaranteed to run exactly to time, one could envisage a situation in which schedules and routes could be designed to allow gate-to-gate flight without conflict, and there was no need for any active intervention by air traffic controllers. Clearly, this is not the case today, so the purpose of ATM can be seen as one of managing aircraft in an uncertain context. ATM is a complex socio-technical system with a great deal of potential for uncertainty, and controllers and pilots frequently make important decisions based on uncertain or incomplete information, especially where they use predicted data, and during abnormal and emergency situations.

To date, the ATM community has managed uncertainty mainly by seeking to eliminate or minimise it at source, developing ever more accurate and reliable system tools and standardising procedural rules for operators. Most of the information which pilots and controllers receive is, at least apparently, complete and precise, and the residual uncertainty is rarely presented explicitly.

Controllers and pilots working in real-time operations also commonly express their role as one of reducing uncertainty - they ‘spend a lot of time and cognitive resources in eliminating ambiguity’ [2]. Abilities to manage uncertainty in other ways do not appear to be explicitly sought in personnel selection or strongly developed in training, although some Crew Resource Management programmes now include uncertainty management within error management.

The culture of eliminating uncertainty therefore seems quite deeply ingrained in ATM, but it may not be sustainable or optimal in future. New concepts and tools, such as those for planning and conflict detection, tend to increase the amount of data that can be presented and the degree of reliance placed on predicted information. Even where such increased reliance is compensated for by the greater accuracy that a well-designed system can achieve (compared to unaided human judgement) there may be scope to do even better by means of good presentation.

Types of Uncertainty

There are several definitions of uncertainty, and to avoid constraining the study unduly, the study set out with a very broad interpretation. The term ‘uncertainty’ can include, for example:

- ambiguous information
- variability in parameters (e.g. fluctuations in wind speed)
- inaccuracies and errors in measurement or display
- incomplete understanding, lack of knowledge or missing data
- the likelihood of future events or conditions
- subjective uncertainty: the degree of belief or trust in the information received, in one's own judgments or those of others.

Other models and taxonomies of uncertainty can be developed – for example to make a distinction between uncertainties in factual data (i.e. in information about what already exists or has happened) and the additional uncertainties in predictions, arising from errors in predictive algorithms, and the users' trust in such predictions.

What Uncertainties Could be Presented?

Where an uncertainty is to some extent predictable, it may be possible to present it to the users. For example, conflict detection tools rely on predictions of aircraft trajectories, in 3-D space and time. While these predictions are subject to uncertainty, the existence of the uncertainty is foreseeable and its range is, in most cases, bounded. So this kind of uncertainty could, in principle, be presented to the user.

Benefits and Disbenefits of Presenting Uncertainty

In principle, it would seem almost undeniable that, to make a good decision, the user needs to be aware of the reliability of the information upon which it will be based. So, presenting the uncertainty in information to the user may improve their decision-making ability.

In addition, the total elimination of uncertainty may not be a desirable aim. Just as the 'ironies of high-integrity systems' [3] diminish the returns from increasing system reliability , it is likely that some uncertainty in the system is necessary to maintain user attention, situation awareness and job satisfaction. Presenting uncertainty, and asking pilots and controllers to manage it more explicitly, may alleviate some of the feared impacts of increasing automation, such as de-skilling and loss of situation awareness. Making inferences from incomplete information, and good decisions where there are insufficient data to apply a structured rule (see [4] for further discussion) are areas in which humans are often better than machines.

On the other hand, presenting uncertainty may overload the user with information, and he or she may not know how to act upon it. There is a trade-off between the value of presenting additional information and the display clutter and cognitive overload that may result.

The State of the Art

A preliminary study [5] of the issues mentioned above was funded under Eurocontrol's CARE Innovative Actions programme [1], which aims to support innovative research in ATM.

The preliminary study identified several examples of situations in the control room and on the flight deck , based on both hypothetical consideration and historic incidents, in which uncertainty could usefully be presented. However, it also found that there were significant gaps in the scientific foundation for answering the questions of whether and how to present uncertainty. Despite the vast amount of research into presentation and human-machine interaction in aviation, remarkably little has been specifically concerned with uncertainty. Research on uncertainty in aviation has generally been limited to experimental studies of highly specific tasks and tools, such as [6], whose results cannot confidently be extrapolated to provide guidance to designers of other systems. Informative work of a more general nature has been done on the psychology of uncertainty (see [7] for example) and there is an extensive literature on decision-making under uncertainty, but these more general studies are not easily applied to any particular ATM problem. So there appeared to be a gap between the general and specific, which merited exploration.

