An Integrated Approach of Human Oriented Interactions with Complexity

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Abstract. This paper presents a theoretical study in the field of Human Oriented approach of interactions with complexity. This study aims to contribute to one of the current challenges in Human Factors research consisting to provide methods and structured approaches to face the increasing complexity of ATM concepts. This theoretical study consists to articulate two models of complexity, previously published, in a single matrix able to delimit the scope of Human Oriented Approach of Complexity (HOAC). This matrix named the HOAC matrix aims to provide properties to classify methods and to structure HF activities in order to support a systemic approach of the design of interactions improving a better integration of humans in complex systems. The HOAC matrix is illustrated by four examples of methods supporting the design of *simplex artefacts*.

Keywords: Human factors · Methods · Complexity · Systemic · User centered design · Framework

1 Introduction

One of the current challenges in the aeronautics field is to design systems and Human-machine interactions supporting human performance dealing with complexity characterized as a system of systems. Obviously, the automated and interconnected systems contribute to the overall safety of aeronautics [1]. But the evolution of these systems also increases, for instance, the number of parameters to monitor and the mediation of pilot control [14]. Pilot's role is increasingly focused on his expertise and adaptation capacity to manage high context variability including multidimensional complexity variations. Indeed novelties arisen in different fields contribute to increase the overall systems of systems network, but also open new investigation fields for the Human Factors (HF) research. Indeed the past decades produced a technological (r)evolution from simple artefact to interconnected and multimodal systems and this evolution has multiple side effects on the HF specialist job, tools and methods.

Thus, the current HF challenge is to design systems both: (a) structurally complex from a technological and organizational standpoint; and (b) conceptually simple from an operator standpoint. In other words, the aeronautics has to create interaction dealing with complexity or in short: simplex systems [17].

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Today to ensure the overall performance of the Human-System Interactions, in aeronautical field the flight deck design is usually based on user-centered methods. These methods require a systemic approach of the dynamic interactions composing the whole activity of the pilots. This approach aims at diagnosing threats and vulnerabilities parameters involved in the activity. Nevertheless, an activity, as the pilot's role, is composed of large number of elements, exchanged and challenged during operation. Therefore one of the major difficulties for a Human Oriented designer is to compose a realistic model of an activity under analysis. The application of user-centered design in this field is usually efficient to produce materials describing the current and future operations (e.g. by use of *task models*, *interviews*, *design exposure*, *authority allocation*…). Of course, these different outcomes will reflect the complexity of the activity under study. Therefore the role of the Human Oriented designer will consist in organizing a variability of points of view in a coherent and realistic manner as a whole. Usually, at this point, the designer faces major issues: How to transform outcomes from user-centered methods as part of the project the designer is working for? Actually, the way to adapt user centered knowledge to a particular project will also strongly depend on the purpose of this project. In short, all this variability creates difficulties to generalize knowledge related to design and assessment of simplex systems. At this point the HF research field aims to provide some integrated approaches of HF methods [11]. Nevertheless the HF field is far to propose a standardized methodological framework to harness the complexity linked to the wide evolution of systems of systems.

Therefore the purpose of this paper is to expose a structured view of a Human Oriented approach of interactions with complexity. Most precisely, this paper exposes the result of a theoretical study providing a matrix supporting a Human Oriented systemic approach of the design and evaluation of interactions dealing with complexity. Actually this matrix, named Human Oriented Approach of Complexity matrix (HOAC matrix), can reflect the organization of methodologies currently developed or used to harness the design and evaluation of simplex systems. So, this paper presents both the details of the theoretical study conducting the HOAC matrix then illustrated with a panel of methods applied or under (i.e. *simplexity criteria* [16], *authority design* [12], *eye-tracking evaluation*, *complexity simulator*).

2 Theoretical Background

This section provides the main theoretical backgrounds supporting the ideas presented in this paper. This background involves both the *paradigm of complexity* and the emerging theoretical concept of *simplexity*. Of course the concept of *simplexity* is itself partially based on the concept of usability especially in the field of Human Machine Interactions. But we prefer the concept of *simplexity* to highlight the involvement of complexity characteristics in the design of simplex artefacts. Of course the design of these simplex artefacts shall include the main, and now well known, standardized principles of usability [13].

2.1 Paradigm of Complexity and Complexity Characteristics

Our postulate is to consider that complexity requires an adapted approach and should involve a set of methods, tools and theoretical backgrounds in line with and supporting such complexity. Indeed we consider that complexity is not only a dimension or a continuum between "simple" and "complex". Actually we consider complexity as a part of complexity sciences in such way complexity should be considered with its own characteristics or criteria. Therefore complexity could be viewed as a paradigm, the paradigm of complexity [15]. Through this paradigm, the notion of agents can be used to characterize that an activity is conducted by a defined entity either human or technical within an organizational setting [8]. The *paradigm of complexity* can help to generalize the notion of activity independently of the type of agent involved. To achieve expected performance, agents gather information from their external or internal environments, analyze and take decisions and implement and monitor the outcome of their decisions through a variety of cognitive or physical actions. Achieving performance depends also on having the adequate information on other agent's activity and knowing how to collaborate. Finally, the situational, societal and organizational characteristics of agents' environments determine the way how actions are performed in addition to the specificities of each entity, such as for example previous experience or individual motivations.

