

SPECIFICATION FOR HMIs TO BE EVALUATED USING eDEP/ HF LAB

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DS: This document has been reviewed by Dirk Schaefer, EEC; comments are inserted in the text in italics.

1. INTRODUCTION

This note is intended to inform the implementation contractor of the objectives for and specification of HMIs to be developed and evaluated using EUROCONTROL's early Demonstration and Evaluation platform (eDEP) and Human Factors Laboratory (HF Lab), as part of the CARE Innovative Action 'Presenting Uncertainty'. Brief descriptions are provided for HMIs in two main areas:

- The presentation of uncertainty in conflicts as shown in the Potential Problem Display of MTCD/CORA (Section 3); and
- The presentation of uncertainty in aircraft climb/ descent within the Vertical Aid Window (VAW) of MTCD/CORA (Section 4).

For each, we describe the function and form of the display and the algorithms required, and make some initial suggestions for aspects to be evaluated.

While the form of algorithms is defined sufficiently to permit development of the software, decisions on some of the parameter values require some further detail (which RMC is pursuing) and/ or tuning during the evaluation itself. So, parameter values should be specified as inputs that can be adjusted during evaluation.

2. PURPOSE AND SCOPE OF EVALUATION

The work forms part of the CARE Innovative study 'Presenting Uncertainty'. The overall purpose is to provide guidance on whether and how information about the uncertainty in ATM information might usefully be presented to air traffic controllers. The end point of the study is to provide an *informed basis* for deciding whether any of the prototype presentations developed in the study could merit integration with full simulation platforms and detailed, formal user testing. Thus the work proposed here is exploratory – it is not required to develop sophisticated algorithms, or to carry out extensive detailed evaluation.

The evaluation of HMIs for MTCD/ CORA as described here is one strand of the work. Other, more radical, solutions have been developed and evaluated for the TLS tool – these consider novel ways of organising the controllers' roles and the design of the workspace, as well as graphical display issues. The MTCD/ CORA work described here is intended to explore some of the more practical issues involved in implementing and evaluating graphical displays of uncertainty within existing, more clearly defined contexts and tools. A standard PLC/EXC division of roles is assumed.

The solutions considered here are principally intended for use by a Planning Controller (PLC) rather than an Executive Controller (EXC). In discussions with users it has been found that they generally found the idea of uncertainty information less useful when working in the EXC position – they are concerned with short-term decisions in which they have to assume that the information presented to them is correct. In the PLC position, there is more time to consider other possibilities.

Because MTCD/CORA rely on a trajectory predictor (TP), the solutions proposed here might also have potential as more generic solutions to the problem of presenting information about uncertainty in trajectories or other key ATM parameters. While it has been demonstrated by the work on TLS that any solution must be adapted to the specific operational context and environment, there may be some graphical symbologies that can be used, or at least considered, for wider application.

3. POTENTIAL PROBLEM DISPLAY

3.1. Functions and Form of the Display

The existing PPD display shows distance and time to Loss of Separation (LOS), Closest Point of Approach (CPA) for conflicts that have been detected by MTCD. In the example in Figure 1 below, the boxes show the LOS, the line extensions the time of CPA. While conflict 1 is clearly the most urgent to resolve, as the distance and time to LOS/ CPA are both small, it is unclear which of conflicts 2 or 3 should be addressed first.

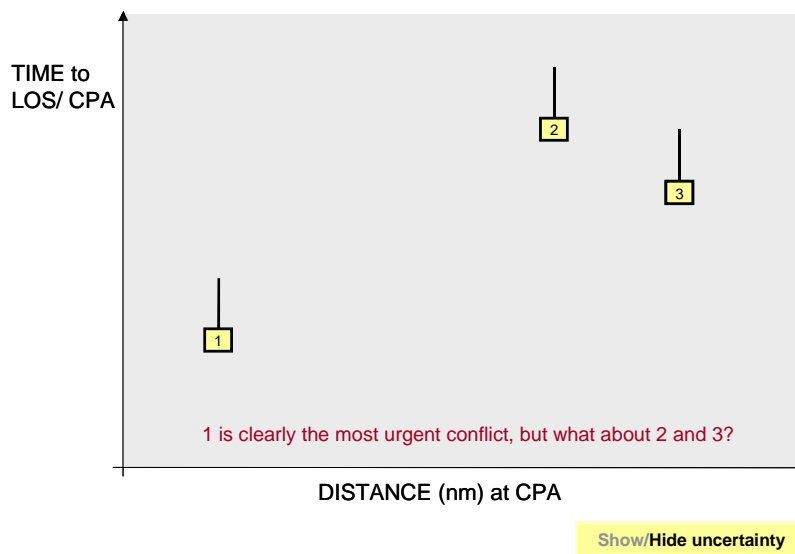


Figure 1: PPD Display – Uncertainty Not Shown

DS: Please note that Figure 1 shows an older version of the eDEP PPD; the new version is in line with the ESCAPE MTCD philosophy and displays the number of the conflict at the CPA, not the LOS, i.e. at the top and not the bottom of the vertical line in Figure 1.

