RECOMMENDATIONS FOR HMI EVALUATION IN THE CONTEXT OF CWP DEVELOPMENT: A SYNTHESIS OF RELEVANT LITERATURE

EEC Note No. 03/03

Project HRS/HSP-006
(Core Requirements for ATM Working Positions)

Issued: February 2003
<table>
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<th>Security Classification:</th>
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<td>EEC Note No. 03/03</td>
<td>Unclassified</td>
</tr>
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<th>Originator:</th>
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<tr>
<td>EEC - ACS (ATM Concepts and Studies)</td>
<td>EUROCONTROL Experimental Centre Centre de Bois des Bordes B.P.15 F - 91222 Brétigny-sur-Orge CEDEX FRANCE Telephone : +33 (0)1 69 88 75 00</td>
</tr>
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<tr>
<td>EATMP Human Factors Sub-Programme</td>
<td>EUROCONTROL Agency Rue de la Fusée, 96 B -1130 BRUXELLES Telephone : +32 2 729 9011</td>
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**TITLE:**

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<td>Core Requirements for ATM Working Positions</td>
<td>HRS/HSP-006</td>
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**Distribution Statement:**

(a) Controlled by: Head of ACS
(b) Special Limitations: None
(c) Copy to NTIS: YES / NO

**Descriptors (keywords):**


**Abstract:**

This document provides a synthetic review of literature relating to the evaluation of HMI. It identifies three targets for evaluation, HMI Requirements, Specifications and Behaviour and the phases of the development process in which they are of importance. It identifies methods and supportive tools relevant to the evaluation of each of the targets. Methods are described at a comparatively high level in the parent document but in the 'electronic form' links (indicated by 📕) allow access to structured 'method forms' explaining objectives, application context, process, and data recording and analysis. Further links give access to original source documents or to relevant websites.
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Recommendations for HMI Evaluation in the context of CWP development: A synthesis of relevant literature

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FOREWORD

This document in the context of CoRe

This document is part of the evaluation guidance material developed within the CoRe Requirements for ATM Working Positions Project (CoRe) to improve the process and the outcomes of the activity of defining and developing effective controller working positions (CWPs) for ATM. It has been produced under a contract with PACTE NOVATION.

The CoRe project is part of the Human Factors Sub-Programme of the EATMP Human Resources Programme managed by the EUROCONTROL Human Factors and Manpower Planning Unit. It is a three-year project reaching completion at the end of 2002 and the work has been carried out within the ATM Systems and Concepts Business Unit at the EUROCONTROL Experimental Centre, Brétigny, France.

Rather than taking a formal system development approach, CoRe began by trying to understand current processes and practices and to improve them. Methodologically, CoRe views the development of working positions for ATM applications as a socio-technical process, one involving a variety of human actors and technology with collective objectives. Within this perspective, CoRe employed a bottom-up approach to the understanding of the problems involved in integrating a variety of expertise to arrive at a successful development outcome. Many of these problems are directly related to communication difficulties between actors and between processes. A fundamental objective of CoRe has been to improve communication, not only within development activities but also between them.

The project also identified a need for a more structured approach to evaluation and testing. Related to this is the need for a shift to a more requirements oriented approach, not only for evaluation but also to better support harmonisation and re-use through transfer of requirements, solutions, experience and design rationale from one project to another.

To support the realisation of both process and ‘cultural’ improvements, the project exploited software engineering technology (the UML1, case tools, etc) and methods to develop a requirement oriented process and a specially designed support framework. The framework helps to reconcile the functional and component views appropriate to different stakeholders, and to different stages and activities in development. It also improves communication by supporting consistency, traceability and document management.

To illustrate the approach and the improved process, CoRe has produced deliverables in 3 main areas as shown in Figure 1:

- a qualitative, organisational model of the activities involved in developing adequate controller working positions. This is supported by additional explanatory documentation and guidance material;
- the UML/XML2 based supportive development framework;
- a baseline CWP - a worked example of a high quality (but basic functionality) en route CWP, completely described using the framework (CoRe Baseline HMI).

---

1 Unified Modelling Language
2 Extensible Markup Language
The additional documentation referred to in the first bullet point includes:

- a general introduction to requirements capture and management [11],
- recommendations on HMI evaluation techniques (this document),
- a general review on the subject of style guides for ATM applications [12], plus, as an example, the actual style guide for the CoRe Exemplary HMI [13]; and
- an overview of the CoRe³ project itself [14].

³ Information and documents from CoRe can be found on http://projects.eurocontrol.fr/consultproject?LOID=6.0.33310
The role of this document

CoRe has identified the need for a more structured approach to evaluation and testing. To support the development of guidance material relating evaluation techniques to the type of development processes being proposed in CoRe, an activity was launched with two main phases:

- A review of the literature on both general Human Machine Interaction (HMI) evaluation and the ATM controller working position in particular.
- A critical synthesis of the reviewed material and recommendations for the application of method appropriate to the type of development processes supported by CoRe.

In the context of HMI, the review considered evaluation of, Requirements, Specifications and HMI Behaviour. The process of the review involved the preparation of structured ‘reading forms’ for each of the key references identified. On the basis of this material the critical synthesis was prepared.

The present document is the end product of this activity. Although it can be printed as a paper document, it is designed to be used in an electronic form.