Cilliers [7] presents the following characteristics of complex systems. These characteristics match with the ATM ones:

- The number of elements is sufficiently large that conventional descriptions (e.g. a system of differential equations) are not only impractical, but cease to assist in understanding the system. Moreover, the elements interact dynamically, and the interactions can be physical or involve the exchange of information.
- Such interactions are rich, i.e. any element or sub-system in the system is affected by and affects several other elements or sub-systems. In this way ATM is usually described as a system of sytems.
- The interactions are non-linear: small changes in inputs, physical interactions or stimuli can cause large effects or very significant changes in outputs.
- Interactions are primarily but not exclusively with immediate neighbours and the nature of the influence is modulated.
- Any interaction can feed back onto itself directly or after a number of intervening stages. Such feedback can vary in quality. This is known as recurrence.
- Such systems may be open and it may be difficult or impossible to define system boundaries.
- Complex systems operate under far from equilibrium conditions. There has to be a constant flow of energy to maintain the organization of the system.
- Complex systems have a history. They evolve and their past is co-responsible for their present behaviour.
- Elements in the system may be ignorant of the behaviour of the system as a whole, responding only to the information or physical stimuli available to them locally.

2.2 Human Oriented Approach of Complexity: A Step Toward Simplex Artefacts

Human oriented approach as User Centred Design (UCD) places humans at the centre. But beyond an orientation of a design process, a Human Oriented approach of complex systems should be viewed as a prerequisite for the overall system optimization because Humans are already a great Embodied Complex Adaptive System. In short, we need humans in large complex systems because they are able to increase the overall efficiency of a system on the long term. In this way a Human agent should be viewed as an agent with a specific characteristic which is its embodiment [19].

The aim of a Human oriented design process, dealing with interactions with *complexity*, is to provide to Humans simplex interactions absorbing a part of environment, organizations, human or tasks complexity. One can name such products *Simplex artefacts*. These simplex artefacts are mandatory to ensure an efficient involvement of Humans in complex systems such as future ATM concepts.

3 Toward an Integrated Framework to Harness Human Oriented Approach of Complexity

To face such complexity the HF specialist needs an appropriate referential and adapted guidance material. The aim of this section is to present a global framework able to harness the main dimensions of the Human Oriented approach of complexity in aeronautics. This framework is mainly composed by two components, first a model describing the dimensions of Human Oriented complexity and secondly a set of layers on which the Human Oriented approach of complexity can apply. The following sections describe these two components.

3.1 A Pyramidal Model to Understand the Human Oriented Approach of Aeronautics Complexity

No consensus exists on a universal approach of complexity of pilot's activity, the different perspectives used (e.g., dynamic, sociotechnical system, cognitive complexity) take into account common parameters which are weighted according to the scope of the studies. These common parameters are grounded in the definitions of these notions closely related together. Complexity is, in this regard, associated with the intricate inter-twining or inter-connectivity of elements within a system and between a system and its environment [9]. In order to approach the operational complexity of pilots, this section presents (a) the methodology deployed to define our conceptual model; (b) the main components of our model to describe the operational context; and (c) the main dimensions of our model which may be applied on the components and their interactions to describe the operational situation.

Methodology. This model is based on a qualitative data analysis and has been previously presented in [16]. The data come first from the scientific literature related to the design of complex systems (e.g., on the complexity definition, on the Human-Automatism cooperation) and secondly from aeronautical operational reports. So, on the one hand, the model presented in this section refers to three models: the AUTOS pyramid [4], the STS model [18] and the task complexity model [14]. On the other hand, in order to structure the knowledge, a set of 810 recommendations have been extracted from gathered data and classified by complexity dimensions. All along this work, the content and formalism of the recommendations as well as of the classification and construction of it have been reviewed by Human Factors Experts.

Main Components Interacting in Operations. The first part of the presentation of the model is based on the description of the main components in interaction during pilots' activity (see Fig. 1). From a systemic point of view, it is generally admitted that user's performance will depend on the interactions between his/her own characteristics, the characteristics of the artefact(s), of the task(s) and of the environment(s) involved. Being Human-Oriented, the description of the main components of our model is based on two perspectives: environmentalism and interactionism.

