Human-Centered Development of Perceived Complexity Criteria:

Draft methodological guide for using developed criteria

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Human-Centered Development of Perceived Complexity Criteria:

Developed Criteria

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Abstract

This document is a draft methodological guide to analyze perceived complexity of installed equipment in a commercial aircraft flight deck. This guide provides a framework for human factors (HF) issues related to perceived complexity (section 2), a methodological approach for assessing perceived complexity (section 3), and a procedure to evaluate perceived complexity (section 4). This information is intended in particular as an aid to AMC 25.1302 for showing compliance to 25.1302, especially step 2 of the proposed methodical approach and paragraph 4.1 (b) of the AMC. Applicability of this information is not restricted to the scope of CS 25 and can also be useful in determining perceived complexity of installed equipment for other purposed (e.g. determination of transition training requirements).

This guide was issued as a result of a study conducted by EURISCO International (European Institute of Cognitive Sciences and Engineering) and Airbus under contract with DGAC-F (French Civil Aviation Authority) n° DAST/SEA/2006/001.

This draft methodological guide was developed with the participation of test pilots, airline pilots, certification specialists, aeronautical engineers, and human factors specialists. The experience of Airbus in certification campaign was taken into account.

Acknowledgements

Thanks to Florence Reuzeau (Airbus S.A.), Stéphane Deharvengt (DGAC-F) and Claude Valot (IMASSA) for their comments towards improving the content of this report.

Contents

1. Introduction

This report focuses on the way criteria were developed and the synthesis that led to the current delivery of criteria on perceived complexity, as well as a method to use them.

This study was performed in a participative way. Consequently, comments on this final document may be forwarded *(preferably by e-mail)*, to:

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This document is also based on previously documents produced by EURISCO International:

- A state of the art on perceived complexity for the purpose of human-centered design of commercial aircraft cockpit (Technical Report DGAC/EURISCO No. T-2006-172); and
- The results of a user-experience gathering on perceived complexity carried out with airline and test pilots as well as with certification people and designers/engineers (Technical Report DGAC/EURISCO No. T-2007-189).

This document focuses on perceived complexity (PC) evaluation and provides recommendations for a PC-based human-centered design approach of controls, displays, system behaviour, and system integration as well as design guidance for error management. The current study was conducted in the framework of the regulatory context (CS 25.1302; AMC 25.1302).

The different sections of this report detail a methodical approach to some aspects of certification compliance, as well as design considerations, a description of potential development for candidate Means of Compliance and their applicability.

Perceived complexity criteria were developed to be usable and useful during certification, development and training.

This report provides a framework for human factors (HF) issues related to perceived complexity (section 2), a methodological approach for assessing perceived complexity (section 3), and a procedure to evaluate perceived complexity (section 4).

2. A framework for HF issues related to perceived complexity

Complexity in the real world needs to be elicited from observation and interaction with appropriate agents. We carried out several interviews and GEM[1] sessions with test pilots, certification experts, airline pilots (in France and Italy) as well as human factors (HF) specialists and aeronautical engineers. Altogether, 24 experts were involved in this investigation.

The main difficulty in complexity assessment is that complexity is related to expertise, and even if expertise is easy to assess it cannot be anticipated correctly. **A**rtifacts, **U**sers and **T**asks should then be designed in an environment that is clearly specified. Environmental factors are usually split into the **O**rganizational and the **S**ituational factors. We used the **AUTOS** pyramid framework to guide the categorization of concepts defining perceived complexity.

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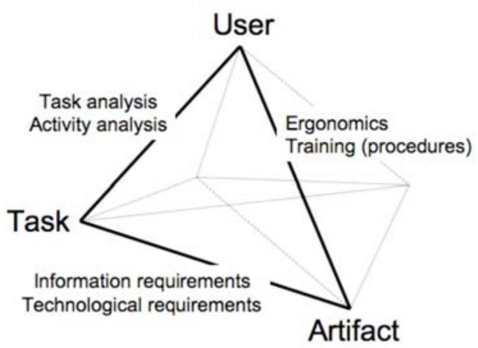
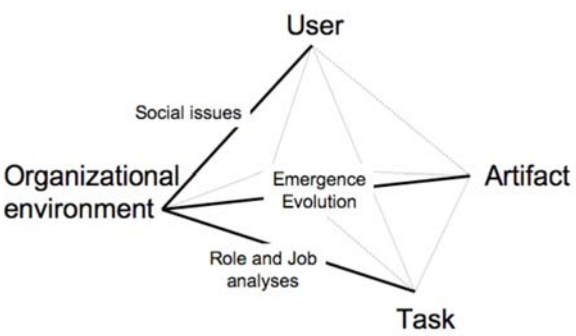
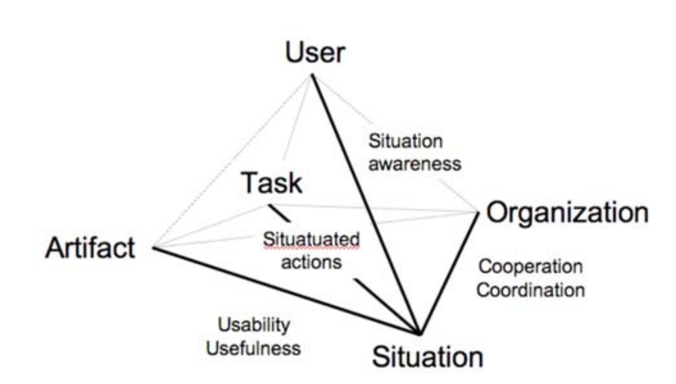
<tr><td>
</td><td>The AUT triangle enables the explanation of three edges: task and activity analysis (U-T); information requirements and technological limitations (T-A); ergonomics and training (procedures) (T-U).</td></tr>
<tr><td>
</td><td>The organizational environment includes all the agents that interact with the user performing the task using the artifact. It introduces three edges: social issues (U-O); role and job analyses (T-O); emergence and evolution (A-O).</td></tr>
</table>

[1] Group Elicitation Method, a brainstorming method and a categorization technique augmented by a priority assignment mechanism and consensus reaching method. GEM is supported by a groupware that drastically decreases investigation time and quickly leads to efficient results. Results are expressed in terms of ordered lists of concepts where consensus and divergences among experts can be clearly stated. A GEM session is typically run in a 5-hour period.