Introducing information about the uncertainty into the display may help the user with this and other decisions. In Figure 2 below we indicate the uncertainty in each conflict by an ellipse around the LOS box

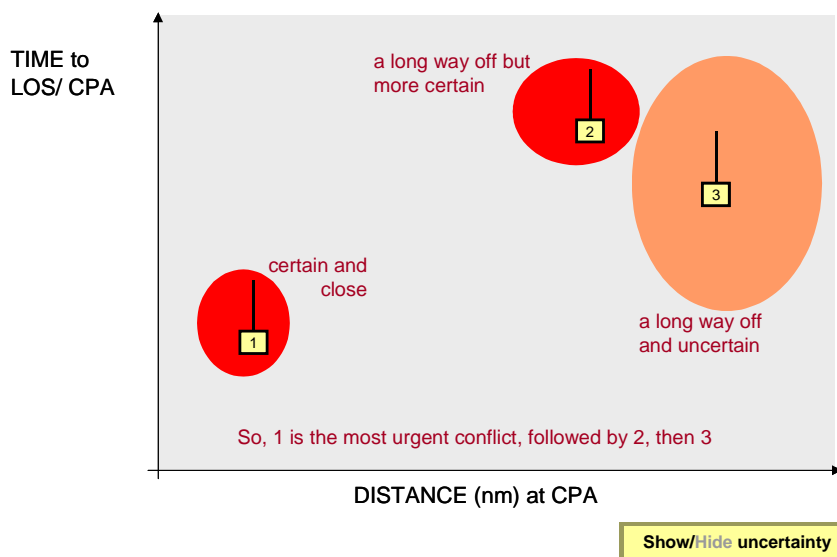


Figure 2 Possible Display of Uncertainty in PPD

The uncertainties in time and distance are shown by 'bubbles' around each conflict. As the bubbles (in general) decrease in size with time, the colour saturation increases, representing greater certainty. This increase in saturation should counter the general graphical convention that 'big = important'.

From user feedback already received, we suggest that uncertainty should only be displayed on request. Hence a 'show/ hide uncertainty' button is provided, to toggle between the presentations with and without uncertainty.

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DS: Show/hide uncertainty switch: Figure 1 shows the PPD display with the uncertainty display disabled; at the same time the button show/hide uncertainty highlights the chosen option and not the one that can be chosen; this seems to be counter-intuitive; the option that can be chosen should be highlighted, i.e.

show/hide uncertainty *uncertainty not displayed, display can be invoked*

show/hide uncertainty *uncertainty displayed, display can be disabled*

DS: The bubbles display the uncertainty in distance and time at LOS but the distance in the PPD is the distance at CPA – obviously the uncertainty needs to be displayed around the CPA because otherwise the bubble would be besides the conflict mark or at least skewed to the right (in Figure 2).

3.2. Algorithms for uncertainty – the error functions

Each bubble is an ellipse, whose axes are the 95% (say) confidence limits on time and distance respectively. It should also be noted that the bubble is not necessarily symmetrically distributed about the nominal conflict. A 95% confidence limit is chosen here purely as an example. The most appropriate percentile will need to be investigated and tuned as part of the evaluation.

For simplicity, it is proposed that only the uncertainty ellipse around the LOS is shown, not around the CPA as well. The relative merits of showing one or the other could be an aspect to consider in evaluation.

For this trial implementation, it is proposed to base the uncertainty (error) functions on normal distributions, and to represent only TP uncertainty. Other kinds of uncertainty, such as operational uncertainty in controller time to issue instructions or pilot response time are not included. While it is appreciated that TP uncertainty may not always be the most important uncertainty, it should allow exploration of some important presentation issues within the limited scope of this study.