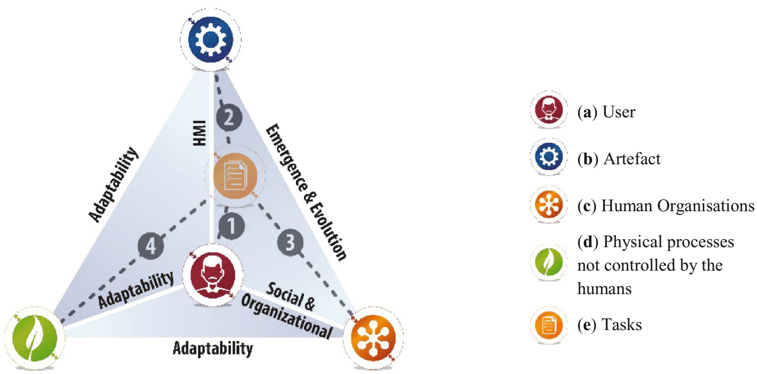

Fig. 1. Integrated view on the main concepts of the framework to understand a Human-Oriented complexity

On the one hand, environments may be defined in terms of internal and external standpoints with regard to user's activity. Usually, the internal environments refer to the resources available while the external environments refer to the elements which may have a direct or indirect incidence (positive or negative) on the user's activity. The difficulty in aeronautical domain is related to, for instance, the weather which is at the same time a resource for pilots' activity (e.g. fuel consumption strategy) and may disturb their activity (e.g. weather avoidance). So, to be adapted to pilots' activity, the viewpoints will be more dependent here on his/her direct (internal) or indirect (external) physical interactions with his/her environments regardless the interaction modality used (e.g., visual, auditory). More precisely, according to the components' references illustrated in Fig. 1, first, the internal environments of the activity refer here both to physical and operational properties of (a) the user or human operator and (b) the artefact such as computer, command and control system. Then, the external environments of the activity refer both to the characteristics of the social and infrastructural (c) organisations controlled by the human such as governmental organizations, airline, Air traffic controller and the atmospheric and topographical characteristics of (d) the physical processes not controlled by the human such as weather, birds, volcanic ash, landscapes.

On the other hand, from the perspective of the interactions involved, our model takes into account the direct interactions between the components previously presented [4]. For instance, the icing conditions may freeze the probes of the artefact. With respect to the interactions directly dependant from the tasks, the teleological, procedural, informational, spatial and temporal characteristics of (e) the tasks component are a mean to access to a set of parameters involved in pilots' activity because this component is the core of complex interactions. The characteristics of the tasks component are also a mean to analyse the interactions between the components. According to the references illustrated in Fig. 1, the analyses can refer to: (1) the task and activity requirements like the goals, action level, user's experience level [4, 18]; (2) the information and technological requirements like the automation and/or computerisation level [4, 18]; (3) the human organisation requirements like the responsibility, authority, role, operational procedure, training [4, 18]; (4) the adaptability requirements like the level of adjustment and temporal constraints.

The instantiation of these main components (i.e., User, Artefact, Human Organisations, Physical processes not controlled by the human and Tasks) in a space-time relationship allows the description of the operational context.

The complexity overview of the operational situation requires to apply some dimensions of complexity on each of the main components as well as on each of their interactions. The section hereafter explains these dimensions.

Main Dimensions Impacting the Complexity of Operations. The second part of the presentation of the model is therefore based on seven abstract parameters that may impact the complexity state of the operational situation. These dimensions extracted from the qualitative data analysis are: (a) *Variability* referring to the unstable characteristics of the elements [14] and to the nature of their influence on each other. For instance, small changes in inputs can cause large effects in outputs [7]; (b) *Ambiguity* referring to the lack of a perfect knowledge about all the elements [7, 14] like the cause-effect chain or else the behaviour of the system as a whole; (c) *Occurrence* referring to non-routine events and operations caused, for instance, by interruption [14]; (d) *Discrepancy* referring to the deviation of a component from the prescription and/or norm; (e) *Self-regulation* referring to the process permanent evolution like the own dynamic of a process or else the self-organisation of the elements [7, 17]; (f) *Dependency* referring to the relationship between the elements depending on their degree of direct dependence [7]. The relationship may be conflictual/negative [14] and/or positive when the elements have common characteristics such as references, history [7]; and (g) *Quantity* referring to the number of elements and/or interactions in their individual characteristics and in their relation to each other like the number of distinguishable properties, number of elements per unit area or unit volume for a given time. Quantity refers also to the quantity of resources required [14] like cognitive and/or physical resources, energy resources.

The interactions between the main components and their dimensions situated in a space-time relationship allow the description of the operational situation. In other words the situation complexity emerges from the interactions between the different components described above. Nevertheless, this model refers to the complexity of local execution, but the HF specialist designing a new operational concept or function have also to deal with other dimensions that are important to consider in an overall Human Oriented design process. We describe these different dimensions as a set of different layers in the next section. Actually these layers express different instantiations of the pyramidal model through layers with different proprieties.