The AUTOS framework is an extension of the AUTO tetrahedron that introduces a new dimension, the “Situation”, which was implicitly included in the “Organizational environment”. The three new edges are: usability/usefulness (A-S); situation awareness (U-S); situated actions (T-S); cooperation/coordination (O-S).

Figure 1. The AUTOS pyramid framework.

The resulting C-Map is provided in figure 2.

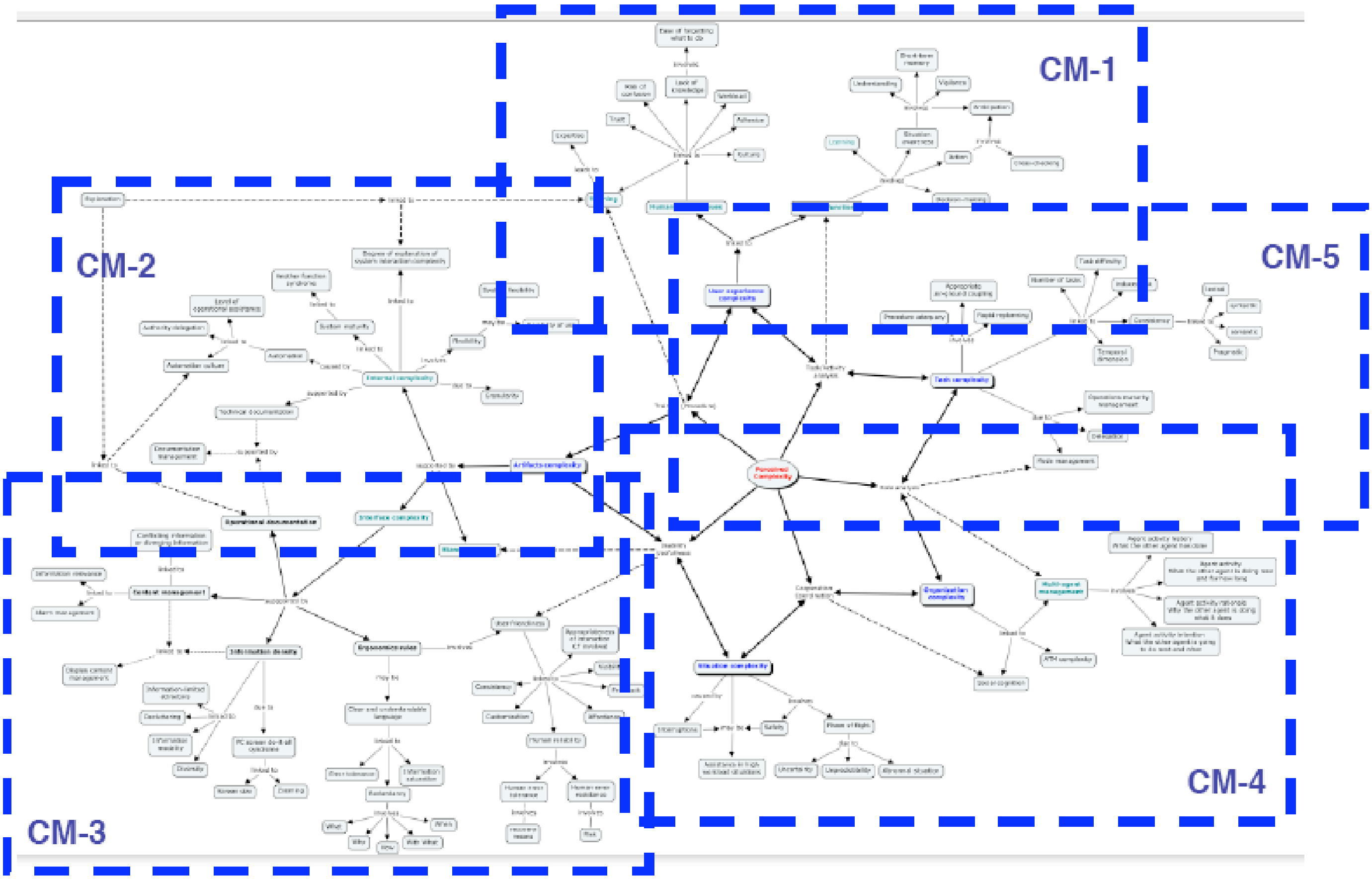


Figure 2. A “perceived complexity” C-Map.

The perceived complexity C-Map can be displayed into five sub-C-Maps, {CM-i; i=0, 5} that are presented in Figures 3 to 8, as follows. Note that CM-0 (Figure 3) shows the center of the “perceived complexity” C-Map presented in figure 2. Figure 4 presents “user experience complexity”. Figures 5 and 6 presents "artifact complexity". Figure 7 presents "situation and organization complexity". Figure 8 presents "task complexity".