It was also apparent from the preliminary study that the potential range of presentations available was not being fully exploited - information for ATM is currently presented in a limited number of forms, mainly via the visual channel in windows on the radar screen. The presentation of uncertainty, as a relatively new consideration for ATM, may offer scope for creative development of presentational forms.

A review of the topics presented at past ATM R&D seminars supports the view that there is little existing research on the presentation of uncertainty. The majority of papers which mention uncertainty (references [8], [9] for example) have been concerned with improving the accuracy of algorithms for predictive tools, i.e. with minimizing uncertainty, rather than presenting it. A notable exception is [10] which considers how to present the outputs of theoretical algorithms for trajectory prediction.

The Current Project

As a result of the preliminary study [5], Eurocontrol selected this project as suitable for further support. Reference [11] describes the selection process. The work now being carried out aims to develop principles and guidance for presenting uncertainty, by exploring the tentative findings of the preliminary study in more detail with users, and in relation to three case study tools.

The study is being performed by RM Consultants Ltd (UK) and Deep Blue s.r.l. (Italy), with support from and involvement of the Eurocontrol Experimental Centre (EEC). The work has synergies with another project under the CARE Innovative Actions programme – CREA! [12, 13]– in which Deep Blue s.r.l are exploring the creative design process in ATM, defining an inter-disciplinary approach that encourages intersections between art, design and technology, and considering the design of the whole workspace and the interactions between users as well as traditional display issues.

Objectives and Scope of Study

The purpose of the study is to develop, apply and test principles for deciding whether, whether, how, when and to whom uncertain information should be presented. The study considers these questions using, as case studies, three controller tools: the Tactical Load Smoother (TLS), Medium Term Conflict Detection (MTCD) and the Conflict Resolution Adviser (CORA). The intended benefits of the work are:

- to lead to more scientifically justifiable, practical and relevant advice on the presentation of uncertainty in ATM in general; and
- to add value to the development of the human-machine interfaces (HMIs) for the case study tools.

The current study, due to end in July 2003, will develop and evaluate examples of low-fidelity mock-ups of methods of presentation. It will provide an informed basis for deciding whether to proceed to integration with the case study tools and formal user testing.

Up to the time of writing (January 2003) work has focussed on identifying scenarios in which there is potential benefit from presenting uncertainty, and envisioning solutions which describe, at a high level, ways in which such a presentation could be provided. This paper presents the methods, the results to date, and lessons learned in the process. More concrete mock-ups and visualisations will be developed in the period up to the ATM R&D 2003 seminar in June 2003, and it is anticipated that some of these could be presented at the seminar itself.

Overview of Method

In simple terms, the steps in a traditional design process for ATM tools can be seen as:

- capture and definition of user requirements
- design of prototype tools to meet these requirements
- evaluation and iterative refinement of the prototypes in consultation with users.

In the present study, the nature of the topic made it difficult to complete the first of these steps – it was not possible to define, *a priori,* what uncertainties should be presented. It became apparent that there were too many variables to identify and weigh the various advantages and disadvantages of presentation in the abstract. Some notion of the design concept and how it would be used was required, since whether a particular uncertainty should be presented will depend strongly on the roles of those involved, the procedures in use, and the tools available. Individual attitudes to uncertainty and differing mental models further complicated the picture - uncertainty is a ‘slippery’ subject, and many of the stakeholders initially found it an alien concept.

Consequently, a more iterative approach was developed, in which these decisions about what to present were taken in consultation with users, in relation to specific scenarios of use that controllers could recognize and discuss, and in parallel with the envisioning of solutions. This approach is in accordance with the emerging ideas on the creative design process project from the CREA! project [12].

The main steps in this new, iterative approach are shown in Figure 1.