3.2 Layers to Design Human Oriented Interactions with Complexity

Since agents in complex systems execute actions in collaboration and cooperation with other entities, the organization of these entities needs to be described more in detail to understand the wide-ranging impact of actions. Actions can be conducted by human or technical agents that belong to the same or different spatial, temporal or social units. These units can be characterized along layers ranging from a detailed Nano-Layer to a high-level Macro Layer. This differentiation is quite common in different domains such as economy, sociology as well as ecology. However additional levels were required for complex interactive systems and have been previously described in the field of incident report [20] and adapted to the context of authority sharing in ATM [12] introducing a NANO-layer. In line with the concept introduced by Bonfenbrenner [12], the Micro-layer covers a pattern of activities and roles in a specific context and can be understood as linked to an individual unit; the Meso-layer addresses a setting in which an individual engages for a certain amount of time, and the Macro-layer entails social and cultural values that exert strong influence. An agent may be connected to different layers at the same time. Depending on the layer where an agent is acting, its impact is different and in consequence the HF specialist may describe the interaction with complexity through the characteristic and scale of the corresponding layer. For example if the HF specialist is designing an authority philosophy (s)he could consider the interaction with an HMI at the Micro level and the definition of roles and responsibilities by authorities at a Macro level. On the same line the space and time of actions and design are impacted by the different layers. For example at the Micro level space and time may be the cockpit and tactical actions whereas at a Macro level the HF specialist should consider the impact of a new concept directly at a traffic scale (and none on a single aircraft) with long term perspective. The following sections provide instantiation of the layers properties by use of an example about authority and responsibility design, of course this example can be replicate following the same logic on other dimensions such as time, space or social units. The sections hereafter propose an adaptation of the layers used by different disciplines to the aeronautical domain.

The **Macro-layer** usually characterizes large social units such as nations, globally acting institutions, cultures or societies (for example Eastern versus Western Societies) of groups of agents. The macro-level typically prescribes the responsibilities of the socio-technical components of the overall aviation system. Authorities (e.g. Military authorities, Civil authorities, FAA, EASA) usually design the regulations and global players such as major aircraft manufacturers, accident investigation offices, standardization groups, or the International Civil Aviation Organization (ICAO) may define the high-level principles of operations such as distance-based aircraft separations, air space organization, or free route. The rules defined at this level may impact the actions of agents either in a direct way (by applying the regulations) or indirectly (by applying the rules defined at a Meso-level). But also, at the Macro-layer actions and authority issues can be found, since the units of this layer are proper entities. The time frame for such activities is long and involves many contributors and can directly impact human activities, systems, organizations and the environment (e.g. CO_2 management, traffic capacity).

The **Meso-layer** refers to social units of an intermediate size, which can be articulated in form of specific organizations of groups of agents executing the high-level rules of operations defined at the Macro-level or sharing a common set of activities. Such organizations (e.g. Airlines, Industrial collaborations, Pilot/ATCO associations) usually define global missions for activities. The Meso level refers mainly to the management of both planning and execution phases of a mission (such as flight leg). Responsibilities at this level are related to an overall area, mission, flight, or work amplitude. The missions defined at this level directly impact the actions of agents. Equally, action and authority issues can also be found at this level. The time frame follows the same logic and is at a mission scale, the environment consideration is also at a mission level and is mainly supported by the forecasts (e.g. traffic density at arrival, weather).

The **Micro-layer** refers to the social unit of a single agent which can be either a human or a technical system. The events produced at this level usually refer to the execution phase. An example for authority at this level can be seen in an alerting system, which has the power to provide information or guidance. This level also deals with the allocation of authorities between human and machine (e.g. TCAS, Flight Mode Annunciator). The Micro-level should consider the properties of an agent such as its competences, strengths and weaknesses, and of course its responsibilities and authorities to perform actions. The time frame is tactical (e.g. less than 10 min of anticipation) and the environment considerations are based on detection by sensors.

Finally, the **Nano-level** refers to the specific properties (such as concrete knowledge, inputs, etc.) or components (such as system functions) that produce the actions. At Nano-level, also the definition of roles can be introduced. Roles are related to an aggregated set of connected actions, hence an agent may integrate different roles. An agent may play different roles depending on the level of the societal context he is involved with. The time frame and environment are immediate. Figure 2 characterizes how Layers can be linked to actions around responsibility/authority/accountability attribution and may be instantiated on a case by case basis through the different layers.

The attribution of responsibility/authority/accountability may also change over time. The example of the 2002 Ueberlingen accident reflects the change of the responsibility organization in relation to TCAS. This technical agent triggers instructions to pilots who have authority to execute a tactical avoidance manoeuvre. Before