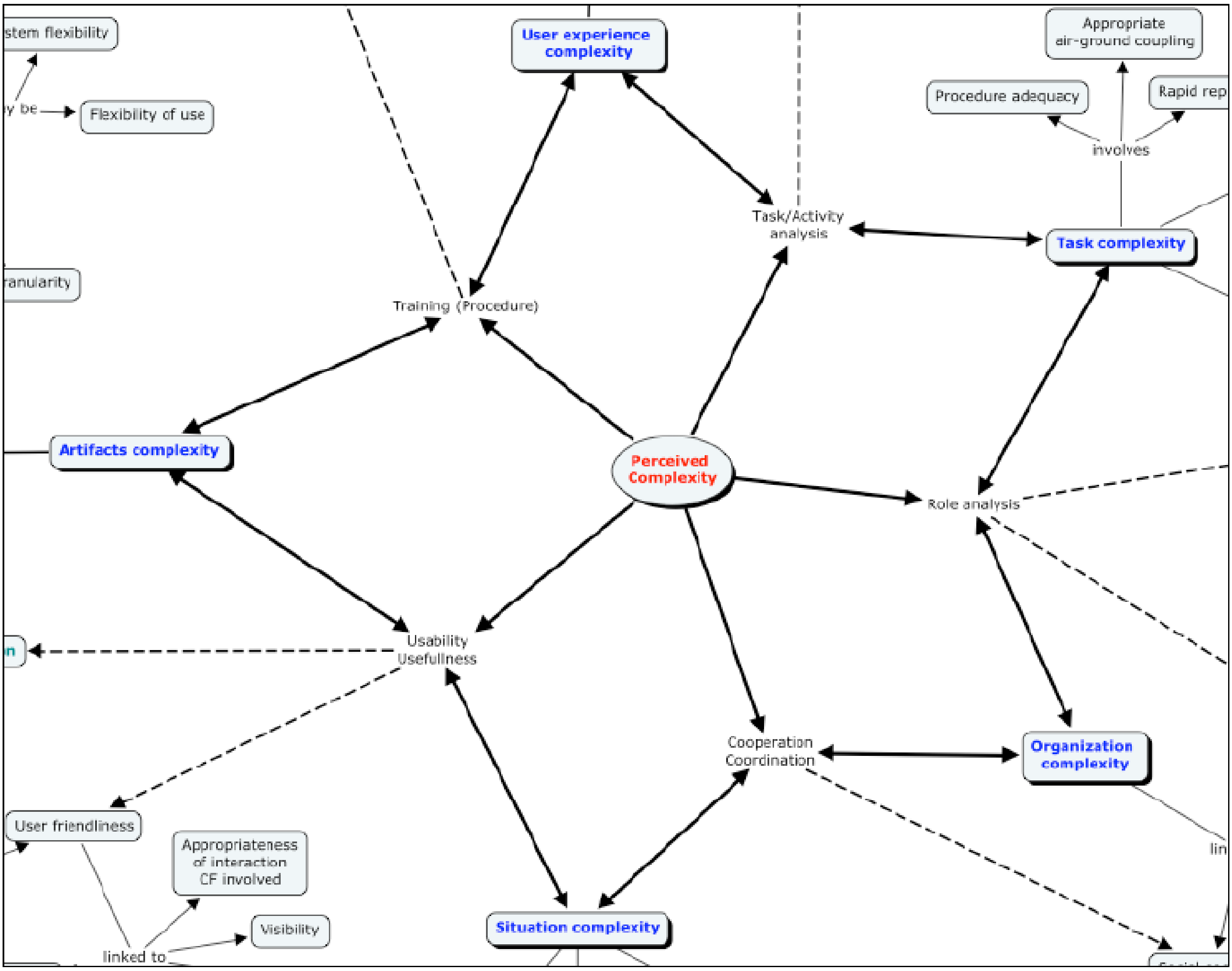


Figure 3. Perceived complexity in the center of the AUTOS pyramid (CM-0).

Perceived complexity[2] is analyzed according to the five entities of the AUTOS pyramid:

- Artifacts complexity;
- User experience complexity;
- Task complexity;
- Organization complexity;
- Situation complexity;

and the relationships between these entities:

- A/U: Training (procedure);
- U/T: Task/Activity analysis;
- T/O: Role analysis;
- O/S: Cooperation/Coordination;
- S/A: Usability/Usefulness.

The attributes (or concepts) attached to the concept of "perceived complexity" are categorized with respect to these various entities and relationships. The following figures present these concepts and the relevant relations among them.