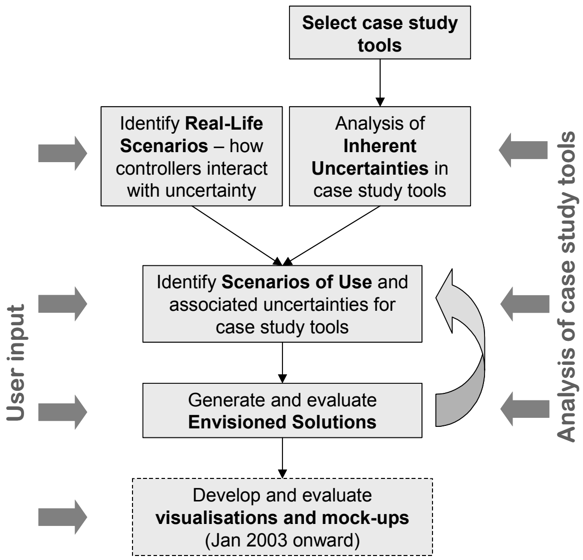

Figure 1: Overview of Method

Note that there is a high degree of iteration between the identification of scenarios of use in which presentation could be useful and the development of envisioned solutions for these scenarios. Note also how the steps are fed from two parallel input strands: an open-ended, user-centered process of working with the controllers, and a more analytical strand, concerning the specific uncertainties associated with the case study tools. Each of the main tasks shown in Figure 1 is outlined further in the following sections, with examples of results to date.

Selecting The Case Study Tools

The case study tools, TLS, MTCD and CORA, were chosen to provide a broad range of example problems in which uncertainty presentation could be an issue. As ongoing developments within Eurocontrol, they also provided good opportunities for access to designers and potential users. All three rely upon Trajectory Prediction (TP) - perhaps the most obvious and widespread use of predicted (and hence uncertain) information in ATM. However, they span a range of applications of TP: planning, conflict detection and conflict resolution respectively.

The selection of these case studies has led to a focus on controllers' tools and points of view rather than those of pilots. This was largely a matter of practicality, in that controllers were more easily accessible to the project than pilots. Nevertheless, the airborne element will be covered in so far as the study will consider how far the principles and ideas generated for controllers could be transferred to the cockpit, and what factors affect such transferability.

Tactical Load Smoother (TLS)

The TLS [14, 15] is one of the tools intended to support a new role of Multi-Sector Planner (MSP) The function of the MSP is to survey traffic over a number of sectors, identify conditions which could lead to excessively complex situations for the sector controllers, and intervene where necessary– for example by asking the Planner controllers (PLCs) of upstream sectors to re-route aircraft through different sectors.

The TLS supports the MSP by providing graphical displays of the predicted *complexity* across the area, at times of up to 30-90 minutes ahead. Complexity is defined as a measure of the difficulty that a particular traffic situation will present to a controller [15]. The algorithm for calculating complexity includes parameters such as the traffic density, conflict density and a number of other elements such as the diversity of aircraft types and flight types (arrival, departures, overflights) and the proximity of sector boundaries. Complexity therefore includes, implicitly, some notions of uncertainty. For example the parameter for flight type recognizes that the trajectories of climbing/ descending aircraft are less predictable than those for aircraft in level flight. However, the existing HMI does not explicitly present this uncertainty. A more explicit visualization of the accuracy of particular predictions was identified as a possible improvement [14].

A second type of uncertainty that [14] suggested could be made more evident to the user is that associated with the fact that the TLS presents a prediction of the future traffic pattern. Some of the current TLS displays (Figure 2) look similar to the familiar radar picture used by Planner (PLC) and Executive (EXC) controllers, showing (forecast) aircraft positions and their labels. There was concern that, unless some indication of the uncertainty of these forecasts is given, the MSP might be inclined to think 'tactically' – for example by requiring a heading change for a specific aircraft 30 minutes ahead, rather than thinking in terms of planning re-routes and other changes at the area-wide level.