TP uncertainty can be divided into along-track and cross-track components. The following, simple, functions (derived from other references as noted in the project report CARE-Innovative-RMC-T4-D2-1.0, July 03) are proposed:

Along-track error

As described in [13], this can be represented in the form

$$\text{Along-track Error (nm)} = a(t) \cdot A$$

where:

A is a normal distribution with zero mean and unit variance

and $a(t)$ represents the growth of error with time

Ref [13] quotes 0.25 nm/ minute for the rate of growth of error as a typical value for aircraft in level flight.

Cross track error

As described in [10], we propose a rate which also grows with time, but to a limited value, since, while along-track errors continue to grow with time, cross-track errors should be controlled by the aircraft Flight Management System (FMS).

$$\text{Cross-track Error (nm)} = b(t) \cdot B$$

where:

B is a normal distribution with zero mean and unit variance

and $b(t) = b (1 - e^{-(t/t_c)})$ represents the growth of error with time

where b and t_c are constants

Ref [10] does not suggest any real data for this, but they can be derived from Required Navigation Performance (RNP) requirements on lateral navigation accuracy [25]. Cross-track errors can be significant in some situations, such as during radar vectoring, but in the en-route, flight-plan based part of the flight, cross-track error is generally seen to be small compared to the along-track component [13]. Hence, for the purpose of this initial investigation, cross-track error does not merit such detailed attention as the along-track component.

In discussions with controllers, they 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 they could not decide on any useful action. It is proposed that, initially, the existing rules for when to present a conflict should be retained. However, the evaluation of the presentation of uncertainty in each displayed conflict may lead to a better understanding of how to set such thresholds.

3.3. Aspects for Evaluation in the HF lab

Initial suggestions for evaluation relate mainly to aspects of the display that cannot be fully defined at this stage, as mentioned in the preceding section:

1. From user feedback already received, we suggest that uncertainty should only be displayed on request. Hence a 'show/ hide uncertainty' button is proposed, allowing the user to toggle between the presentations with and without uncertainty. There is however a potential conflict between the controllers' expressed desire to see uncertainty information only 'on demand' and the general principle that information should be consistently presented to all users. For example, if two or more controllers were looking at the same potential conflict it would be inadvisable for them to have differing views of its perceived likelihood. However there may be room for personal choice in what additional information controllers choose to look at (which windows they have open, traffic filters, radar scale etc) and the proposed availability of an uncertainty bubble around each potential conflict could fall into this 'personal choice' category. Feedback on this issue should be sought in the evaluations.
2. What is the most appropriate confidence limit percentile to define the boundaries of the ellipse? This will need to be investigated and tuned as part of the evaluation. Factors to consider will include providing a helpful complement to users' intuitive mental models of the spread, and ensuring that bubbles do not overlap so much as to become indistinguishable.
3. For simplicity, it is proposed that only the uncertainty ellipse around the LOS is shown, not around the CPA as well. The relative merits of showing one or the other could be an aspect to consider in evaluation, although it is appreciated that this may add excessively to the work required in development.

DS: Show uncertainty around the CPA not LOS; see comment above.

4. It is proposed that, initially, the existing rules for when to present a conflict should be retained. However, the evaluation of the presentation of uncertainty in each displayed conflict may lead to a better understanding of how to set such thresholds.

Other types of evaluation – e.g. measurements/ user evaluations are to be defined as work progresses.

4. VERTICAL AID WINDOW

4.1. Functions and Form of the Display

The VAW shows the vertical profile of aircraft climbing and descending. There are significant uncertainties in when and how fast aircraft climb or descend, and the VAW was therefore considered a good example of a display in which information about uncertainty could be helpful.