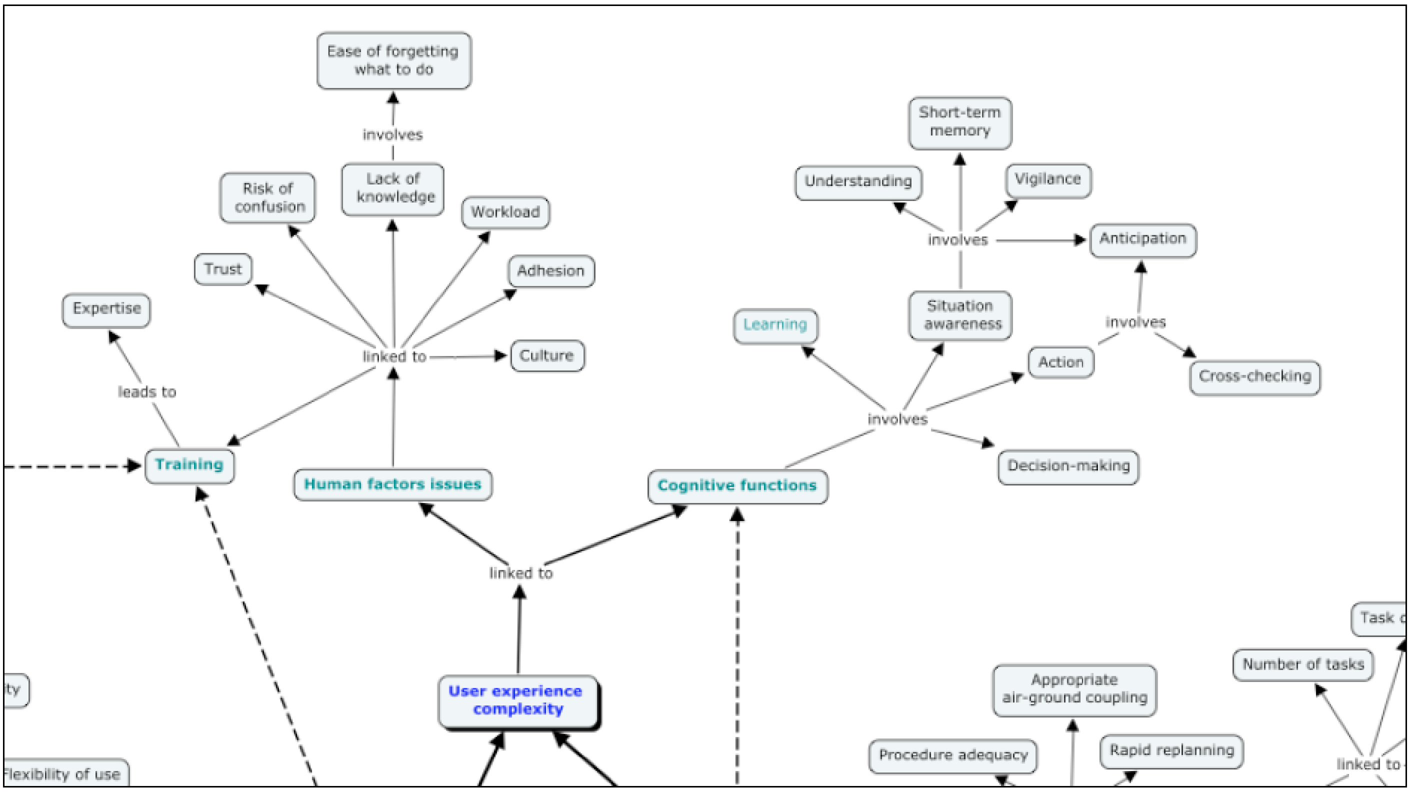


Figure 4. User experience complexity (CM-1).

[2] Note that the term "perceived complexity" needs to be interpreted as "complexity of an equipment or system in the flight deck as perceived by a pilot", or for short "equipment complexity".

User experience is linked to human factors issues and cognitive functions involved in the use of appropriate an artifact (Figures 5 and 6) for executing the prescribed task (Figure 7) in specific situation and environment (Figure 8).

Human factors include training (expertise), trust, risk of confusion, lack of knowledge (ease of forgetting what to do), workload, adhesion and culture.

Cognitive functions include learning, situation awareness (that involves understanding, short-term memory and anticipation), decision-making and action (that involves anticipation and cross-checking).

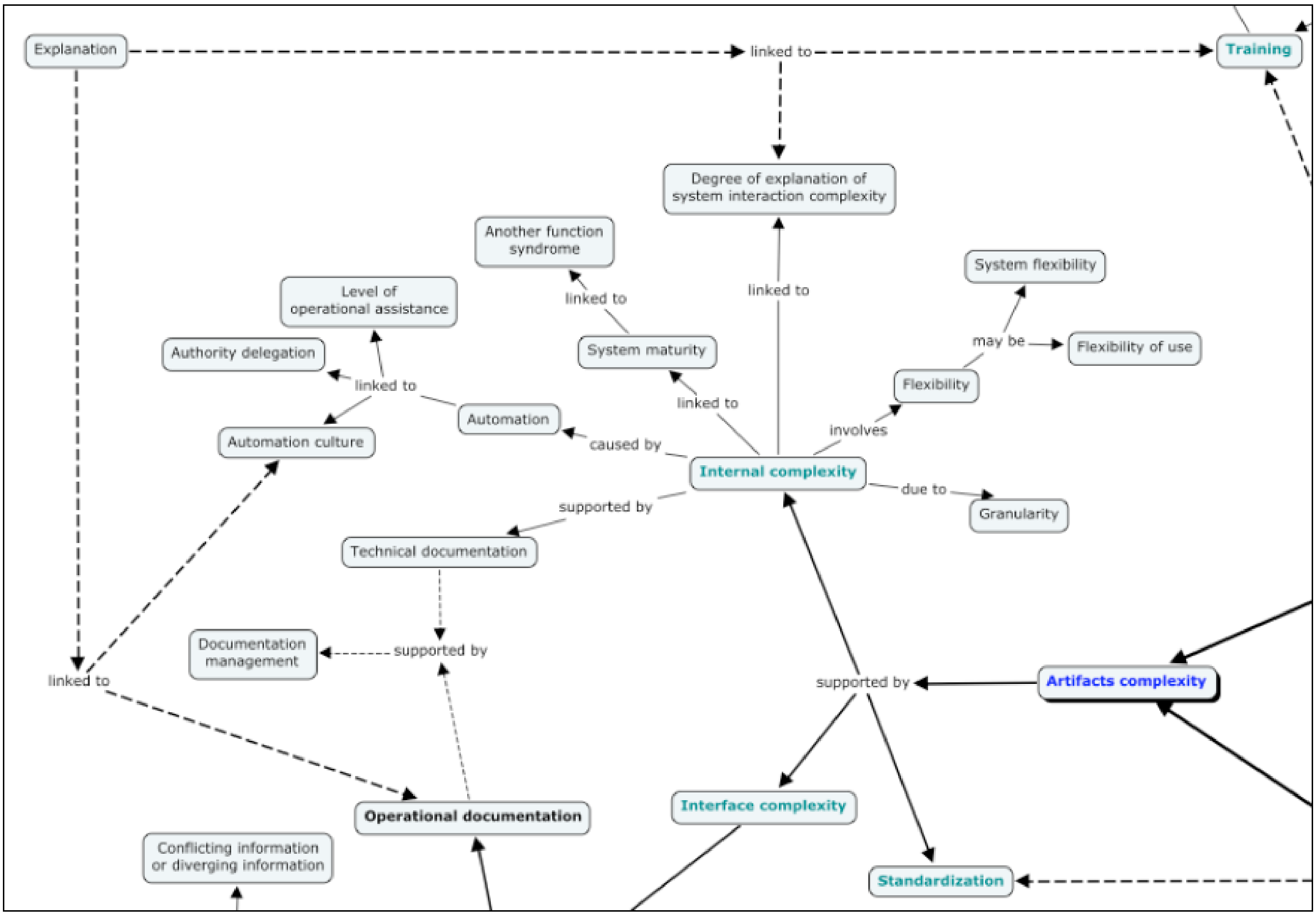


Figure 5. Artifact complexity (CM-2).