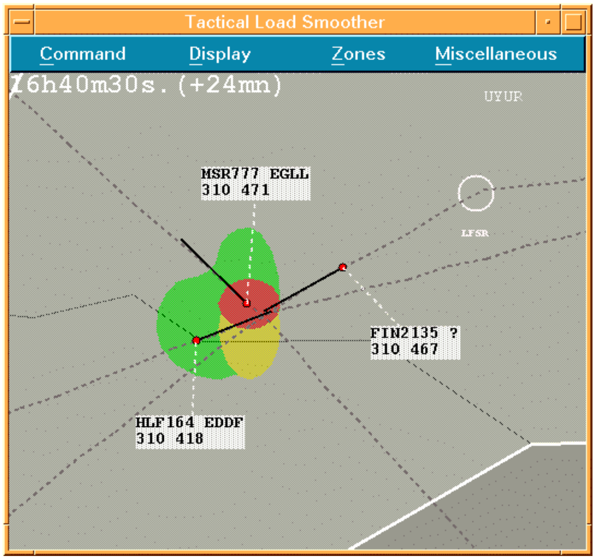

Figure 2: Example TLS Display from [15]

Medium Term Conflict Detection (MTCD)

MTCD provides a visual alert to a PLC or EXC in the event that a conflict is predicted to occur in, typically, the next 10-20 minutes. The key uncertainties therefore relate to the accuracy with which a conflict can be detected, and hence rely on the accuracy of TP for the aircraft concerned. A number of MTCD tools are in existence of development – in this study we considered that being developed as part of the Mediterranean Free Flight programme.

Conflict Resolution Adviser (CORA)

CORA [16] offers a number of potential solutions (based on distillation of expert experience) to a conflict detected by MTCD. So, there are uncertainties in the solutions proposed, on top of the uncertainties in conflict detection 'inherited' from MTCD. CORA is in an early stage of development.

Real–Life Scenarios

The user-centred, open-ended strand of work began with discussions with controllers that, initially, were unrelated to the case study tools. Controllers were encouraged to tell worst-case stories about their own experience, or incidents they had heard about. In terms of the CREA! model of the design process [13], this corresponds to the 'divergent' phase – the aim being to gather a rich picture of how controllers relate to uncertainty, without restricting it to specific tools or techniques.

The findings of this strand of work were captured in a number of 'real-life scenarios', describing cases in which uncertainty had been relevant to controllers. The scenarios provided insight into controllers' cognitive models of uncertainty, their attitudes toward it and their ways of dealing with it. Box 1 below shows how each scenario was recorded.

Box 1: an example real-life scenario

Shift Handover in a Hurry

Rationale - general description of the scenario and how uncertainty arises within it: During their shift, both PLC and EXC build up a dynamic knowledge about their sector. Handover is an important moment as the controller has only a couple of minutes to pass relevant information to the incoming controller, and the risk of losing some precious information is relatively high. This is particularly true of information that is not measurable nor displayed, such as the memory of past sector events which helps to understand its current dynamics.

Uncertainties: the cause of a lateral deviation from flight plan, integrity of information passed during shift handover.

Actors: an EXC beginning the shift, the PLC, a pilot.

Tools and Resources available to actors: radar (routes display); radio, pilot/ EXC cooperation (via radio), EXC/ PLC cooperation (oral).

Procedures: bad weather circumnavigation, shift handover.

Storyboard: The EXC has just sat in front of the workstation. She notices that two aircraft have changed their route around Kimco but doesn't understand why, as this change makes the path longer. She asks the PLC planner for explanation. He answers: 'Didn't Mario tell you? There's a thunderstorm (Cb) over … near Kimco …AZA453 reported it ten minutes ago…more or less…'

'I'm asking for confirmation…IB2346 (flying 30 miles east of Kimco) is there a Cb on your left?...' From the answer, the EXC can make up her mind about the current Cb extent.

Many controllers were initially uncomfortable with the idea that there is uncertainty in ATM. The real-life scenarios provided a valuable way of beginning the conversation about uncertainty.

Inherent Uncertainties in the Case Study Tools

In parallel with the user-centred development of real-life scenarios, the more analytical strand of work identified uncertainties associated with the specific case study tools which could, at least in principle, be presented.

Discussions with the tool designers, and analysis of specifications, simulation reports and other documentation provided a list of the uncertainties inherent in the tool's inputs, algorithms and outputs.

The analysis also provided an understanding of the technical ability to foresee, quantify or rank each uncertainty – a necessary prerequisite for presenting it. For example, the uncertainty in aircraft ground speed is likely to remain within certain bounds, and can in principle be forecast, on the basis of knowledge of aircraft performance and meteorological predictions. The actions of controllers in adjacent sectors, on the other hand, are more open-ended - the sequence of actions and consequences can develop along so many potential branches that forecasting them would be extremely difficult, or even impossible.