If you have downloaded it electronically, the document and its three associated sub-folders (Reading Forms, Methods Forms, and Resources) should be placed in the same folder on your PC. If you have the document on CD it will already be structured correctly. If you only have the paper form of the document, the full electronic form can be obtained by contacting the EATMP DIS/HUM website4 or the EUROCONTROL Experimental Centre5

This report provides a synthetic review of literature relating to the evaluation of HMI. It identifies three targets for evaluation, HMI Requirements, Specifications and Behaviour and the phases of the development process in which they are of importance. It identifies methods and supportive tools relevant to the evaluation of each of the targets. Methods are described at a comparatively high level in the parent document but in the ‘electronic form’ links (indicated by □□) allow access to structured ‘method forms’ explaining objectives, application context, process, and data recording and analysis. Further links give access to original source documents or to relevant websites.

Acknowledgements

The CoRe project team would like to thank the many people who have made the conduct and completion of the project possible over the last three years.

These include our sponsors who kept faith; the different contractors who have helped develop the guidance material; the many people at the Experimental Centre who have assisted and contributed; the controllers from a number of European member states who have participated in our small-scale simulations, and through their helpful criticism encouraged us to improve our products; and all those others involved in HMI development in Europe and the US who have provided us with information and assisted in our faltering efforts to establish a forum for discussion in our community.

Alistair Jackson
CoRe Project Manager
5th February 2003

4 http://www.eurocontrol.int/humanfactors/publ.html
5 http://www.eurocontrol.fr/ and select the ‘Documents’ option.
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1. INTRODUCTION

1.1 Purpose of the document

This document presents a synthesis of a literature review on “Evaluation methods and techniques” conducted for the CoRe project (WBS3). This review constitutes the first step aimed at leading to practical recommendations to be integrated within the framework of CoRe deliverables.

In this context, this document provides a structured list of evaluation methods and techniques, and methodological issues related to the design of future Air Traffic Control systems.

To carry out this study, research and industrial resources dealing with HMI evaluation – not only from within the ATM literature but also from other fields (Software Engineering, Requirements Engineering, Web usability etc.) - have been collected and reviewed.

Some of the material contained within these resources is particularly relevant for use within the CoRe process.

The main purpose of this work is to identify, for each phase of the development process, which evaluation method should be used to ensure that criteria such as usability, reliability, efficiency, and safety are respected.

1.2 Definitions and scope of ‘Evaluation’

From reviewing the literature, it is possible to identify a common theme for characterising 'Evaluation', involving the use of concepts such as “measurement”, “assessment” and “verification”. The most useful definition (for the purposes of this document) is one that emphasises the information processing and feedback functions of Evaluation. For example

*Evaluation is the systematic acquisition and assessment of information to provide useful feedback about some object.*[1]

1.2.1 Evaluation and the design process

This initial, generic definition can be refined by introducing the specific context of the study: ATC systems development. To do this, it is necessary to place the activity involved in Evaluation in the context of the other activities of the system development process.

Generalising across the different models employed for representing development processes (V model, spiral model, etc.), we focus here on the technical activities (i.e., analysis, specification, software design, etc.) which are more or less common to all models, despite the differences of vocabulary that are encountered.

We start from the fact that “Evaluation” is one such technical activity.

Figure 1.2.1 shows the context, illustrating the conceptual relationships between “Evaluation” and “Analysis”, Design & Development” and “Validation”. In addition, the figure emphasises the nature, the function and the object of the evaluation activity.
1.2.2 Evaluation and traceability of transformations

Another perspective is provided by characterising the nature of the activity on which “Evaluation” relies.

The development process can be defined as a “succession of transformations of information components" including the traceability of these transformations.

Thus, in the “world of needs” (see Figure 1.2), system objectives, users’ needs, organisational and technical constraints are transformed into “Requirements". Moving to the “world of solutions" then consists of transforming these “Requirements" into "Specifications" which will subsequently be further transformed.
to produce “Design components” and eventually “Software and organisational components”.

Figure 1.3: Transformation/Verification cycle in a design process

As shown in Figure 1.3, the need for verification arises each time a transformation is made; it is not a "one shot" step in the life cycle. From this perspective, traceability becomes a central concept for consideration because of the role it plays in the evaluation process: Traceability supports the verification of the validity of the transformation itself whereas Evaluation addresses the result of the transformation.

To pursue this idea, one can state that verification relies on a comparison process, in which a "product" to be verified (requirements, specifications, etc.) is confronted with some "reference".

This "reference" can be derived from two perspectives:

- A general perspective: the reference consists of existing, commonly accepted "standards" (rules, principles, thresholds, etc.). The product to be evaluated is analysed against dedicated criteria which are derived from scientific resources or pragmatic experience and which provide feedback about efficiency, safety, usability, quality, etc., of the system.

- A “context specific” perspective: the reference is represented by the needs that the system must satisfy and Evaluation consists in verifying the adequacy of the design products against these needs. This notion is akin to that of Validation. For the current study, the needs to be taken into account are primarily those of the users who, in this context, are the controllers using the working position under development.

There is some commonality between these perspectives. The “standards” are themselves the consolidation of experience gained over the years; they were originally elaborated to meet specific “users’ needs” and have then been generalised. This matches the “consolidation philosophy” underlying the CoRe methodological process.

Nevertheless, a difference exists at a methodological level. The general perspective inclines towards methods based on checklists to guide the Evaluation process, whereas the “context specific” perspective requires good traceability throughout the design process and relies, for the most part, on experimental techniques.
As a synthesis of these different points of view, we can define Evaluation as an activity that:

- Consists of a comparison process;
- Operates on Requirements, Specifications and behaviour of the socio-technical system being developed;
- Provides qualitative and quantitative data for verifying and validating these different “components” produced during the system design process;

1.3 The Approach, basic concepts, difficulties and limits

The first step (and the first difficulty) for this study was to find a categorisation of the methods which:

- Took into account the specific methodological context prescribed by existing CoRe material.
- Guided the use of the methods:
  - according to the step of the design process to which they were applicable
  - as a function of the “object” to be evaluated.
- Allowed, if possible, an exclusive classification of the relevant methods.