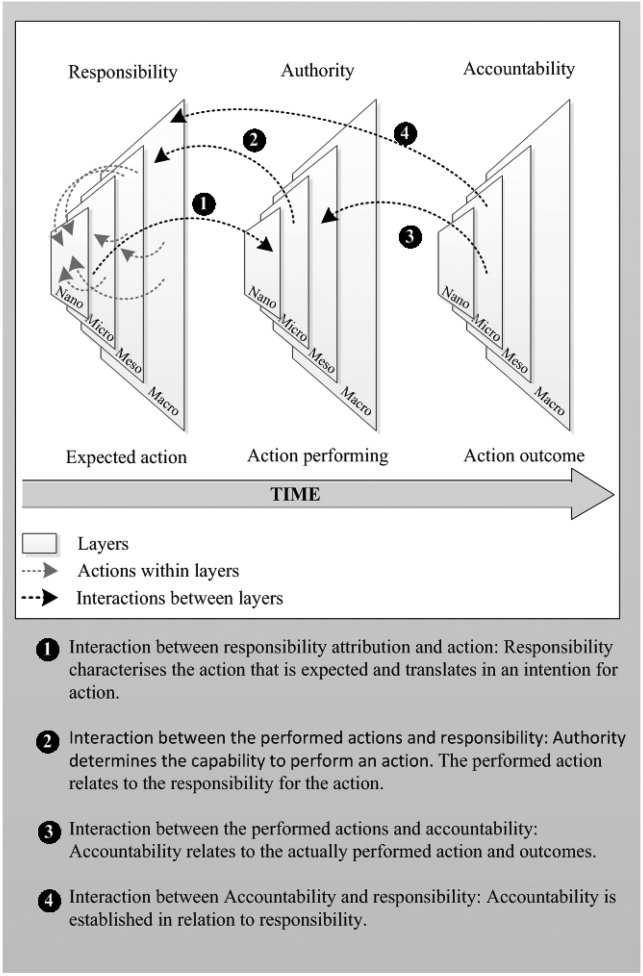

Fig. 2. Relationship between Authority, Responsibility, and Accountability based on the action concept

this accident, there was an absence of harmonization between German and Russian procedures at the Macro-level, one giving the authority to make decision to the TCAS agent and the other one to the ATCO. This lack of harmonization led pilots and ATCO, at the Nano-level, to follow different uncoordinated instructions during the execution of action causing a mid-air collision. After this event, the procedures were harmonized giving the authority to TCAS whatever the context. It means that an event that occurred at the Nano-level led to modifications at the Macro-level, which was in turn again resulting in modifications at the Nano level. Figure 3 illustrates the relationship between concepts.

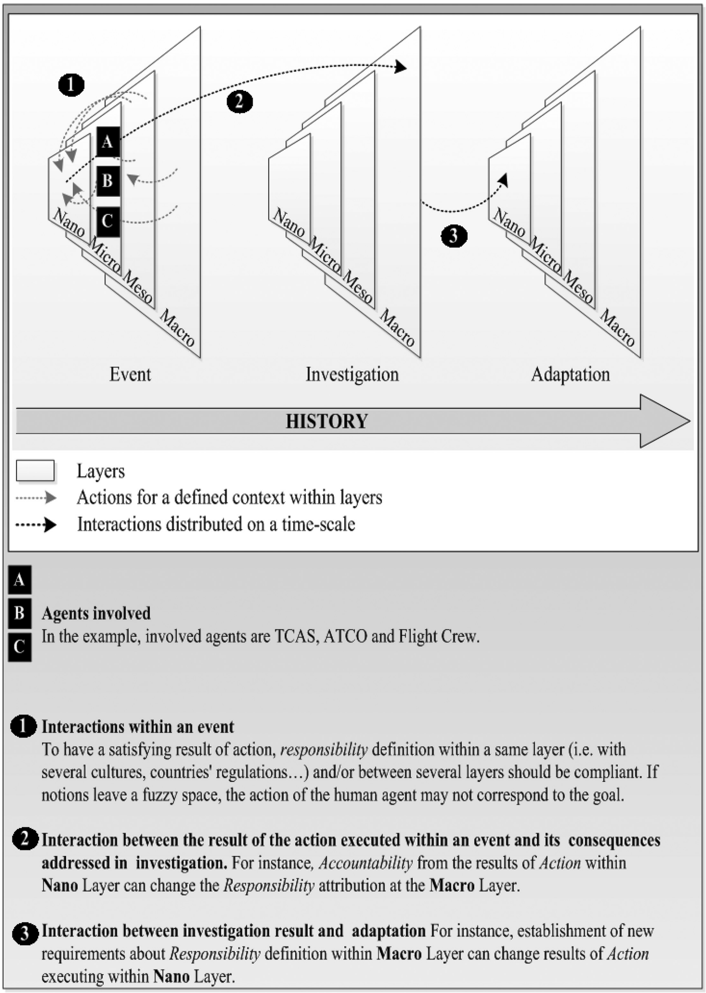

Fig. 3. Dynamic relationships between Authority, Responsibility, and Accountability notions after an event across the different layers

4 A Framework for Human Oriented Interactions with Complexity

Obviously the components presented in the two previous sections could be mixed in order to draw a big picture of Human Oriented approach of complexity in aeronautics. In fact this is the main aim of this paper. Nevertheless the entire integration of these two components cannot be express in the frame of this presentation. Therefore we focus only on a part of the pyramid model presented in the Sect. 3.1. So we describe only the interaction between the Tasks and the vertex of the pyramid: HMI, Environment, Human Organization and Users. These four relations are numbered from 1 to 4 on the

Fig. 3. The following sections illustrate more in detail this mix between the interaction proper to the pyramid with the four layers Nano, Micro, Meso and Macro.

4.1 The Complexity Framework Mixing Pyramid Models and Layers

The main purpose of the complexity framework is to improve the awareness of the HF specialist regarding is own activity and also in the choice of the appropriate methodology in line with the level of his/her intervention. As we mentioned in the previous section we only consider the relation of the task with the vertex, of the pyramid model, with the different layers. Therefore we could consider the mix between these two components as a 4 * 4 matrix presenting in the lines the different relations to the task and in the column the four different layers. In the cells of this matrix might emerge the different HF activities addressing interactions with complexity and by extension the different methods and tools supporting these different activities. The Table 1 shows the result of this mix between the two components and presents a codification that we will use in the rest of the paper to guide the description of different methodologies able to cover the different cells of this matrix.