Artifact complexity is supported by internal complexity and interface complexity (see CM-3). Internal complexity is related to explanation, in particular to the degree of explanation of system interaction complexity. There are several concepts related to artifact complexity: flexibility (both system flexibility and flexibility of use); system maturity (before getting mature, a system is an accumulation of functions –the "another function syndrome"—maturity is directly linked to function articulation and integration); automation (linked to the level of operational assistance, authority delegation and automation culture); and technical documentation (operational documentation).

Technical documentation and operational documentation are not in the scope of CS-25, however descriptions of how the system works and how to use it are very useful to generate during the early stages of the design process in order to figure out both internal and perceived complexity. Operational documentation is very interesting to be tested because it is directly linked to explanation of artifact complexity. The easier an artifact is to use (i.e., artifact complexity is low), the less related operational documentation is needed. Conversely, the harder an artifact is to use, the more related operational documentation is required and therefore it has to provide appropriate explanation at the right time in the right format.

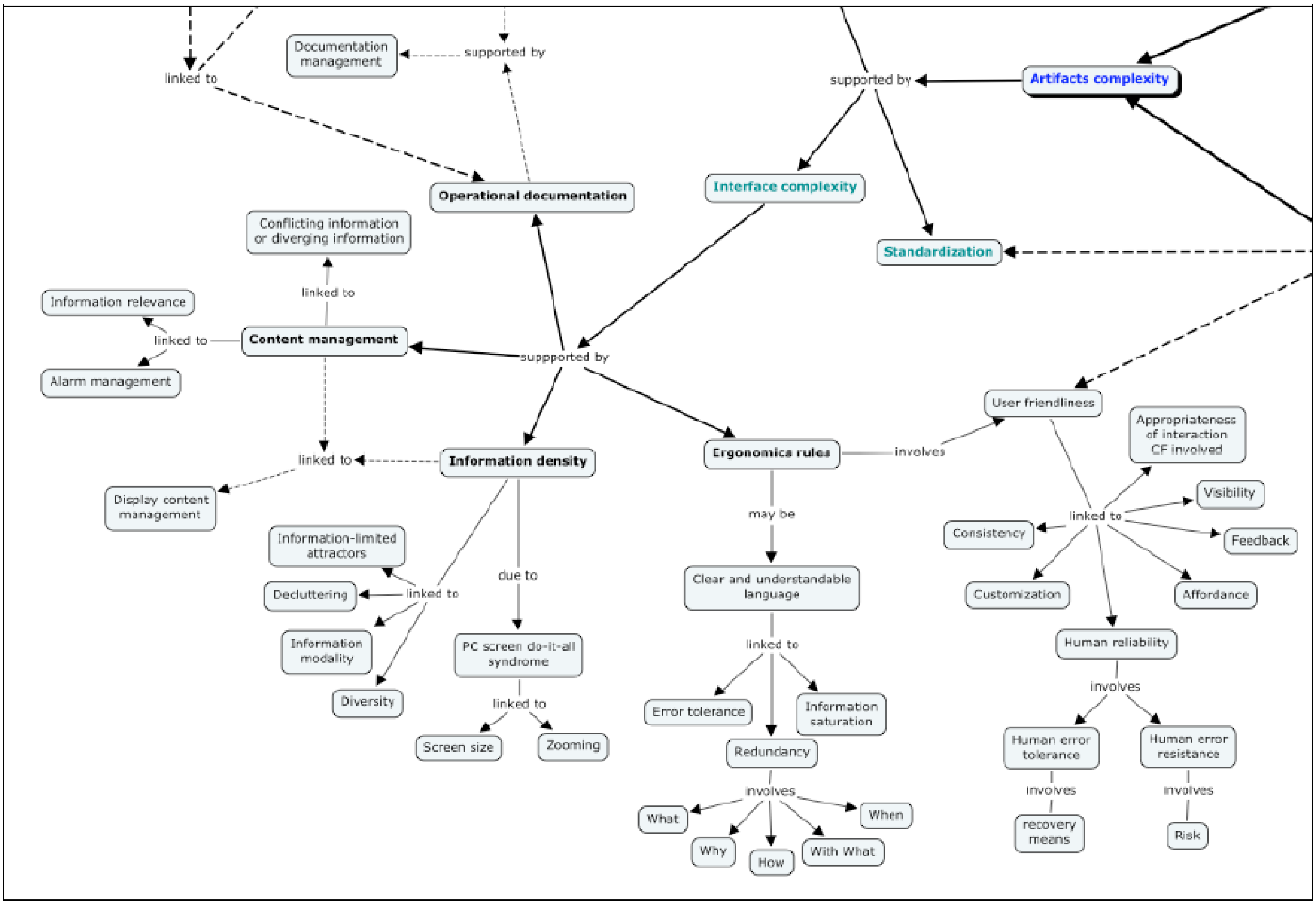


Figure 6. Artifact complexity (CM-3).

As already said, artifact complexity is related to interface complexity. As internal complexity, interface complexity is supported by operational documentation. Content management, information density and ergonomics rules also support it. Content management is, in particular, linked to information relevance, alarm management, and display content management.

Information density is linked to information-limited attractors, i.e., objects on the equipment or display that are poorly informative for the execution of the task, decluttering, information modality, and diversity. The "PC screen do-it all syndrome" is a good indicator of information density (attributes are screen size and zooming).