1.3.1 Integration context and categorisation of methods

Figure 1.4 presents a way of integrating the evaluation methods within the CoRe “methodological toolkit”.

Integrating the “evaluation question” (what is the “object” of the evaluation?) within the technical activities defined in the CoRe process leads to a first categorisation of methods to be studied, and defines the high-level themes to be addressed, as a function of the “object” of the evaluation:

- Evaluation of Requirements,
- Evaluation of HMI Specifications,
- Evaluation of HMI behaviour.
1.3.2 Detailed categorisation

Starting from the main classification presented in Figure 1.4, the working strategy consisted of identifying the research domains involved, the existing methods and tools, and the recommendations that could be made for each of the axes of evaluation.

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<th>What is evaluated?</th>
<th>Literature Review</th>
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</thead>
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• Functional requirements  
• User Interface requirements  
• Requirements related to organisational factors  
• Working environment  
• SW Technical requirements | • Requirement Engineering  
• Marketing related works  
• Ergonomics (norms) |
Recommendations for HMI Evaluation in the context of CWP development: A synthesis of relevant literature

<table>
<thead>
<tr>
<th>Evaluation Scope</th>
<th>What is evaluated?</th>
<th>Literature Review Which research domains?</th>
</tr>
</thead>
</table>
| Evaluation of HMI Specifications | • Documentation quality  
• Traceability between requirements & specs  
• Adequacy with respect to HCI guidelines  
• A priori usability of mock-up | • HCI  
• Predictive & Formal Models  
• Usability |
| Evaluation of HMI Behaviour | • Conformance with specifications  
• HMI performances  
• Usability of target system  
• Safety related aspects | • Software engineering  
• Usability  
• Performance  
• Safety and human reliability |

Table 1.1: The proposed classification of evaluation methods

The different questions and criteria derived from this classification lead to the particular organisation of the presentation of methods in the following sections.

1.3.3 Some basic concepts

1.3.3.1 Usability

In Figure 1.4, two major themes require further explanation: Quality and Usability. Where HMI design is concerned, these two concepts are closely linked, with Usability being the most important criterion when speaking of HMI Quality. Many definitions of Usability, as well as related concepts, exist in the literature.

Usability is defined as:

“… the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments” [3], where:

- “Effectiveness” refers to the extent to which a goal, or task, is achieved.
- “Efficiency” refers to the amount of effort required to reach a goal.
- “Satisfaction” refers to the level of comfort that the users experience when using a product and how acceptable the product is to the users as a means of achieving their goals.

According to Bevan [4], “this approach is synonymous with quality in use: ensuring that a product meets user needs. To achieve quality in use requires not only ease of use, but also appropriate functionality, response time and reliability”.

“Usability of a system or equipment is the capability in human functional terms to be used easily and effectively by the specified range of users, given specified training and user support, to fulfil the specified range of tasks, within the specified range of environmental scenarios” or in short “the capability to be used by humans easily and effectively” [5].

1.3.3.2 Some observations on the use of standards, checklists and guidelines

A lot of the methods listed below are based on the use of dedicated checklists or guidelines. Most of the time these define criteria allowing the “evaluator” to produce qualitative data, following design principles, standards, or heuristic rules.
Guidelines have the advantage that they can be applied early in the design, and adherence to most guidelines can be assessed merely by inspection of the product without user testing. However, guidelines also have a number of limitations:

- Many alternative design solutions can be equally compatible with guidelines, but changing an interface feature to be compatible with one guideline often makes it incompatible with another. There is no easy way to trade off the benefits of different guidelines.
- There is no guarantee that any particular set of guidelines is exhaustive and deals with all relevant aspects of the user interface.
- The effectiveness with which guidelines are applied depends on the skill of the designer in interpreting and applying them and in making any necessary trade-offs.
- Some usability attributes are context-dependent properties of interaction that can only be evaluated when a product is actually used by representative users to carry out representative tasks.
- Evaluating whether or not a product is consistent with guidelines can be very time consuming. For instance, applying the menu guidelines standard to a complete product requires that every menu in the product is checked for conformance with every applicable recommendation.
- Following guidelines does not ensure that a product reaches any particular level of usability. In particular, the \textit{structure} of a dialogue design is just as important as the more easily assessable surface features. In many cases the usability of a product will be improved by redesigning the interface to be consistent with guidelines. However, a much bigger usability improvement can often be made by considering whether a fundamental redesign would enable the task to be carried out more effectively, (e.g. avoiding the use of menus to search for information by supplying a unique key to allow direct access).
- Detailed and specific guidelines are likely to be appropriate only for specific systems and specific types of users. On the other hand, guidelines and principles expressed in general terms are difficult for developers and evaluators to interpret - they can mean very different things to different people. (This is eloquently demonstrated by Grudin [6]).
- Where guidelines are expressed in general terms, their interpretation may depend so much on expert opinion that objective evaluation is simply not possible.
- Guidelines often attempt to generalise across a wide range of user, task and environment characteristics. It is very difficult to specify rigorously the limits of the context in which a guideline is applicable.
- When guidelines are used for evaluation the result is a checklist showing which parts of a product conform to which recommendations. While this can be used to identify potential problems with the interface, it is difficult to understand the importance of any deviation.

\subsection{1.3.3 Scenario-based approaches}

The use of scenarios in design or evaluation appears to be an approach offering wide applicability. It could be used for evaluating functional requirements, in experimental methods to elaborate exercises, or in the heuristic evaluation of an HCI to guide the strategy for examining the interface.
Most of the time, scenario-based approaches are closely related to task analysis, whatever the supporting tool employed. For this reason the scenario-based approach does not appear as a ‘method’ in the following tables.