Table 1. Mix of pyramidal model and layers also called the Human Oriented Approach of Complexity matrix (HOAC matrix)

	Nano layer	Micro layer	Meso layer	Macro layer
1 task → User	1 (na)	1 (mi)	1 (me)	1 (ma)
2 task → HMI	2 (na)	2 (mi)	2 (me)	2 (ma)
3 task → Orga.	3 (na)	3 (mi)	3 (me)	3 (ma)
4 task → Envi.	4 (na)	4 (mi)	4 (me)	4 (ma)

The Table 2 provides some examples of instantiations through the HOAC matrix. These examples expect to guide the HF specialist in aeronautics to understand more concretely the link between his/her own (daily) activity with the different complexity dimensions of the HOAC framework. Indeed this instantiation reflect some activities in which the HF specialist, or the HF arguments, may be involved.

We can focus on some of these cells to highlight their content in terms of activities in which the HF specialist can be involved and their relations and independencies. As a case study we propose to follow the main needs involved in a new concept of Trajectory Based Operation in cruise phase. The TBO could be viewed only through a board system optimisation such as the improvement of vertical profile according to wind and temperature forecast in cruise for a single aircraft. But in this case the entire complexity of the concept is not considered because dimension as 4 (ma) the long term benefit on the traffic capacity is not considered as well as the (3 me) sharing of this TBO with the ground that may be have a strong positive impact on traffic predictability for ATC. Furthermore with a Human Oriented approach in design of simplex system the HF *transition factors* involving the elaboration of new (2 mi and 2 me) mental

Table 2. Examples of instantiations of the combination in the HOAC matrix

	Nano layer	Micro layer	Meso layer	Macro layer
1 task → User	concrete user actions/inputs for the task execution	properties of an agent such as its competences, strengths and weaknesses	users acting directly on planning and execution phases of a mission (a flight leg)	definition by authorities of users responsibilities in a task execution or long term impact of user on task and *vice versa*
2 task → HMI	concrete execution of components as system function	functional model supporting the immediate task execution at a tactical level	HMI supporting the mission execution at a leg level (e.g. FMS, ND, Display of ATC sector)	design of HMI interaction philosophy at a manufacturer level
3 task → Orga.	agent may embodied different roles and a set of aggregated set of connected actions	transfer of responsibility to an agent to other one according to defined procedure	co-execution, sharing a common set of operations at a mission level (ATC/pilot cooperation, pilots task sharing)	definition of rules or law structuring the overall inner and inter organisations
4 task → Envi.	concrete and direct action of the environment such as gust or flock of birds	adaptation of the task to the local sensed environment (constraints due to detected weather, terrain)	adaptation of the mission to the forecasted environment (weather forecast, escape routes)	study of the impact of task on the overall environment such as fuel consumption and traffic impact

representations of board and ground actors using this new TBO in cruise have to be considered, studied and rationalised. Otherwise this may negatively impact the acceptance of this concept both by 1 (ma) actors in execution phases but also by 3 (ma) organisation that can buy and maintain this new concept in operations.

In the case of these different dimensions are not considered in the design of that TBO concept, this may viewed as a way of simplification (on the contrary of simplex) of the design process and a way to win time in development on a short term. Nevertheless as this already mentioned in [3] if the whole needs of a new ATM concept are not considered or ignored in the early steps of a design project this may have a strong negative impact on the long term success of this concept because some important needs will be not identified whereas they still exist.

4.2 Examples of Methods Supporting the Human Oriented Approach of Complexity

This section expects to continue the illustration of the HOAC matrix but this time in terms of methods to support a Human oriented approach of complexity. On this line we introduce and describe four different methods candidate to be use or already supporting different cells of the complexity matrix. Obviously this set of methods is not exhaustive and is used only to illustrate the capacities of the HOAC matrix to delimit the scope of a Human oriented approach of complexity, to classify methods and HF activities, to support the understanding of the relations between the HOAC matrix cells and finally to predict the needs to new methods or new interactions between methods. The combination of these four HOAC matrix capacities is its main added value in the overall design process of *simplex artefacts*. In this way the following sections describe a first proposal of *Simplexity criteria*, a systemic approach for *Authority design*, two different views of *eye-tracking studies* and the last method deals with *complexity simulator*. To ensure the link between the description of methods and the HOAC matrix we use the codification able to localize the cells of the matrix impacted by the different methods.

Simplexity Criteria [1 (mi); 2 (mi); 3 (mi); 4 (mi)]. The diagnosis task is a key task within a design process. Indeed, the diagnosis both, emerges from the need analysis and/or results from assessments carried out, and allows to define requirements and recommendations for the conception or else key points needed to be assessed through user-test. The approach presented hereafter focuses on the method implemented to define simplexity criteria which may be implemented at the Micro layer in the HOAC matrix.