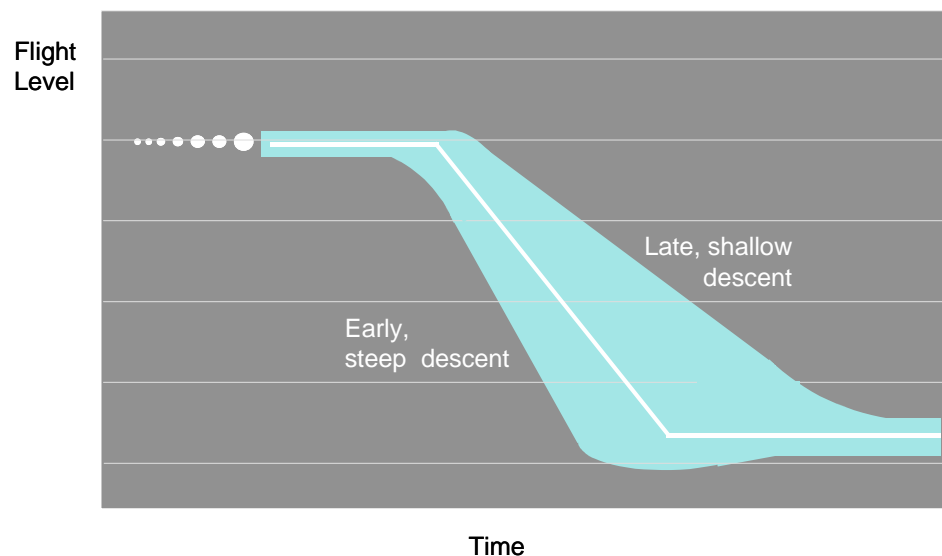


Figure 3 Uncertainty in Climb/ Descent

The uncertainty is shown by a region around the nominal path, corresponding to (say) the 95% confidence limits on the region within which the aircraft will remain (Figure 3). As for the PPD, the most appropriate percentile will need to be explored in evaluation. Also, as with PPD, it is proposed that the uncertainty region should be displayed only on request (though with the concern in mind that this may lead to inconsistent views between users).

4.2. Algorithms for uncertainty – the error functions

Distributions of aircraft climb/ descent paths about their nominal values, derived by a mixture of analytical methods and experimental data, are given in Ref [26]. The components of vertical error described in this paper are:

- Error in Top-of-Descent (TOD) or start of climb
- Weight error
- Wind gradient
- Speed error
- Interim altitude (steps)
- Wind forecast error

As in the PPD proposals, these are not a complete set of uncertainties, nor necessarily the most important, but they provide a credible basis for exploring presentation issues. The forms of algorithms representing the combination of these errors are proposed here, but some details of how to define parameter values are still being clarified by RMC.

Vertical error also influences along-track error, and hence should strictly also be taken into account in the proposed PPD uncertainty. However, for simplicity, the

vertical and horizontal elements will be kept separate in this study. (Note that this assumes that the VAW is still presented as a graph of FL versus time. If FL versus distance were to be presented, the along track error, which grows during the climb/descent, needs to be shown.)

Although all the component errors are defined in terms of vertical error in [26] we propose that separate, time-based, error distributions are used for the TOD or start of climb, component. TOD and start of climb are 'one-off' errors rather than a continuously growing variation about the nominal descent/climb path. For TOD/ start of climb we propose that the error in time this can be represented in the form

$$\text{Error (t)} = T$$

where T is a normal distribution with zero mean and variance V_{TOD}

(parameter values for this have yet to be defined)

For all other components of vertical error, the distribution generally grows with time during the descent/ climb, and then reduces again as the aircraft levels out and its altitude is relatively accurately controlled by the FMS. Although the distributions vary somewhat in their form and how they vary with time, it is proposed that, as a first approximation, we assume they are all skewed normal distributions. The distribution is skewed to allow for the difference between early, steep descents and late shallow descents. Assuming, furthermore, that the contributory distributions are independent, the quoted standard errors from each contributor can be combined to give a single, time-varying distribution about the nominal path - the standard error (SE) of the overall distribution being the square root of the sum of the squares of SEs in each component.

The standard error values quoted in [26] are the peak values over time, and derived for a climb/ descent of 33000 feet. To define the error function we therefore need to scale these to allow for

- the fact that the standard error increases and then decreases over the duration of the climb; and
- the effect of climbs/ descents other than the assumed 33000 ft .

We thus define error functions as follows:

Error in climb

$$\text{Error in climb} = V_c \text{ (ft)}$$

where V_c is a random variable (normal distribution) with mean M_c and standard error S_c .

Values for these parameters will have to be checked against some questions we have on the source paper and/or tuned in the evaluation, so they should be specified as input parameters that can be adjusted. However, as a starting point I suggest a mean of 200 ft and a SE of 2000 ft

As a first approximation, to allow for climbs other than the assumed 33000 ft, we obtain the peak standard error by scaling that for a 33000 ft climb in proportion to the actual climb height, C . Thus

$$\text{Peak standard error} = SE_c \times C/33000$$

To allow for the fact that the error increases to this value and then decreases, we need to multiply this by a time dependent function which fits the following points (T_c being the climb duration)

- Value =0 at time $T=0$
- Value = peak = 1 at $T=0.5T_c$
- Value = 0 at time $T=T_c$