1.3.4 Some difficulties and constraints

As emphasised in Figure 1.2.1, Requirements and Specifications are produced by Design activities and constitute the objects (inputs) of Evaluation. Moreover, within an iterative view of the development process, Evaluation appears as a means to provide inputs (feedback) for Design activities.

![Figure 1.5: Interaction between Design and Evaluation](image)

This two-fold relationship between Evaluation and Design is one source of the difficulties of elaborating a clear strategy for bibliographic search. In fact, some methods presented as Evaluation have more to do with Design. For instance, “task analysis and modelling” appear in some documents as an evaluation method and in others as a design method for eliciting users’ requirements. In fact, we consider that Evaluation could rely on task analysis and that task analysis thus constitutes an input to Evaluation.

Another aspect of the role of Evaluation – consolidation – is suggested by the relation it bears to Design. By providing feedback on Design issues, Evaluation contributes to the consolidation (or rejection) of some design choices, and thus contributes to the establishment of favourable conditions for the reuse of components from one system to a subsequent generation.

This imposes a requirement on Evaluation methods: the results of an evaluation must be reusable other contexts. Methods must therefore be explicit about their original context in order to be generalisable.

This aspect - which is clearly mentioned in the objectives of CoRe - is not explored further in the presentation of methods. Nevertheless, for each main category of methods, we clearly identify the “methodological context” in which the methods are envisaged. This is done by diagrams illustrating the inputs, the objects and the output of the methods under consideration (see Figures 2.1, 3.1 and 4.1).

Another source of ambiguity comes from the use of terms such as “Method” and “Technique” in the literature. We consider here that a method is a set of organised activities directed by an explicit objective implementing generic human factors techniques to provide required outputs. From this perspective, activities such as interviewing, cognitive walkthrough, brainstorming, observation, etc. will not appears as methods but as techniques useful for collecting data within particular methods.
1.4 The organisation of the study and the expected results

This study has been conducted in three steps:

- **Step 1**: bibliographic search.
- **Step 2**: compilation of a structured synthesis of the literature (this report).
- **Step 3**: elaboration of recommendations for the practical implementation of evaluation methods.

The results of the study are organised as shown in Figure 1.5:

![Figure 1.5: Organisation of the study and expected results](image-url)

![Figure 1.6: Expected results of the study](image-url)
The following sections present the resulting "catalogue of methods" organised by the "objects" of evaluation.
2. EVALUATION OF REQUIREMENTS

The methodological context for the evaluation of requirements is expressed in Figure 2.1.

![Figure 2.1: The methodological context of “Evaluation of requirements”](image)

The following subjects related to requirements are considered:

- Requirements related to system stakeholders
- Functional requirements
- User Interface requirements
- Working environment requirements
- Requirements related to organisational factors
- Software Technical requirements

2.1 Evaluation of requirements related to system stakeholders

2.1.1 Evaluation questions and sub-criteria

(The objective is to identify groups of people with similar needs, and to allow each set of needs to be considered separately.)

- Is there an explicit identification of the system stakeholders (different groups)?
- For each group, is there an explicit identification of their objectives and roles in relation to the system?
- For each group, is there an explicit identification of their intrinsic characteristics?

2.1.2 Related methods, tools and techniques

Different approaches can be used to evaluate requirements related to stakeholders:

<table>
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<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stakeholder meeting</td>
<td>This method could be used to support design (elaboration of requirements) and for evaluation (verification). The purpose is to:</td>
</tr>
<tr>
<td></td>
<td>• Ensure that all factors that relate to use of the system are identified before design work starts.</td>
</tr>
<tr>
<td></td>
<td>• Bring together all the people relevant to the development, to create a common vision.</td>
</tr>
</tbody>
</table>
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A synthesis of relevant literature

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus groups</td>
<td>This is a data collection technique, which gathers some 6 to 9 users to discuss issues about the system.</td>
</tr>
<tr>
<td>Stakeholder specific checklist</td>
<td>A checklist can be used to help the evaluator (Human Factors team for example) to verify the different information contained in documents. (Maguire [7], <a href="http://www.ejeisa.com/nectar/respect/5.3/index.htm">www.ejeisa.com/nectar/respect/5.3/index.htm</a>)</td>
</tr>
<tr>
<td>Stakeholder dedicated interviews</td>
<td>Interviews and meetings can be realised with people who lead the studies about the new system.</td>
</tr>
</tbody>
</table>

2.2 Evaluation of functional requirements

2.2.1 Evaluation questions and sub-criteria

Two aspects can be evaluated at the functional requirements stage:

- **Completeness**: are the tasks identified in the Task/Activity model (textual description or graphical model) reflected in the functional requirements?
- **Relevance**: is each functional requirement justified by the Task/Activity model? The goal is to eliminate functions “inherited” from previous versions of the systems which are no longer relevant in the future context.