These simplexity criteria are based on the principles presented in previous sections and especially the Sect. 3.1 describing the pyramidal model. More precisely, the aim of these simplexity criteria is to assist the identification and the classification of ergonomic problems linked to the simplex artefact (e.g. usability, assistance flaws).

The criteria formalism as evaluative referents [6] has the advantage to be enough conceptual to be adaptive to various HF specialists backgrounds, study scopes, but also to be understandable by specialists from different disciplines. In short, criteria formalism allows exposing widespread knowledge required for a systemic approach and for convergence between several points of views.

The elaboration and assessment of these simplexity criteria follow a process in line with the process used for the ergonomic criteria focused on Human interactions with Graphical User Interfaces [5], or with Virtual Environments [2]. More precisely, the design of the criteria is first based on a qualitative data analysis in line with the *Grounded Theory* principles [10], and then follow a standard user-centered design. The users' feedbacks and performances are collected from two kind of empirical studies. Indeed, the validity level of the proposed criteria depends of their (a) intrinsic validity, that is their usability level and agreement level to support a problems classification; (b) extrinsic validity, that is their reliability level to identify problems in interactive systems.

Table 3. List of the main simplexity criteria

1st version	2nd version
1. Suitability with user requirements	1. Compatibility
2. Detection of information	2. Guidance
3. Recognition of information	3. Adaptability
4. Variability management	4. Actions and information costs
5. Actions implementation	5. Homogeneity/Consistency
6. Workload	6. Threat and error management

So, a first criteria list has been extracted and defined from the codification and classification of a set of recommendations, itself deciphered and grounded on an analysis of scientific and operational literature (see Sect. 3.1). This first list structured in two levels was composed of 6 main criteria (Table 3 – 1st version) and 24 elementary criteria. The definition of each criterion, as well as its rationale and examples of recommendations, are exposed in a technical paper report.

10 Human Factors specialists from the aeronautical filed participated to the assessment of the intrinsic validity of the criteria. This study was based on an assignment task. The results from this first study highlighted that the proposed criteria covered the scope of Human-Simplex System Interactions as well the relevance of these criteria for the HF specialists' diagnosis. The participants have appreciated the possibility to have quickly access to the main properties to consider and the integration within the criteria of current questions like the situated relationships between Augmented Reality and Real Environment. Nevertheless, the criteria should be improved, and so the intrinsic validity of the criteria should be reassessed. More precisely, the organization of this first version was too many distributed to carry out an ergonomic inspection, half of the criteria definitions required to be improved, and some of the criteria needed to be subdivided. An update on the criteria has been performed. This new version structured in three levels is composed of 6 main criteria (Table 3 – 2nd version) and 32 elementary criteria. The assessment of the extrinsic validity of the criteria has been performed based on this second version. 30 participants with Human Factors or engineer backgrounds have performed an inspection of two simplex artefacts. The results are currently ongoing analysis. The update on the criteria will thus be performed.

As the already implemented ergonomic criteria, the main difficulty related to the establishment of the Simplexity criteria lies in the fact to find the right level of abstraction which allows both to have a criteria number cognitively accessible and to ensure that the criteria covered the scope of the intended purpose, to diagnose ergonomic problems. Nevertheless this first tentative is promising because the participants to the two experiments highlighted the good level of guidance to define the scope of interactions with complexity. So, in spite of the difficulties to find the appropriate granularity detailing each criterion, the first step of the appropriate delimitation of the scope of Simplexity criteria, is a positive lesson learned.

Authority Design. The design of authority and responsibilities in new ATM concept is a key point to ensure a good cooperation between agents and by extension absorb a part of the operational complexity. We provide hereafter an abstract of an approach for *authority design* that has been previously adapted to a systemic approach of ATM and detailed in [12]. So, this approach is already adapted to a declension of authority/responsibilities and accountabilities across agents at a Nano, Micro and Meso level. In this way this approach is able to cover many cells of these layers in the HOAC matrix in terms of execution of authority/responsibility. But according to the system impacted by the design of authority some responsibilities have to be designed at a Macro level especially in the cell 3 (ma) in which standard and organization regulation are designed by authorities (e.g. ICAO, FAA, EASA) but on the basis of argumentations elaborated in the previous cells at Nano, Micro and Meso levels. We briefly illustrate the use of this method through a case study based on the management of *Wake turbulences during visual separation in approach* already presented in [12] and updated in order to match with the HOAC matrix. In this perspective, the following case study is tagged by use of the HOAC codification in order to identify which part of the case study match with this matrix.

The case study describes, by use of the proposed Authority design framework, the management of wake vortices during visual separation operations from a pilot perspective. In the US, visual separation in approach is a daily activity to increase traffic capacity. Operations at many airports are based on maintaining visual separation from preceding aircraft using 4 (na) direct visual information on this aircraft. This kind of operation has a strong impact on the 1 (mi) responsibilities of each agent. Indeed, when the 1 (na) flight crew accepts to maintain visual separation, the responsibility of separation 3 (ma) is delegated to flight crew and does not fall under the responsibility of ATCO. Visual Separation allows for reduced spacing between pairs of aircraft which 4 (ma) must be spaced greater than separation minima (i.e. ICAO Wake Vortices Separations) in standard operations. This operation is, for now, not supported by any 2 (mi) on-board function but solely based on 1 (mi) the pilot skills.