Ergonomics rules may be characterized by clear and understandable language. In particular, error tolerance, redundancy and information saturation are typical indicators. Redundancy is always a good rule whether is repeats information for cross-checking, confirmation or comfort, or by explaining the "how", "where", and "when".

Ergonomics rules formalize user friendliness, i.e., consistency, customization, human reliability, affordance, feedback, visibility and appropriateness of the cognitive functions involved. Human reliability involves human error tolerance (therefore the need for recovery means) and human error resistance (therefore the existence of risk to resist to).

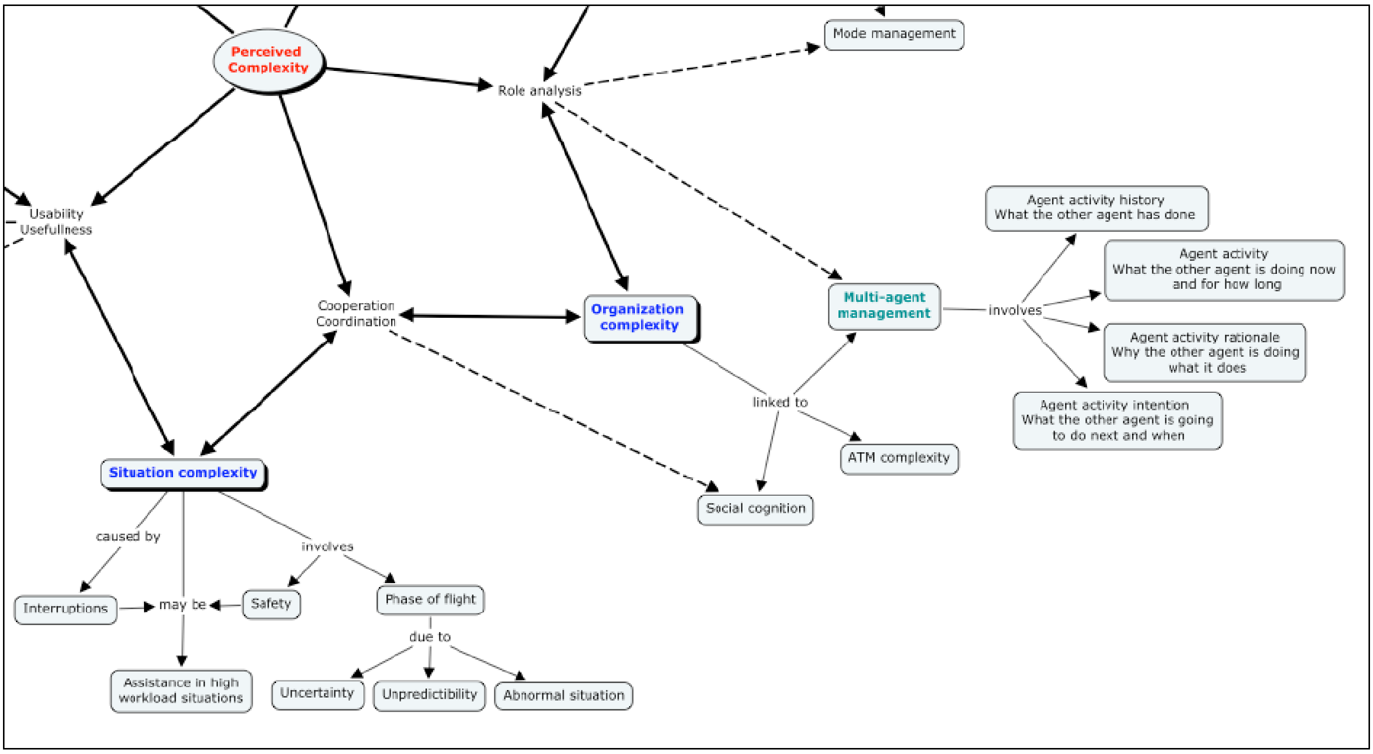


Figure 7. Situation and organization complexity (CM-4)

Situation complexity is usually caused by interruptions. It involves safety and high workload situations. It is commonly analyzed by decomposing the flight into phases of flight. Within each phase of flight, the situation is characterized by uncertainty, unpredictability and various kinds of abnormalities.

Organization complexity is linked to social cognition, ATM complexity, and more generally multi-agent management. There are four principles for multi-agent management: agent activity (i.e., what the other agent is doing now and for how long); agent activity history (i.e., what the other agent has done); agent activity rationale (i.e., why the other agent is doing what it does); and agent activity intention (i.e., what the other agent is going to do next and when).

Multi-agent management needs to be understood through a role (and job) analysis.