2.2.2 Related methods, tools and techniques

Different approaches can be used to evaluate functional requirements:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task/Activity analysis</td>
<td>Task analysis is used to identify what a user is required to do in terms of actions and/or cognitive processes to achieve a task. A detailed task analysis can be conducted to understand the current system and the information flows within it. <em>The ISO “Guidance on task requirements” material [2] could be used.</em></td>
</tr>
<tr>
<td>Experimental methods</td>
<td>The “object” of experimental methods is, classically, the functioning of the system rather than requirements. Nevertheless, insofar as traceability is maintained between requirements, specifications and system design, experimental methods provide the most complete approach to evaluating requirements.</td>
</tr>
</tbody>
</table>
2.3 Evaluation of User Interface requirements

2.3.1 Evaluation questions and sub-criteria

Three dimensions of HMI requirements can be evaluated:

- Conformance with the individual's usability goals
- Conformance with collective usability goals (team work)
- Conformance with standard HCI requirements

2.3.2 Related methods, tools and techniques

Various approaches can be used to evaluate HMI requirements:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heuristic evaluation</td>
<td>Method used for evaluating heuristics related to single-user's usability and/or groupware usability:</td>
</tr>
<tr>
<td></td>
<td><strong>Heuristics for single-user’s usability:</strong></td>
</tr>
<tr>
<td></td>
<td>Visibility of system status, match between system and the real world, user control and freedom, consistency and standards, error prevention, recognition rather than recall, flexibility and efficiency of use, aesthetic and minimalist design, help users recognise, diagnose and recover from errors, help and documentation</td>
</tr>
<tr>
<td></td>
<td><strong>Heuristics for groupware usability:</strong></td>
</tr>
<tr>
<td></td>
<td>- ‘Mechanics of collaboration’: communication, coordination, planning, monitoring, assistance and protection.</td>
</tr>
<tr>
<td></td>
<td>- ‘Locales’ Framework: locales foundations, mutuality, individual view of multiple locales, interaction trajectories and civic structures</td>
</tr>
<tr>
<td>ISO standards checklist</td>
<td>The following ISO material could be applied:</td>
</tr>
<tr>
<td></td>
<td>- ISO /DIS 9241-11: Guidance on Usability</td>
</tr>
<tr>
<td></td>
<td>- ISO/IEC CD 14598-1: Information Technology - Evaluation of Software Products - General guide</td>
</tr>
<tr>
<td></td>
<td>- ISO 9241-3: 1993: Visual display requirements</td>
</tr>
<tr>
<td></td>
<td>- ISO DIS 9241-5: Workstation layout and postural requirements</td>
</tr>
<tr>
<td></td>
<td>- ISO DIS 9241-6: Environmental requirements</td>
</tr>
<tr>
<td></td>
<td>- ISO DIS 9241-7: Display requirements with reflections</td>
</tr>
</tbody>
</table>

---

6 The terms “task” and “activity” are used indistinguishably to avoid the classical – but out of the scope – debate related to this topic.
7 In this theory, “locale” is a conceptual place or domain where social world members come together to collaborate.
8 ISO standards have to be purchased and can be obtained directly from ISO (International Organization for Standardization).
Recommendations for HMI Evaluation in the context of CWP development:
A synthesis of relevant literature

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
</table>
|                           | - ISO DIS 9241-8: Requirements for displayed colours  
|                           | - ISO DIS 9241-4: Keyboard requirements  
|                           | - ISO DIS 9241-9: Requirements for non-keyboard input devices                                                                                                                                                        |
| HCI dedicated guidelines  | Generic guidelines specifying HCI principles related to: data entry, data display, sequence control, user guidance, data transmission, data protection.  

2.4 Evaluation of requirements related to organisational factors

2.4.1 Evaluation questions and sub-criteria

Have the characteristics of the organisational environment been considered?
- the way work is organised,
- working conditions,
- performance feedback,
- variety provided by the job,
- level of control and autonomy,
- etc.

2.4.2 Related methods, tools and techniques

An existing checklist can be used to evaluate requirements related to the working environment:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
</table>
| Organisation dedicated checklist | The following criteria could guide the evaluation:  
|                           | - Staff and management structure  
|                           | - Availability of assistance.  
|                           | - Interruptions, stressful conditions  
|                           | - Communications structure  
|                           | - Privacy  
|                           | - Job function  
|                           | - Safety and security                                                                                                                                 |

9 Reference not currently available.
2.5 Evaluation of requirements related to the working environment

2.5.1 Evaluation questions and sub-criteria

One dimension can be evaluated in the working environment: conformance with **Environmental standards requirements**.

2.5.2 Related methods, tools and techniques

Only one reference has been found to evaluate requirements related to the working environment:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental standards checklist</td>
<td>A checklist exists, dealing with environmental requirements. It defines questions related to: Vibration or instability, Visual environment, Space and furniture, User posture, Location, Health and safety hazards, Protective clothing and equipment. (see CUErgo Site at <a href="http://ergo.human.cornell.edu/">http://ergo.human.cornell.edu/</a>)</td>
</tr>
</tbody>
</table>

2.6 Evaluation of software technical requirements

2.6.1 Evaluation questions and sub-criteria

Three main aspects can be evaluated at the requirements stage: Technical Architecture, Requirements relating to software development tools, Requirements relating to software quality.

2.6.2 Related methods and tools

An existing checklist can be used to evaluate technical requirements:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architectural design methods</td>
<td>Out of scope</td>
</tr>
<tr>
<td>Checklist related to software quality</td>
<td>The following criteria are considered: Efficiency / performance, Integrity, Adaptability, Interoperability, Re-usability, Portability (see [9].)</td>
</tr>
</tbody>
</table>
3. EVALUATION OF HMI SPECIFICATIONS

The methodological context for evaluating HMI specifications is shown in Figure 3.1:

![Figure 3.1: The methodological context for “Evaluation of HMI specifications”](image)

The following subjects related to HMI specifications are considered:

- Documentation quality
- Traceability between requirements & specifications
- Adequacy with respect to HCI guidelines
- *a priori* usability using mock-up

### 3.1 Evaluation of documentation quality

#### 3.1.1 Evaluation questions and sub-criteria

Does the specification documentation, meet the quality standards?