Combining The Strands - Scenarios of Use and Associated Uncertainties

By bringing together the real-life scenarios (describing how controllers could interact with uncertainty) and the technical uncertainties in each of the case study tools, it was possible to develop a number of scenarios of use for each tool in which specific uncertainties would arise and presentation might be valuable. These scenarios were initially defined in the same way as the real-life scenarios (Box 1) - i.e. in terms of rationale, uncertainties, actors, tools and resources, procedures and a storyboard. For the more promising scenarios, the storyboard was developed into an animated presentation.

The scenarios of use were found to be extremely valuable as a vehicle for dialogue with users. In particular, they continued the 'conversation' which the real-life scenarios had begun, allowing the controllers to move from a generally sceptical first reaction that might be summarised as 'we don't want to know about anything uncertain' to recognition that there were situations in which presentation of uncertainty could be of benefit, and indeed making suggestions of such cases. The storyboards provided a realistic basis for discussion, evaluation and refinement of the scenarios and, as will be described in the next section, for showing the envisioned solutions.

Two basic scenarios were selected for further consideration. These, and the associated uncertainties for which presentation was considered potentially useful are summarised below.

TLS as used by a Multi-Sector Planner

For the TLS, the roles of the actors were not well-defined. The MSP role is a new one, and there a number of options are being considered for how the MSP would work and interact with others. It was therefore necessary to define an (assumed) picture of the MSP role. A model of the communication process was developed, describing the roles and tasks of the actors, the flows of communication, and built into the storyboard.

The main uncertainties are those in the predicted complexity level in an area, in the identification, position and trajectory of 'troublemaker' aircraft and the additional uncertainty associated with the fact that TLS presents a *future (*i.e. predicted) situation

MTCD/ CORA as used by a PLC

It was decided to consider MTCD and CORA together because CORA is a 'client' of MTCD. In general, controllers tend to regard such linked tools as one package, rather than as separate tools. The PLC rather than EXC position was chosen because EXCs generally found the idea of uncertainty information less useful – they are concerned with short term decisions in which they have to assume the information presented to them as correct – the PLC has more time to consider other possibilities. The key uncertainties are those in the detection of conflicts to which MTCD provides an alert and in the effectiveness of solutions offered by CORA.

Generating Envisioned Solutions

Envisioned solutions describe what the controllers need to see or use in relation to the selected scenarios of use and uncertainties. Tools and displays have been envisioned, but only at a high level, to avoid tying the development too closely to a particular technological solution at this stage. This allows scope for change in the light of user feedback, in keeping with the iterative approach to design. For example, it has already been necessary to revise the assumed MSP role quite significantly during development of solutions.

Envisioned solutions involved were developed by means of:

- a free process of creative thinking (brainstorming, writing, drawing) amongst project staff, generating many ideas, and
- working with the controllers to evaluate and develop the ideas in relation to the scenarios of use.

Envisioning solutions involves much more than, for example, sketching a particular symbology, such as a fuzzy line, for displaying the uncertainty in trajectory on the radar screen. It includes further development and definition of process models of communication and actions, roles, and tools to can support the new uncertainty-related activity. The storyboards were central to this task, providing a means of capturing both the scenario of use and the proposed solution.

There was therefore (as shown in Figure 1) extensive iteration between the definition of scenarios of use and the development of the envisioned solutions - solutions are specific to particular tasks in a specific work setting.

Envisioned Solutions - TLS

The envisioned tools are:

- a **large wall-mounted display** of the predicted traffic situation, on which 'bubbles' showing areas of predicted complexity appear. The cause of the complexity is also indicated – in particular whether it is potentially manageable by ATC (e.g. take off times) or outside it (e.g. weather);

- a **hand-held pointer/ interaction device** enabling the MSP to scroll the display to different predicted times; to select particular aircraft or areas and hence perform what-if tests such as re-routing; and to send instructions to the PLCs

