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| | **HoliDes**<br><br>**Holi**stic Human Factors **Des**ign of Adaptive Cooperative Human-Machine Systems | |

# Catalogue for Psychological Model Assessment

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# Table of Contents

# 1 Introduction and purpose

This deliverable consists of the elaboration of crucial HF aspects that need to be considered when constructing an AdCoS (Adaptive Cooperative System). The requirements from WP6-9 (D2.1) served as a basis. A list of exemplary requirements from D2.1 and addressed HF aspects has been compiled. Subsequently, these aspects were broken down to universal HF principles that are applicable cross-domain.

# 2 Requirements relevant for AdCoS

A list has been filled containing HF-relevant requirements for D2.1: Addressed HF aspects and their implications for modelling are assigned to each requirement. In Annex I this list is reported specifying: The identification codes of requirements, their short description and the originator that has been adopted from D2.1. Most of the HF- requirements are universally shared by the different AdCoS (WP 6-9), thus they can be considered cross domain and covering the most important areas of cognitive science. The need to assess psychological models inside the more general cognitive science framework is due to the multidisciplinary approach taken by HoliDes, which goes from psychology to computer science, from behavioural studies to simulations. The main HF aspects are: situation awareness, perceptual interference, cognitive capacity limits, acceptance, trust in automation, auditory, visual and cognitive distraction that will be discussed in the subsequent sections with reference to the major cognitive domains.

# 3 Catalogue for Psychological Model Assessment (EAD-DE, DLR)

## 3.1 AdCoS features necessary for analysis

This section provides a list of features of the AdCoS systems that need to be modelled, in order to assess HF-specific system performance properties.

### 3.1.1 Situation Awareness

A lot of requirements from the list in Annex I have a clear reference to the operator’s situation awareness. These are:

- WP7_HON_AER_REQ26
- WP7_HON_AER_REQ26
- WP9_TAK_AUT_REQ17
- WP6_IGS_HEA_REQ03
- WP9_TAK_AUT_REQ29
- WP9_TAK_AUT_REQ41

They clearly state that the machine part of an AdCoS shall assess information from the external and internal context, and that – on the other hand – this information should be properly provided to the operator(s). Thus, an adequate cognitive representation of the environmental and the system state is enabled. Situational awareness is a term coined by Mica Endsley and has been elaborated ever since. The concept of **situation awareness** (SA) has been introduced for the first time in the late 80s in the aircraft domain. The use of the concept has rapidly spread in other domains, from driving to healthcare, prompted by the technological development that has required operators to deal with a lot of information coming from different sources. The emphasis on SA has been motivated by the effort of designers to project and realize decision aids and system interfaces to accomplish operator needs in managing the huge quantity of information.

Informally speaking, Endsley (2000) defines SA in terms of "knowing what is going on" in a specific environment. A more formal definition describes SA as "the **perception** of the elements in the environment within a volume of time and space, the **comprehension** of their meaning and the **projection** of their status in the near future". This definition has been formalized by the author (1995; 2000) in the following model:

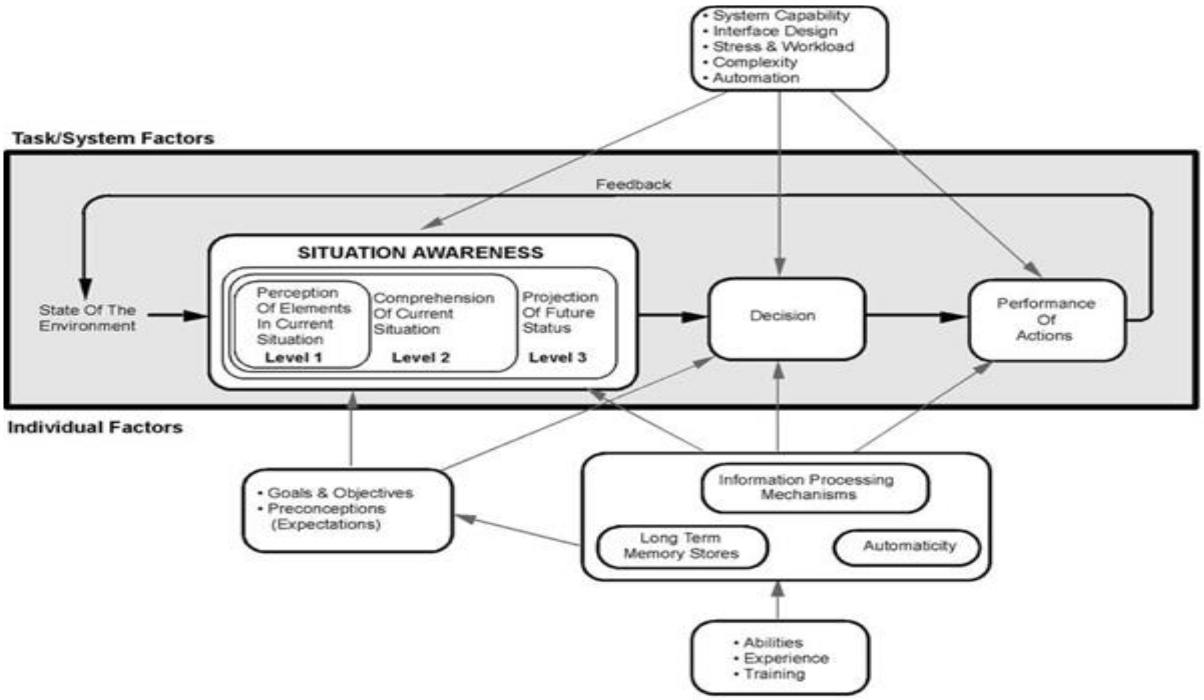


Figure 1: From Endsley, 1995.

In the model, SA is represented as a three level process, separate from decision making and performance, but the three stages can affect each other in an ongoing circular way. SA is the base for decision making, as the way a problem is framed influences the decision to solve it. However, as noted by Endsley (2000), an operator with a perfect SA can choose a wrong strategy of action. SA, even if not directly, also influences the performance: a poor performance is supposed to be a consequence of an incorrect of incomplete SA. However, an operator conscious of the lack of SA can modify the behavior to reduce the possibility of poor performance (Endsley, 1990).

SA is derived, integrated and interpreted from different sources of information, as summarized by Endsley in the following figure:

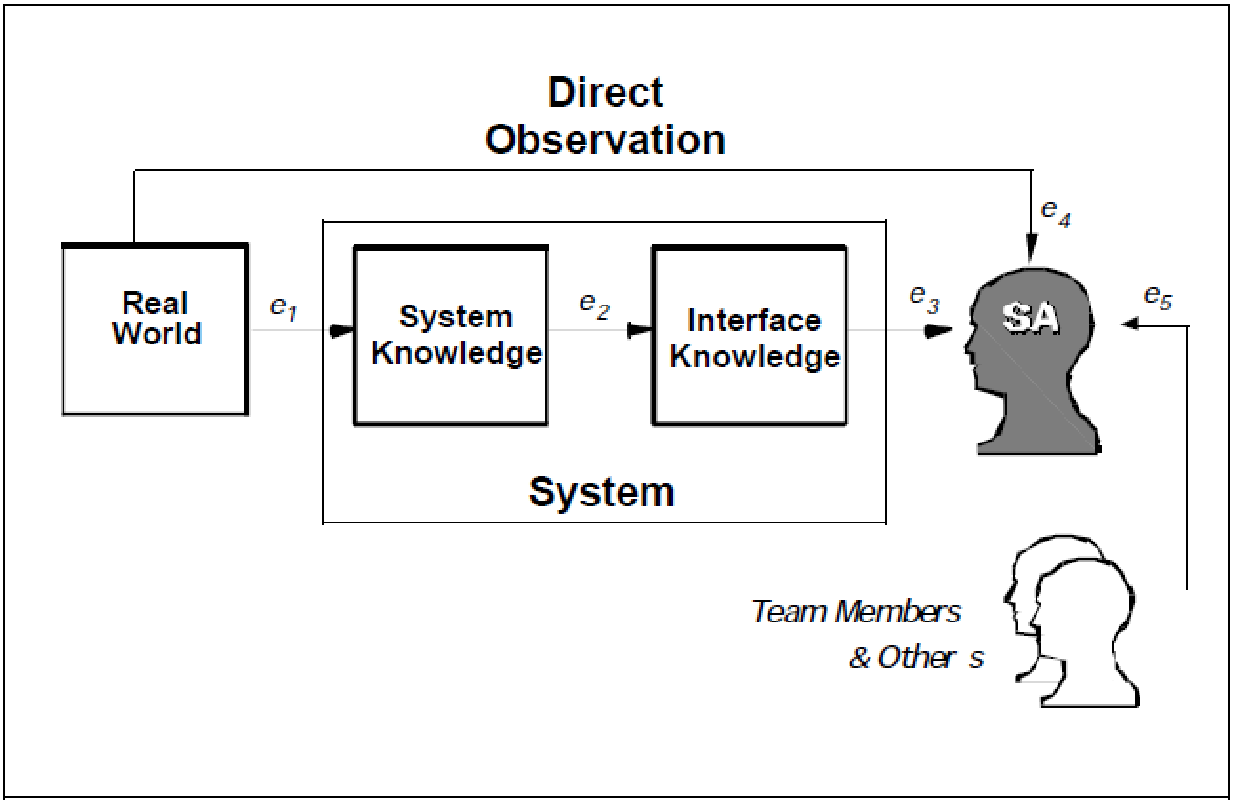


Figure 2: From Endsley, 2000.

- Directly perceived information (e4): In some cases operators can be able to directly extract information from the environment through different receptors, visual and aural above all.
- Information from the system (e3): A portion of the data that a system possesses is displayed to the operator via an interface; the portion of displayed information, that the operator actually perceives and interprets, results in SA. It is worth to note that the operator is not involved in a process of receiving displayed information but in most of

the cases the operator can actively set the system to acquire desired information.

- The third source of information is the verbal and non-verbal communication with team members (e5).

According to the author, the entire process calls into play different cognitive mechanisms and structures:

- Attention: In a complex environment, the huge number of stimuli and tasks an operator needs to attend to can easily exceed the attention limit of a person. To circumvent this limit an operator can adopt an optimization strategy sampling the information.
- Long-term memory: The information sampling process is aided by long term memory, particularly the portion where priorities and the frequency of information changes are represented.
- Working memory: Working memory also plays a crucial role in an optimization strategy allowing operators to change the attentional focus on the base of perceived information and active goals.
- Mental models: with experience, operators develop mental models about the systems and the environments in which they operate and learn to allocate in that context the limited attentional resources in a more efficient way.
- Automaticity: expertise can help operators not only to elaborate situation specific mental models but also to develop a form of automaticity in certain tasks aiding to overcome attention limits. A risk in the engagement of an automatic cognitive process is the poor

sensitivity to new stimuli. The collaboration between humans and machine agents can prevent automaticity risks.

In a complex context, to collaborate in an adaptive way, as suggested by Kokar and Endsley (2012), humans and computer agents need to share mental models, the understanding of goals and tasks to achieve the goals. To share SA with a human operator, an agent needs specific characteristics:

- a mental model which defines what is important in an environment and constitutes a framework for the integration of perceptive low-level data; the state of the model needs to be continuously updated by means of a process of active learning about new things in the system;
- a mechanism to capture and understand goals that define information's relevance and make sense to low-level data;
- a mechanism for goal prioritization, based on states, to account for / model competition between different goals.

### 3.1.2 Trust in automation and complacency

Some requirements refer to the design of alarm systems and symbology. These are:

- WP7_HON_AER_REQ37
- WP7_HON_AER_REQ38
- WP7_HON_AER_REQ39
- WP7_HON_AER_REQ39

- WP7_HON_AER_REQ39
- WP9_TAK_AUT_REQ07
- WP9_TAK_AUT_REQ35
- WP9_TAK_AUT_REQ36
- WP9_TAK_AUT_REQ37

These requirements imply that operators must be able to a) understand and accept alarm symbology (indicating different levels of severity) and b) rely on the system in an appropriate way. An appropriate level of reliance (trust) is reached if an operator's attention to system states and his/her readiness to check proper machine functioning is in accordance with the objective capabilities of the automation (Lee & See, 2004), see figure 3.