#### 3.1.2 Related methods and tools

An existing checklist can be used to evaluate document quality:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality related checklists</td>
<td>The following criteria of evaluation can be found in checklists of this type: conciseness, simplicity, readability, lack of ambiguity, completeness, ability to be verified, consistency. (For examples, see the RMIT University documents listed in the associated Method document.)</td>
</tr>
</tbody>
</table>

### 3.2 Evaluation of the traceability between Requirements and Specifications

#### 3.2.1 Evaluation questions and sub-criteria

Does the correspondence between requirement items and specification items exist and is it easily obtained?

#### 3.2.2 Related methods and tools

Principles arising out of software engineering, relating to traceability are applicable:
Recommendations for HMI Evaluation in the context of CWP development:
A synthesis of relevant literature

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The UML</td>
<td>Complete methodological set supported by software tools (e.g. Doors™ or Rational™ products for example, and particularly the Requisite Pro tool).</td>
</tr>
</tbody>
</table>

3.3 Evaluation of adequacy with respect to HCI guidelines

3.3.1 Evaluation questions and sub-criteria

Does the HMI specification content conform to principles expressed in User Interface Guidelines?

3.3.2 Related methods and tools

Principles derived from the HCI bibliography are applicable:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 9241 applicability workshop</td>
<td>Participatory technique in which designers attend a workshop with analysts and HCI specialists (who act as facilitators) to examine the ergonomic issues associated with the system and establish the scope of the work required to develop solutions.</td>
</tr>
<tr>
<td>Other related ISO standard checklists</td>
<td>The following ISO™ material can be used:</td>
</tr>
<tr>
<td></td>
<td>• ISO 13407/DIS (1997): Human-centred design processes for interactive systems</td>
</tr>
<tr>
<td></td>
<td>• ISO 6385 (1981): Ergonomic principles in the design of work systems</td>
</tr>
<tr>
<td></td>
<td>• ISO 9241-10 (1996): Dialogue principles</td>
</tr>
<tr>
<td></td>
<td>• ISO/CD 9241-12: Presentation of information</td>
</tr>
<tr>
<td></td>
<td>• ISO/DIS 9241-13: User guidance</td>
</tr>
<tr>
<td></td>
<td>• ISO/DIS 9241-14: Menu dialogues</td>
</tr>
<tr>
<td></td>
<td>• ISO/DIS 9241-15: Command language dialogues</td>
</tr>
<tr>
<td></td>
<td>• ISO/DIS 9241-16: Direct manipulation dialogues</td>
</tr>
<tr>
<td></td>
<td>• ISO/DIS 9241-17: Form-filling dialogues</td>
</tr>
<tr>
<td></td>
<td>• ISO/IEC 10741-1: Dialogue interaction &amp; Cursor control for text editing</td>
</tr>
<tr>
<td></td>
<td>• ISO/IEC DIS 11581-1&amp;: Icon symbols and functions</td>
</tr>
</tbody>
</table>

ISO standards have to purchased and can be obtained directly from ISO (International Organization for Standardization).
Recommendations for HMI Evaluation in the context of CWP development:
A synthesis of relevant literature

### Existing material | Brief description
--- | ---
User Interface design principles | The following evaluation criteria are considered: Legibility, Guidance, Homogeneity, Compatibility, Explicit control, Error management, Conciseness, Flexibility, Feedback (see [10]).

### Other HCI guidelines
The following themes are covered: Task adequacy, Transparency, Controllability, Conformity to user expectations, Error tolerance, Error handling, Flexibility, Learnability, Simplicity, Consistency, Shortcuts, Screen Layout, messages and feedback, Efficiency, Help facilities.

### 3.4 Evaluation of *a priori* usability by means of a mock-up

#### 3.4.1 Evaluation questions and sub-criteria
Starting from a mock-up designed to illustrate HMI specifications, one can try to evaluate (*a priori*, because the mock-up does not provide a complete representation of the future HMI) some aspects of usability. The question is “does the future system (as represented by the mock-up) respect principles relating to usability?”. 

#### 3.4.2 Related methods and tools

Principles drawn from software engineering, relating to traceability can be applied:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heuristic evaluation</td>
<td>Method for structuring the review of an HMI using a set of relatively simple and general heuristics. Heuristic evaluation is best used as a design time evaluation technique because it is less costly to correct problems at that stage than at a later stage.</td>
</tr>
</tbody>
</table>

| 'Pencil & Paper' prototyping | This method enables draft screen designs to be very rapidly simulated and tested. Members of the evaluation team create a paper-based simulation of interface elements (menus, dialogues, icons etc.) using paper, card, acetate, and pens. |

| Wizard of Oz (WOz) techniques | Most existing WOz systems have been developed to study the use of speech (and natural language) recognition for information retrieval systems. Telephone information services such as telephone directories, flight or train information and reservation services, have been an interesting field for experiments. Applications within ATC could be envisaged (co-ordination between controllers, for instance) but no study has been found in this field. Comparison can be drawn with video prototyping for graphical interfaces. |
4. EVALUATION OF HMI BEHAVIOUR

The methodological context for evaluating HMI behaviour is shown in Figure 4.1:

![Diagram showing the methodological context of “Evaluation of HMI behaviour”]

The following subjects related to HMI behaviour are considered:

- Conformance with specifications
- HMI performance
- Usability of prototype, simulation or implementation
- Safety related aspects

At this stage of the design process, we assume that software quality principles - Reliability, Accuracy / correctness, Maintainability, Testing strategies – are respected.
4.1 Conformance with specifications

4.1.1 Evaluation questions and sub-criteria

Is the system behaviour an adequate realisation of the HMI Specifications?

4.1.2 Related methods and tools

Apart from methods dealing with quality and traceability, no particular material has been found in the literature.

4.2 Evaluation of HMI performance

4.2.1 Evaluation questions and sub-criteria

Does the HMI respond correctly to the users’ actions in terms of:

- Response time
- Display update
- Etc.