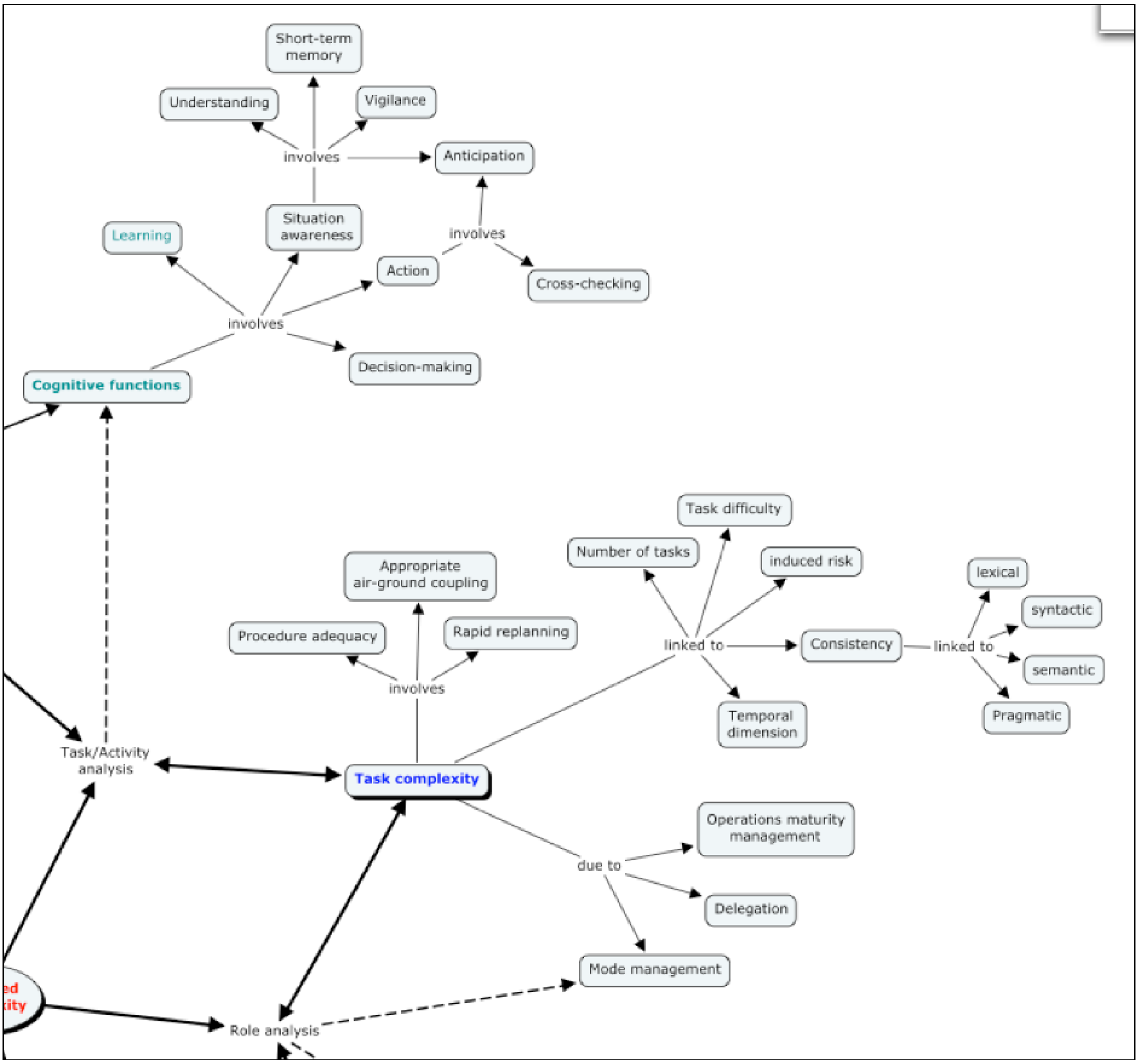


Figure 8. Task complexity (CM-5).

Task complexity involves procedure adequacy, appropriate air-ground coupling and rapid prototyping. It is linked to the number of tasks, task difficulty, induced risk, consistency (lexical, syntactic, semantic and pragmatic) and the temporal dimension. Task complexity is due to operations maturity management, delegation and mode management. Mode management is related to role analysis.

3. Methodological approach

The main goal of this study is to define a methodology that would help manufacturers (designers and engineers) to determine criteria that they will use during the design process, even when the system does exist yet, in order to build the certification plan.

Criteria are categorized with respect to the AUTOS pyramid framework. They are noted C-Ai for a criterion for an A-analysis (artifact), C-Ui for a criterion for an U-analysis (user), C-Ti for a criterion for an T-analysis (task), C-Oi for a criterion for an O-analysis (organization), C-Si for a criterion for an S-analysis (situation).

Some of the criteria of a category that are given below can be related to another from another category.

Complexity analysts are required to be trained on the rationale of perceived complexity using the various papers and reports produced during this study. EURISCO International can provide support for such training.

3.1. Task complexity analysis (T-analysis)

A task is characterized by a number of sub-tasks (sub-sub-tasks and so on). Each sub-task and a group of sub-task can be analyzed with respect to several factors such as consistency, a temporal dimension, an induced risk, reversibility or irreversibility attributes, difficulty and so on.

A task involves various types of modes, delegation, management and procedural support (in the form of documentation or software-based assistance).

T-analysis criteria that are proposed for complexity analysis of the equipment in the flight deck are the followings:

- C-T1: number of tasks, sub-tasks and so on;
- C-T2: difficulty of each task;
- C-T3: induced risk of each task;
- C-T4: temporal dimension;
- C-T5: consistency (lexical, syntactic, semantic, pragmatic);
- C-T6: appropriate procedure;
- C-T7: appropriate air-ground coupling;
- C-T8: rapid re-planning;
- C-T9: operations maturity management;
- C-T10: delegation;
- C-T11: mode management.

Some of these criteria (C-Ti) may not be appropriate nor relevant for analysis of all equipment. They can be used as an evaluation vector or combined together to form an integrated index appropriate for a specific task. Such combination needs to be thought through according to instances of the AUTOS pyramid being analyzed.

3.2. Artifact complexity analysis (A-analysis)

An artifact can be analyzed with respect to its usability and usefulness, involving several principles such as consistency, feedback, visibility, human reliability, information density, appropriate content and ergonomics rules.