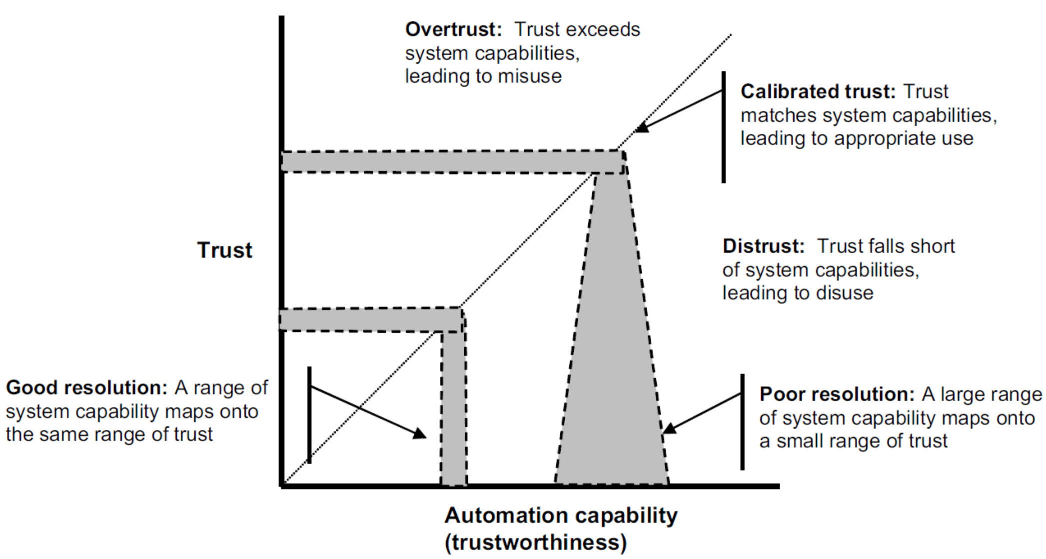


Figure 3: Trust in automation vs. automation capability (Lee & See, 2004; p.55)

If trust is unjustifiably low, operators' tend to check system parameters and states too often and try to carry out tasks originally not allocated to them. This is called disuse (Parasuraman, 1997). On the other hand, operators can also rely on the system's functioning too strongly, resulting in complacency. In this case, the operator does not monitor the system in a sufficient way. This is called misuse. Transferred to alarms, the operator is overconfident that in case of no alarm no critical system state is at hand.

Alarms are strongly related to operators' trust in the system. Trust is very fragile and can be highly affected by improper alarm functioning. If too many false alarms indicating that a high level of severity takes place, operators stop taking them seriously resulting in risky situations. This behaviour is called complacency.

A behavioural indicator of complacent behaviour is the frequency and duration of checking behaviour, which can be well operationalized through eye movement analysis. Bagheri & Jamieson (2004) found that high reliabilities of automation in combination with no information about reliability-affecting contexts led to higher average times between eye fixations and thus a more idle monitoring behaviour.

As a consequence, levels of trust and complacent vs. sceptical behaviour of operators should be incorporated into cognitive models. This can be realized by introducing varying levels of attentional flexibility. Antecedents of these attitudes of operators towards machines are manifold. In addition to person-specific factors like personality and culture, previous system behaviour is crucial. An outstanding example is false alarm rates leading to a decreased likelihood of response to correct alarms. This could be implemented in a model by a dynamic threshold for response behaviour to system warnings.

### 3.1.3 Perceptual Interference

Some of the requirements referring to D2.1 refer to possible perceptual interference. These are:

- WP9_TAK_AUT_REQ01
- WP9_TAK_AUT_REQ03
- WP9_TAK_AUT_REQ06
- WP9_TAK_AUT_REQ13
- WP9_TAK_AUT_REQ12
- WP9_TAK_AUT_REQ01
- WP9_TAK_AUT_REQ02
- WP9_TAK_AUT_REQ03
- WP9_TAK_AUT_REQ21
- WP6_AWI_HEA_REQ02
- WP7_TRS_AER_REQ01
- WP7_TRS_AER_REQ21

Perceptual interference is an extensive topic in cognition leading to many debates among authors. It raises when two sensory informations that share common features compete to be selected by the system. This may have different results going from a delay in time to select the correct answer to the selection of the incorrect answer and consequently to an error.

Perceptual interference occurs mainly with multiple stimuli in one sensory modality rather than in multimodal conditions even if the degree of the effect depends on the similarity of tasks and inputs (Manzey, 1988; Wickens, 2002, see figure 4).