4.2.2 Related methods and tools

Classical software tools can be used:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic activity logging</td>
<td>Piece of software recording the times at which selected events occurred.</td>
</tr>
</tbody>
</table>

4.3 Usability of the target system

4.3.1 Evaluation questions and sub-criteria

Starting from a prototype or a simulator designed to illustrate HMI specifications, some aspects of usability can be evaluated. The key question is “does the future system (represented by the prototype) respect principles related to usability?”.

4.3.2 Related methods and tools

The following methods can be used to guide the evaluation:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heuristic evaluation using Ergonomics criteria</td>
<td>Use of HCI principles (see criteria listed above) for detecting anomalies on the HMI and orienting recommendations.</td>
</tr>
<tr>
<td>Testing using simulation capabilities</td>
<td>This method belongs to the “experimental methods” category. Starting from a defined scenario (traffic samples and instructions for exercises), a simulator is used to exercise controllers in the scenario.</td>
</tr>
</tbody>
</table>
4.4 Evaluation of safety related aspects

4.4.1 Evaluation questions and sub-criteria

(This dimension cuts across the others. Safety can be considered under the functional, organisational, technical and human aspects).

Have safety issues been taken into account in the future system?

4.4.2 Related methods and tools

Some methods are specifically dedicated to studying safety aspects, mainly through incident analysis and analysis and understanding of human errors:

<table>
<thead>
<tr>
<th>Existing material</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical incident analysis</td>
<td>A method to identify the sources of operator-system and maintainer-system difficulties in operational or simulated systems. The aim is the collection of data about incidents within a working environment that have potentially important impacts on system objectives.</td>
</tr>
<tr>
<td>Human error assessment related methods</td>
<td>These methods allow human performance to be formally reviewed, and the human-machine performance against the intended design criteria to be evaluated. This is typically completed through human error assessments and by analysing events. Methods such as Generic Error Modelling System (Gems), Sam 2000, FaultRease (Fault trees principles based), Cognitive Reliability &amp; Error Method (CREAM) and HAZOPs belong to this category.</td>
</tr>
</tbody>
</table>
5. A TRANSVERSAL EVALUATION TOOL DEDICATED TO ATC

One final tool has been discovered which cannot readily be classified using the categorisation we have employed in structuring this document. The “ATC Electronic Checklist” covers the whole system design process. (Downloadable from http://research.faa.gov/volpe.asp or follow the link at the end of this section.)

Developed by the Volpe Center and the FAA (AAR-100), this checklist presents human factors issues that should be considered in the design and evaluation of air traffic control systems and subsystems based on human factors principles, standards and guidelines. This checklist points air traffic controllers and other operations specialists to questions that they may wish to consider in the evaluation of new systems or subsystems, or a new component of an existing system.

The companion handbook, Human Factors in the Design and Evaluation of Air Traffic Control Systems, DOT/FAA/RD-95/3, provides background material on the capabilities and limitations of humans as information processors and discusses a number of related issues in the context of ATC:

- automation
- computer-human interface
- workstation design
- workload and performance measurement
- controller team formation and activities
- developing a human factors plan
- human factors testing and evaluation.

Checklist items can be used:

- to provide a basis for system requirements and specifications,
- as criteria for selection among potential vendors,
- as part of an operational evaluation.

However, in order to translate checklist items into requirements, specifications, or system performance criteria, knowledge of the system is necessary to link the items to specific system functions.

The checklist is intended to add structure and objectivity to the selection and evaluation of ATC systems and subsystems. It is not meant to serve as a comprehensive assessment or to replace usability testing. The checklist can only examine individual components of a system and point to broader issues (such as how these components fit together, the uses of automation, etc.). In many cases, the ability of the checklist to identify potential problems will be entirely dependent on the person using the checklist. Where checklist items are general or broad, an intimate knowledge of the system and how the user will use the system is required to make the connection between the intent of the item and specific system attributes or functions.

Many of the checklist items are objective and precise and can be answered with observations alone (e.g. can the user adjust symbol size?). However, other items are more general and the answer may require objective testing (e.g. are the meanings of auditory displays readily apparent?). Also, some of the items are idealistic; they represent the ideal based on current human factors knowledge. They are not offered as system requirements nor as standards, nor do they preclude...
compromise where compromises must be made (although the implications should be clearly understood). This material is provided solely for guidance and is intended to be used by air traffic specialists as they see fit.

The ATC electronic checklist tool is downloadable: 🌐
6. OUTCOMES AND PRODUCTS

6.1 How to use this material

This document is designed as a “navigation tool” to help the reader to choose an evaluation method which fits with his/her methodological context. This help is provided through the categorisation that we employ to classify the range of materials identified in the literature. It gives “high-level” criteria for choosing an adequate method based on the answers to two questions:

- In which phase of the design process am I?
- What needs to be evaluated?

In order to make this document usable very little detail is presented directly on the methods. The details are “hidden” in “method forms” accessible through the links in the tables. A method form is structured to provide practical help in using a given method, with additional criteria for deciding on its applicability.

The common structure is as follows:

| <method name> |
| Objectives: <General goals of the evaluation method> |
| **Application context:** |
| **When?** <Phase of the design process> |
| **Pre-requisites?** <What is available? What are the inputs?> |
| **Specific objectives**: <Defines the general objectives according to the specific context of application> |
| **Pro & Cons**: <Benefits / Limits, costs> |
| **Process:** |
| **Overview**: <Sequence of activities to implement the method; definitions of checklist items if applicable> |
| **Possible “variants”**: <Available alternatives when using the method> |
| **Data recording and analysis:** |
| **Data to be collected**: <Nature of data to be recorded> |
| **Collection tools and techniques**: <Particular techniques to collect required data> |
| **Data analysis tools and techniques**: <Particular tools for analysing collected data> |
| **Related methods**: <Links to other reviewed methods, if appropriate> |
| **Sources**: <Links towards original sources listed in the bibliography. Could be useful for collecting more details and eventually finding illustrative material> |
6.2 Synthesis and decision matrices

The first decision matrix consists of presenting the methods within a single table organised according to the two main navigation criteria - the design process phase\(^{11}\) (WHEN) and the object of evaluation (WHAT).