A-analysis criteria that are proposed for complexity analysis of equipment in the flight deck are the followings:

- Internal complexity:
    - C-A1: system maturity (the function accumulation syndrome);
    - C-A2: degree of explanation of the complexity of the interaction with the system;
    - C-A3: flexibility (system and use);
    - C-A4: automation [where C-A4 = f (C-A4.1, C-A4.2, C-A4.3)];
        - C-A4.1: level of operational assistance;
        - C-A4.2: authority delegation;
        - C-A4.3: automation culture;
    - C-A5: technical documentation [where C-A5 = f (C-A5.1, C-A5.2)];
        - C-A5.1: documentation management;
        - C-A5.2: operational documentation;
    - C-A6: granularity;
- Interface complexity
    - C-A7: operational documentation;
    - C-A8: content management [where C-A8 = f (C-A8.1, C-A8.2, C-A8.3)];
        - C-A8.1: conflicting and diverging information;
        - C-A8.2: information relevance;
        - C-A8.3: alarm management;
    - C-A9: information density [where C-A9 = f ({C-A9.i, i=1,6})];
        - C-A9.1: display content management;
        - C-A9.2: attractors;

        - C-A9.3: de-cluttering;
        - C-A9.4: information modality;
        - C-A9.5: diversity;
        - C-A9.6: PC screen syndrome (screen size, zooming);
    - C-A10: ergonomic rules [where C-A10 = f ({C-A10.i, i=1,6})];
        - C-A10.1: clear and understandable language (errors, redundancy, saturation);
        - C-A10.2: consistency;
        - C-A10.3: customization;
        - C-A10.4: visibility;
        - C-A10.5: feedback;
        - C-A10.6: affordances;
        - C-A10.7: human reliability (error tolerance and resistance);
    - C-A11: standardization.

Some of these criteria (C-Ai) may not be appropriate nor relevant for analysis of all equipment. They can be used as an evaluation vector or combined together to form an integrated index appropriate for a specific task. Such combination needs to be thought through according to instances of the AUTOS pyramid being analyzed.

3.3. User profile complexity analysis (U-analysis)

User profile can be described by user experience including level of training (general and professional education), culture, trust, workload, fatigue, vigilance, situation awareness and anticipation.

U-analysis criteria that are proposed for complexity analysis of equipment in the flight deck are the followings:

- Human factors
    - C-U1: lack of knowledge (ease of forgetting what needs to be done);
    - C-U2: workload;
    - C-U3: culture;
    - C-U4: adhesion;
    - C-U5: trust;
    - C-U6: risk of confusion;
    - C-U7: training (expertise);

- Cognitive functions
  - C-U8: situation awareness (understanding, short-term memory, vigilance, anticipation);
  - C-U9: decision making;
  - C-U10: action (anticipation, cross-verification);
  - C-U11: learning.

Some of these criteria (C-Ui) may not be appropriate nor relevant for all equipment analyses. They can be used as an evaluation vector or combined together to form an integrated index appropriate for a specific task. Such combination needs to be thought through according to instances of the AUTOS pyramid being analyzed.

3.4. Situation complexity analysis (S-analysis)

The situation to be analyzed should deal with incertitude, imprecision, unpredictability, time pressure, abnormality, emergency and routine, as well as perceived, expected and real situation.

S-analysis criteria that are proposed for complexity analysis of equipment in the flight deck are the followings:

- C-S1: interruption;
- C-S2: assistance in high workload situations;
- C-S3: safety;
- C-S4: flight phase;
- C-S5: incertitude;
- C-S6: lack of prediction;
- C-S7: abnormal situation.

Some of these criteria (C-Si) may not be appropriate nor relevant for all equipment analyses. They can be used as an evaluation vector or combined together to form an integrated index appropriate for a specific task. Such combination needs to be thought through according to instances of the AUTOS pyramid being analyzed.

3.5. Organization complexity analysis (O-analysis)

Analyzing the equipment involves the organization in which this device is inserted. It involves analyzing interaction with other agents, what the other agents did, what they are doing and how long, why they are doing what they do, what they will do next and when, communication, cooperation, coordination, and so on.

O-analysis criteria that are proposed for complexity analysis of equipment in the flight deck are the followings:

- C-O1: social cognition;

- C-O2: ATM complexity;
- C-O3: multi-agent management [where C-O3 = f ({C-O3.i, i=1,4})]
    - C-O3.1: activity of an agent (what does the other agent do and for how long?);
    - C-O3.2: history of the activity of an agent (what did the other agent do so far?);
    - C-O3.3: rationale of the activity of an agent (why the other agent does what it does);
    - C-O3.4: intention of the activity of an agent (what will the other agent do and when?).

Some of these criteria (C-Oi) may not be appropriate nor relevant for all equipment analyses. They can be used as an evaluation vector or combined together to form an integrated index appropriate for a specific task. Such combination needs to be thought through according to instances of the AUTOS pyramid being analyzed.

4. Analytical method of perceived complexity

The above methodology provides a framework and orientations to design an appropriate method for assessing perceived complexity. In this section, we provide an analytical method suited for operational characterization of perceived complexity, i.e., a method that can be used by default of anything better as mentioned in the previous section of this document.

First, let's focus on the main attributes of perceived complexity, each being detailed with appropriate indicators (a restricted list is provided to illustrate the method):

4.1. Internal complexity of the artifact

- number of times the pilot said that the system is not flexible enough (or something alike);
- number of times the pilot said that this automation was not necessary (question of automation culture).

4.2. Interface and interaction complexity

- number of commands and other entities that have been used;
- number of times the user is diverted from the main assigned task.

4.3. Task complexity

- ratio of the number of steps in a task compared the number of steps in an equivalent task with a previous system;
- number of time the pilot said that the task was risky.

4.4. Human factors complexity

- scores on Cooper-Harper scale;
- number of times the user expressed clear frustrations (or clear pleasures).

4.5. Cognitive function complexity

- number of times the pilot made a wrong decision using the artifact;
- action (anticipation, cross-verification).

4.6. Situational complexity

- number of times the pilot was interrupted and could not recover from the disturbed situation using the artifact;
- number of times the pilot was usefully assisted by the artifact in high workload situations;
- number of times the pilot could not be usefully assisted by the artifact in high workload situations.

4.7. Organizational complexity

- number of times the artifact could not be useful in a cooperative activity;
- number of times the artifact required someone else to help executing a given task.

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- Technical Report EURISCO/DGAC No. T-2007-304;
- Technical Report EURISCO/DGAC No. T-2007-305.

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