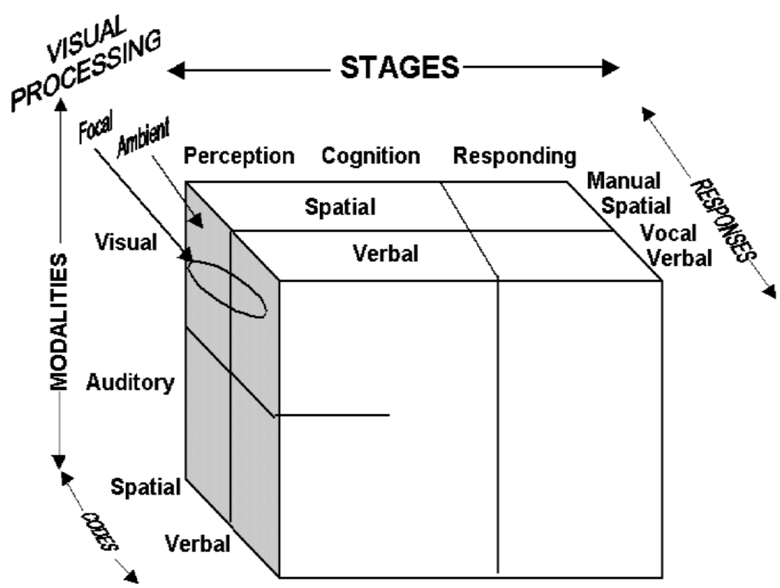


Figure 4: Model of multiple resources (from Wickens, 2002, p. 163)

Perceptual interference significantly affects attention and detection rates of critical events (Wickens & Long, 1995). For example, simultaneous superposition as display clutter or simultaneous acoustic warning signals can induce interference resulting in inattention and asymmetric cognitive models of the current state of the AdCoS.

Applied to a model this would imply that in case of overload of a channel (e.g. the visual channel) with information (measured in bits) relevant information is lost (on a random or weighted basis) and thus not fed to an operator's mental model. As a result, the discrepancy generated between agents' mental models would serve as an indicator for system performance.

### 3.1.4 Distraction

Some requirements can refer to distraction. These are:

- WP9_TWT_AUT_REQ04_v0.1
- WP9_TWT_AUT_REQ14_v0.1

Distraction is a phenomenon related to perceptual interference. Operators' attention is bound by perceptual or cognitive distractors coming by very different sources that can imply low level (e.g. visual stimuli) or high level cognitive processes (randomly appearing memories). Distraction is a complex phenomenon which can involve different stages of processing and analysis:

1) Top-down fashion: an operator pursues irrelevant goals not related to the currently executed task.
2) Bottom-up fashion: In this case attention is distracted by objects due to their properties as for example saliency, the extent of contrast of a figure to its ground or perceptual intensity, such as a loud tone or a large object (Foulsham & Underwood, 2009).

One example of implementation of the processes described above in a modelling architecture is the dynamic saliency maps, able to compute saliencies of objects in a visual scene from indicators like object size and contrast (Itti & Koch, 2000; Itti, Koch, & Niebur, 1998). This model architecture is useful because it attempts to model a complex phenomenon but it still presents some limits: a complete account of the rules for bottom-up attention processes, and many different algorithms for the simulation of visual processing are present in scientific literature. A novel approach that combines both top-down and bottom-up issues is approached by the object detectability concept (Engel & Curio, 2013). It has been outlined in Deliverable D1.2. Object detectability takes both inattention through workload (top-down) and perceptual visual capabilities related to visual factors (bottom-up) into account. It is specifically designed to approach hazard situations and implicitly encodes high-level scene properties (context), i.e. situations.

### 3.3.5 Cognitive Capacity Limits

In this section important capacity limits of cognitive functions are depicted. These range from visual search to memory systems.

- WP8_ADS_CTR_REQ18
- WP8_IRN_CR_REQ03

**Visual Search**

Visual search is defined as scanning behaviour that is needed in order to process properties for object recognition. A well-known paradigm (Treisman & Gelade, 1980) that is widely used showed that processing time – and therefore the time needed of action selection to the object – rises with the number of properties varying across objects and the number of objects. Also, error rates become higher (serial processing). However, this is not the case if different objects share hardly any properties and are unique. Parallel processing enables humans to immediately react to the object.

Regarding AdCoS model assessment, this implies that objects sharing properties are harder to discriminate, resulting in serial rather than parallel processing.