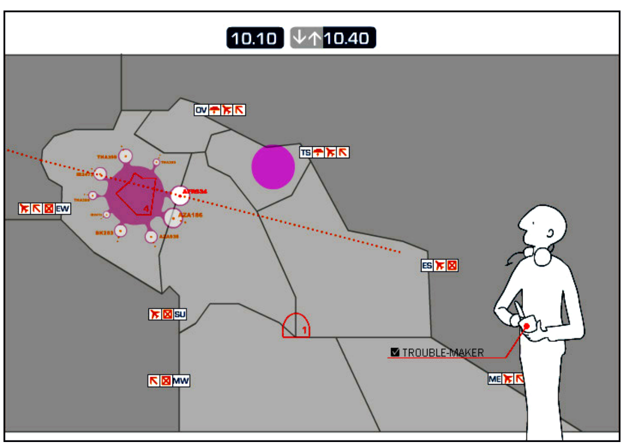

Figure 3: Envisioned Solution for TLS – an example Screenshot from the Storyboard

Figure 3 and the storyboard description in Box 2 illustrate how the MSP could use these tools to interact with uncertainty.

Box 2: Envisioned Solution – a Storyboard for TLS

It is 10:10. Gianni is MSP of Area 'C' (sectors EW, ES, TS and OW) in Rome ACC. A Military Zone in EW sector will be activated in 20 minutes and this will require some re-routing. TLS displays an area of high complexity in EW (cause: 're-routing due to military zone').

He scrolls the TLS time-line to see the predicted traffic condition in EW sector between 10:30 and 10:50. He activates the filter 'aircraft concerned' to see which aircraft contribute to the main complexity area. Then he selects the filter 'most trouble-maker' and AFR534 is highlighted.

He queries TLS to display re-routings around Zone 4. The proposed solution is re-routing AFR534 via DELER, in TS sector, to the north. But he notices that around DELER there is a complexity zone of type 'unmanageable' - a thunderstorm has just been reported. He decides to look for another solution and sees that AFR534 could pass south from Zone 4. He uses the 'what-if' tool to see whether this would improve the situation without creating new complexity areas.

The solution seems good, so Gianni sends the actions to take to change the flight plan of AFR534 to the PLC of sector ES.

Table 1 shows how this solution addresses each of the main uncertainties.

Table 1: How the Envisioned Solution for TLS Presents the Uncertainties

Uncertainty in	Presentation
Complexity level in an area	'Bubbles' showing areas of complexity, with timeline scrolling to enable the MSP to see how these expand, contract and change shape with time
	Information about the causes of uncertainty, in particular whether they lie within ATC control (e.g. aircraft take off times) or not (e.g. weather). This enables the MSP to decide whether the complexity should be reduced at source or worked around.
Identification, position and trajectory of 'trouble maker' aircraft	The 'what-if' facility afforded by the tools allows the MSP to look at the sensitivity of the results to moving 'trouble-maker' aircraft.
Additional uncertainty associated with the future situation	Different visualisation of future and current situations. Display on the large wall screen, rather than on the standard radar screen, is one means of 'distancing' the TLS prediction from the normal radar picture

Envisioned Solutions – MTCD/ CORA

Envisioned solutions for MTCD/ CORA have not yet been developed to the same level as those for TLS, but are likely to be based upon the following initial ideas.

Controllers emphasized that (as in current MTCD displays) there should be a 'threshold of certainty' for MTCD alerts. They did not want to be informed of conflicts whose occurrence was so uncertain that a controller could not decide on any useful action. Similarly, there could be a threshold for CORA solutions – no solution should be proposed unless there is a high degree of confidence that it would work in practice.

The controllers also asked for it to be evident when MTCD is using degraded information, for example where there is a delay while the system processes information; or where the system is working with incomplete or degraded data.

Development and Evaluation of Mock-Ups – Future Work

The solutions shown in the present paper are at a high level and require further consideration. For example, whether complexity is due to manageable or unmanageable causes in TLS is currently indicated by simple colour-coding - there may be better ways to do this.

An analysis is now being conducted of the gaps between developments already in hand for the case study tools and the needs of the various controller roles. This will enable priorities to be set for selecting certain envisioned solutions for further development and evaluation as mock-ups.

The study will continue to work in synergy with CREA! [12] and will also consider emerging results from Eurocontrol's SHAPE project [17], regarding trust in tools. This could be a critical issue for tools which deal with the unfamiliar, and sometimes sensitive topic of uncertainty.