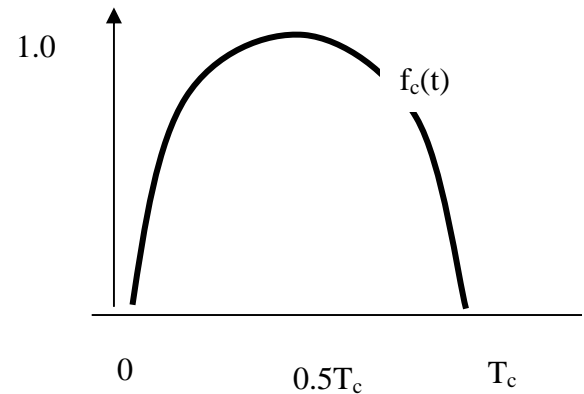
I propose a simple symmetric, parabolic function, $f_c(t)$

$$f(t) = 1 - [(t-0.5T_c) / 0.5T_c]^2$$

Thus the error function becomes:

$$\text{Error in climb at time } t = V_c(t)$$

where V_c has mean zero and standard error = $SE_c \times C/33000 \times f_c(t)$



Error function for descent

Similarly for descent

$$\text{Error in descent} = V_d(t)$$

Where V_d is a random variable (normal distribution) with mean M_d and standard error SE_d

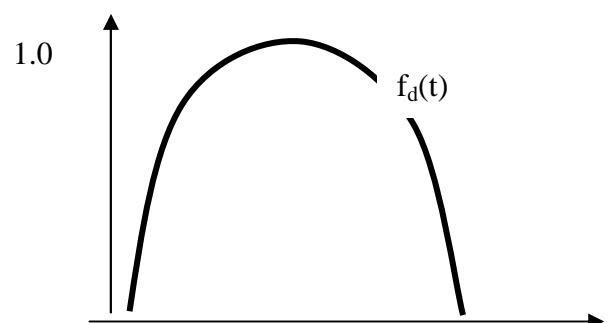
Values for these parameters will have to be checked against some questions we have on the source paper and/or tuned in the evaluation. However, as a starting point I suggest a mean of 300 ft and a SE of 5000 ft

To allow for descents other than the assumed 33000 ft, we obtain the peak standard error by scaling that for a 33000 ft climb in relation to the actual descent height, D as follows:

$$\text{Peak standard error} = SE_d \times D/33000$$

To allow for the fact that the error increases to this value and then decreases, we need to multiply this by a time dependent function that fits the following points (T_d being the descent duration)

- Value =0 at time $T=0$
- Value = peak = 1 at $T=0.5T_d$
- Value = 0 at time $T=T_d$



As for the climb, we propose a simple symmetric, parabolic function, $f_d(t)$

$$f(t) = 1 - [(t - 0.5T_d) / 0.5T_d]^2$$

Thus the error function becomes:

Error in climb at time $t = V_d(t)$

where V_d has mean M_d and standard error = $SE_d \times D/33000 \times f_d(t)$

DS: Maybe I am missing the point but I am wondering whether the calculation of the vertical position error needs to be that complicated; another option would be to use standard deviation around the rate of climb (ROC) / rate of descent (ROD). The nominal ROC/ROD could be calculated from the descent profile and a StdDev of either 500 feet per minute or 0.2 times the ROC/ROD could be assumed – or whatever else seems realistic. Upon the contractor company to evaluate whether the calculation of the vertical position error according to this scheme is feasible and easier.

4.3. Aspects for Evaluation in the HF Lab

Initial suggestions for evaluation relate mainly to aspects of the display that cannot be fully defined at this stage, as mentioned in the preceding section:

1. As for PPD a 'show/ hide uncertainty' button is proposed, allowing the user to toggle between the presentations with and without uncertainty, but does this conflict with the general principle that information should be consistently presented to all users?
2. What is the most appropriate confidence limit percentile to define the boundaries of the uncertain region?

Other types of evaluation – e.g. measurements/ user evaluations are to be defined as work progresses.

5. ON-SITE SUPPORT DURING THE EVALUATION IN THE HF LAB

DS: Experiments in the EUROCONTROL Human Factors Laboratory will take place in week 48 and week 49 2003, i.e. in the period 24 – 28 November and 1 – 5 December 2003. The first week is dedicated to scenario and prototype testing, the second week is foreseen for experiments, presumably two independent runs with one CWP each. The experiments should be considered as early prototype evaluation, consequently the data and evidence collected will be predominantly of subjective nature. Questionnaires, observations, and debriefings will be the main means of data collection.

On site support is required for the experiments. More precisely the experiments require physical presence of one developer

1. during three days of the testing week, preferably Wednesday through Friday
2. for at least the first two days of the experimental week, i.e. 1 and 2 December.