**Memory**

Memory is not a unitary store, it is a multi-component system made by separated components. We can distinguish between different memory systems: working memory (also called short term memory), and episodic, semantic and procedural (all three building long term memory).

Initially researchers attributed to short term memory very elementary processes like the rehearsal. Sperling (1960) described this process like an internal voice with a purpose to revitalize information to prevent the loss.

Recent theories, however, suggested that short term memory presupposes mechanisms more complex than rehearsal. Current idea of short term memory is that of a limited capacity system which temporarily holds active information and supports thought processes by connecting perception, long term memory and action. This system is also known as working memory (Miyake & Shah, 1999).

First author who replaced the concept of short-term memory with that of working memory was Baddeley (1986). According to this author, working memory is a system whose role is to detain and manipulate information during cognitive tasks execution, like comprehension, learning and thinking (Baddeley, 2003).

This system is constituted by:

- the phonological loop: It includes two sub-components: a phonological store whose work is to hold linguistic information and an articulatory rehearsal process based on an internal speech. After very little time, about two seconds, information contained in the phonological store declines but it is possible to keep an active memory trace with a process of sub-vocal rehearsal.

  This theory is supported by experimental data:
  - the phonological similarity effect: a high robust effect consisting in impaired immediate serial recall of elements phonologically similar;
  - the word length effect: difficulties in long words due to the fact that long words contain more elements and are more fragile;
  - irrelevant sounds effect: impaired recall due to the contemporary presentation of critical elements and irrelevant material. Irrelevant material presentation interferes with phonological loop work and it doesn't allow sub-vocal rehearsal.

  Phonological loop seems to be very important in different processes like learning to read or written word comprehension.
- the visuospatial sketchpad: it elaborates visual and spatial information. It works like its verbal equivalent, the phonological loop, elaborating four or five objects at a time;
- the central executive: it is a control system, similar to an attentive mechanism involved in decision making processes.

With regard to long term memory, Tulving in 1972 undermined unitary theories of long term memory suggesting a distinction between semantic and episodic memory based on the encoding specificity principle.

Tulving (1972) implemented an experiment where subjects were asked to memorize twenty-four pairs of words, constituted by a target word and a weak cue for recall; afterwards a list of words closely related to the target words were presented to the subjects asking them to create free connections between materials. The result of this experiment evidenced that, in presence of semantically related words, participants were able to recall the targets but not to identify them like critical words. So semantic information didn’t allow reaching information stored in episodic memory. According to the author, episodic memory is auto-noetic because it concerns personal experiences. Semantic memory, on the contrary, is noetic because we are aware of elements not available from immediate circumstances. Tulving imaged semantic memory like a mental dictionary, which contains words, concepts and links between the two.

In addition, Tulving (1985) assumed the existence of a third memory system, procedural memory, that refers to skills and rules acquisition, to a tacit “know how” which is essential in tasks that required cleverness, like how to use a bike, to drive a car and so on.

Schacter (1987) preferred to call this form of memory implicit memory, emphasizing the fact that information about events is reactivated without awareness.

# 4 General Conclusions

The AdCoS requirements provided by D2.1 have been analysed. They can be assigned to global Human Factors aspects that are universal for all domains throughout this project. These aspects consider human information processing (attention, memory, distraction) and behavioural tendencies (complacency, trust) alike. There are many ways of possible implementation into MTT, and for some cognitive functions, these are quite elaborate, e.g. short-term memory in ACT-R (Salvucci, 2006). On the other hand specific HF aspects like Situation Awareness have hardly been addressed in the modelling context, and a promising suggestion has been made by Kokar and Endsley (2012) or Engel and Curio (2013). In Annex II, possible ways of operationalizing HF aspects in models are suggested, without claiming to be complete. Although these HF aspects are very basic in their nature, it is a difficult task to break them down to certain parameters.

Another important question is whether the implementation of certain HF aspects in MTT is relevant in all cases: For example, it might not be necessary to model declarative knowledge as a variable if one can assume the existence of this knowledge in operators a priori. The answer can only be found within every single use case, i.e. technological domain.

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## APPENDIX

- **D.2.3_Annex_I_HF-Relevant-Requirements**
- **D.2.3_Annex_II_HF-Implementation-Matrix**