Lessons Learned – Towards Generic Guidance

What 'presentation' means

The preliminary study [5] considered a rather narrow interpretation of the term 'presentation', focussing on the relatively explicit display of the variability or range of possible parameter values. In the present study it became apparent that a broader interpretation of 'presentation' may lead to better solutions. Other modes of presentation include:

- **Making the uncertainty evident** - conveying a sense of the reliability of the information, without necessarily displaying the range or variability explicitly.
- **Showing how alternative situations may develop**. This approach matches a common mental model amongst controllers. Many were resistant to the idea that the information they saw might be unreliable, but comfortable with the idea of identifying the ways in which a situation might develop, and having a plan in mind each case.
- **Allowing controllers to interact with uncertainty** - for example by providing 'what-if' tools.
- **Prompting controllers to consider the certainty of their own judgments**.

What to Present – the Creative Design Process

It is possible, in some aspects of ATM system design, to identify and define functions and user requirements at the outset, but the special nature of uncertainty means that there are generally too many variables to identify and decide what should be presented without some notion of the design concept. The difficulties of talking about uncertainty (see below) add to this effect. Hence a more iterative, user-centred approach is essential. The *scenarios of use* were the key to this approach, enabling the discussion to be focused on real examples and providing a concrete basis for working with users on possible solutions. Guidance will be provided on how to develop such scenarios from the user-centred and analytical strands of work.

Talking about Uncertainty

Uncertainty is a relatively unfamiliar concept in ATM, and we found that a relatively gentle introduction was required. The first reactions to the were often remarks such as 'but we don't have uncertainty in ATM' or 'we don't want to know about uncertainty – we can only work with information that is certain'.

The 'real-life scenarios' provided the key to beginning the conversation, and the scenarios of use continued it into more concrete discussion of the specific case studies. By discussing realistic and recognisable scenarios, the controllers seemed able to move from their original 'uncertainty–resistant' position to one of acknowledging, or even suggesting, that there were situations in which presentation of uncertainty could be helpful to them.

Being based on discussion and observation of how controllers behave in practice, the scenario-based approach should be better able to identify informal interactions, and associated means of relating to uncertainty, than one based on task analysis of formal procedures alone.

When to Present Uncertainty

ATM can be seen as a rolling process of detecting and resolving potential conflicts between aircraft (or between aircraft and other hazards, such as terrain, adverse weather or military areas). In general, as time progresses towards a potential conflict, the uncertainty in the situation decreases and the options available for action become more limited. This would imply that uncertainty presentation is most valuable at early times.

On the other hand, decisions become less reversible as time progresses – so it becomes more important to make the right decision. If it is true that good decisions require an awareness of the uncertainty in the information on which they are based, uncertainty presentation could become more important at later times.

The balance between these opposing considerations is likely to be scenario-specific, and there are exceptions. Future work will continue to look for factors and considerations that may help designers decide where the balance lies. It may be helpful to consider this in terms of how long the user can wait for better information, linking it with consideration of risk averse/ risk neutral and risk seeking attitudes (see for example, reference [18]).

Transferability of Solutions

A key lesson from the work to date has been that needs for uncertainty information vary not just with individual attitude and training but according to the role being played at the time. In general, controllers working in the EXC role, and dealing with short-term, 'sharp-end' decisions saw less need for uncertainty information than when working in the PLC or MSP role, with a longer look-ahead time. More generally, there is a need to develop solutions in relation to specific scenarios of use. So, it is unlikely that entire solutions will be transferable to other contexts, tools and scenarios, and caution should be exercised in attempting to do so.

Nevertheless, there are some aspects of the envisioned solutions developed to date which could have a wider applicability, or at least provide some ideas. Examples include: giving information about the causes of uncertainty, different visualisations of current and future situations, what-if tools to allow interaction with uncertainty and time-line scrolling to allow the user to look at different stages in the future. Further analysis is planned to establish what factors determine transferability.

Conclusions

The work to date has developed a process for identifying scenarios in which there could be safety or operational benefits from presenting uncertainty, and for envisioning solutions. This process has been applied to three case study tools, and it is believed that we now have a sufficiently robust idea of what is useful and practical for controllers to enable the study to progress to the development and evaluation of more concrete visualisations.

Some important lessons have been learned which could be more widely applicable. In particular, we stress the need for a broad interpretation of what 'presentation' means, and the need for an iterative design process. Future work will add to and interpret these lessons, to provide generic guidance on uncertainty presentation.

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Key Words

Uncertainty, Scenario-based design, HMI, creative, scenarios, TLS, MTCD, CORA.

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