<table>
<thead>
<tr>
<th>Phase (When)</th>
<th>Object (What)</th>
<th>Evaluation of requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functional requirement</td>
<td></td>
<td>Task/Activity analysis, Experimental methods, Environmental standards checklist</td>
</tr>
<tr>
<td>HMI requirement</td>
<td></td>
<td>Heuristic evaluation, ISO standards checklist, HCI dedicated guidelines</td>
</tr>
<tr>
<td>Other requirements(^{12}) (stakeholders, organisation, technical requirements)</td>
<td></td>
<td>Stakeholder meeting, Focus group, Stakeholders specific checklist, Stakeholders dedicated Interviews, Organisation dedicated checklist</td>
</tr>
<tr>
<td>HMI specification</td>
<td></td>
<td>Quality related checklists, UML (traceability aspects), ISO 9241 applicability workshop, Other related ISO standard checklists, User Interface design principles (INRIA source), Other HCI guidelines, Paper &amp; Pencil prototyping, Heuristic evaluation, WOz techniques</td>
</tr>
<tr>
<td>Coding and testing phases (includes safety aspects)</td>
<td></td>
<td>Usability Questionnaires, Usability Interviews, Heuristic evaluation using Ergonomics criteria, Testing using simulation capabilities, Performance measurement, Automatic activity logging, Critical incident analysis, Human error assessment related methods</td>
</tr>
</tbody>
</table>

---

\(^{11}\) To facilitate integration with CoRe, we start from the design phases specified in the document “Core Requirements for ATM Working Positions: An Overview of the Project Activity”.

\(^{12}\) Activity corresponding to more than one phase in the Design Process used by CoRe, Preparation, Concept Refinement and possibly System Functional Requirements Phases.
Other criteria could be considered for choosing the most adequate method, according to a specific project context.

The following criteria address the resources required for implementing the methods. In this approach, methods are considered in terms of potential costs in time and resources (i.e. ‘HOW −’).

- (C1) Required presence of end users
- (C2) Need for a multidisciplinary team
- (C3) Level of experience required for the evaluators
- (C4) Effort needed to analyse the collected data
- (C5) Complexity of the implementation process
- (C6) Complexity of the tools to be used

The next set of criteria focus on the advantages – in terms of results – that can be expected by implementing the methods. It is a way to consider the benefits (‘HOW +’) of methods.

- (C7) Richness of the collected data (in terms of interpretability)
- (C8) Accuracy of the collected data
- (C9) Resulting “positive side effects” of the method (for instance, user involvement and engagement, team building and communication, facilitation of the reuse of results, etc.)

The following table presents an evaluation of each method based on these criteria. The following notation is used:

- “−” indicates a negative value with respect to the given criterion.
- “+” indicates a positive value with respect to the given criterion.
- “=” indicates a neutral value with respect to the given criterion.
## Recommendations for HMI Evaluation in the context of CWP development: A synthesis of relevant literature

<table>
<thead>
<tr>
<th>METHODS</th>
<th>CHOICE CRITERIA</th>
<th>HOW - TYPES</th>
<th>HOW + TYPES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of requirements</td>
<td></td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Task/Activity analysis</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Experimental methods</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Environmental standards checklist</td>
<td>+</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Heuristic evaluation</td>
<td>+</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>ISO standards checklist</td>
<td>+</td>
<td>+</td>
<td>=</td>
</tr>
<tr>
<td>HCI dedicated guidelines</td>
<td>+</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Stakeholder meeting</td>
<td>-</td>
<td>=</td>
<td>-</td>
</tr>
<tr>
<td>Focus group</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stakeholders specific checklist</td>
<td>+</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Stakeholders dedicated Interviews</td>
<td>-</td>
<td>=</td>
<td>=</td>
</tr>
<tr>
<td>Organisation dedicated checklist</td>
<td>-</td>
<td>-</td>
<td>=</td>
</tr>
<tr>
<td>Evaluation of HMI specifications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality related checklists</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>UML (traceability aspects)</td>
<td>+</td>
<td>=</td>
<td>-</td>
</tr>
<tr>
<td>ISO 9241 applicability workshop</td>
<td>+</td>
<td>-</td>
<td>=</td>
</tr>
<tr>
<td>Other related ISO standard checklists</td>
<td>+</td>
<td>+</td>
<td>=</td>
</tr>
<tr>
<td>User Interface design principles (INRIA source)</td>
<td>+</td>
<td>+</td>
<td>=</td>
</tr>
<tr>
<td>Other HCI guidelines</td>
<td>+</td>
<td>+</td>
<td>=</td>
</tr>
<tr>
<td>Pencil &amp; Paper prototyping</td>
<td>+</td>
<td>+</td>
<td>=</td>
</tr>
<tr>
<td>Heuristic evaluation</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>WOz techniques</td>
<td>-</td>
<td>=</td>
<td>-</td>
</tr>
<tr>
<td>Evaluation of HMI behaviour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Usability Questionnaires</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Usability Interviews</td>
<td>-</td>
<td>+</td>
<td>=</td>
</tr>
<tr>
<td>Heuristic evaluation using Ergonomics criteria</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Testing using simulation capabilities</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Performance measurement</td>
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