In other words, the task of the 1 (na) pilot consists in analyzing the distance from 3 (na) preceding aircraft taking into account 4 (na) contextual information in order to ensure that the own aircraft does not encounter Wake Vortices and, of course, 4 (mi) prevent traffic collision.

Figure 4 illustrates the overall *Assisted Visual Separation* concept by use of the framework of Responsibility and Authority. For each layer and action Responsibility [R] and Authority [A] are identified. The figure shows the big picture of the concept as it could be designed without reflecting the specific execution of the concept during a specific mission.

Around Nano-layer, the detailed actions are analyzed during the execution phase, as one or several agents may be required to conduct actions towards a same goal. Hence, the relevant item at this level is not the responsibility, as responsibility is allocated to a defined agent, but authority. The authority to decide on the adequate distance to maintain from preceding aircraft is given to the pilot.

A human factors issue in relation to this design is the difficulty of this task, since today no tool support is available. The question can be asked if 1(na) human and/or 2 (na) machine shall 3 (mi) and/or 4 (mi) analyze and decide on the distance and speed adjustment to the preceding aircraft. Such a situation can be considered being an authority delegation. Figure 4 shows the 2 (na) ADS-B as a potential mean for such tool support.

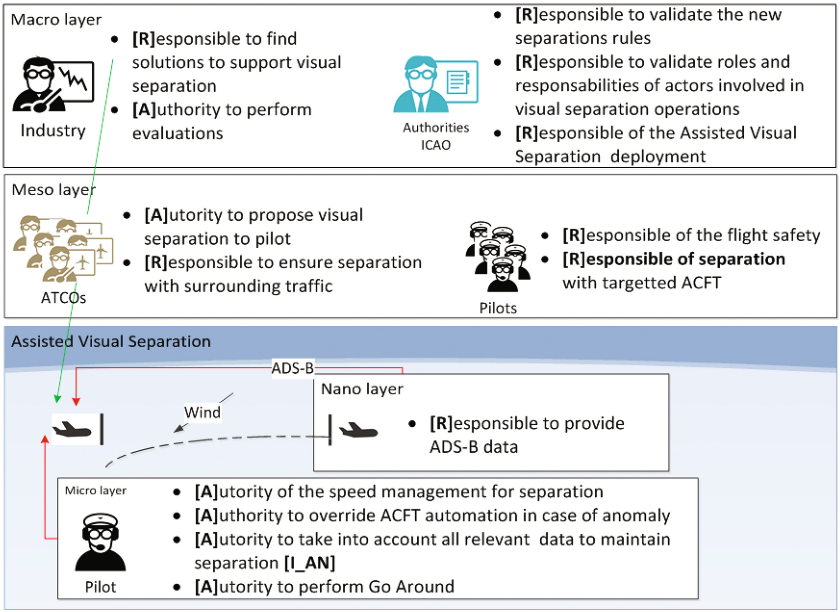

Fig. 4. The framework of responsibility and authority applied to the assisted visual separation concept

Around Micro-layer, in controlled areas the separation responsibility is allocated to the ATCO. Once visual separation accepted, it is the pilot becoming responsible.

Pilot has authority to accept the task of visual separation. Separation is not under her or his responsibility because s/he 3 (mi) is not obliged to accept according to operational descriptions. Only once he has accepted visual separation, he becomes responsible for separation and has to ensure it. Hence, the actions at the Nano-Layer with the pilot analyzing the distance to the preceding aircraft are to be seen in relation to this authority at Micro-Layer.

At the Meso-level, the responsibility between the actors and the social unit could for example be linked to the ways 3 (me) the airlines define directives for 1 (me) pilots depending on their overall mission. Such a directive could be linked to the conduct of the mission, and an example could be seen in requirements of maintaining additional distance to what is judged necessary by the pilot in order to ensure safety and/or the airlines would provide recommendations to their pilots regarding the visual separations.

At the Macro-layer institutions define laws, for example with regard to keeping a certain separation to the preceding aircraft depending on the aircraft category. They impact consequently the accountability of related actors. International institutions, such as the ICAO, have authority to introduce new regulation, but it is up to the definition of the responsibility of more regional authorities by the local states how they are introduced into concrete actions. On the same line the Industrial sector, in the case of *Assisted Visual Separations*, is responsible to provide technical solutions and have also authority to perform the evaluation of the overall efficiency including Human performance of such solutions.

Eye Tracking Evaluations. The increased complexity of ATM concept such as visual separations described, in the previous section, require adapted tools able to provide an adapted level of metrology. In this way eye-tracking evaluations and more broadly neuro-ergonomics provide more and more reliable direct measurements and in some cases indicators able to study more and more precisely fast human interactions in operations. Such measurements provide interesting quantitative and objective data able to assess in a new way complex concepts as for example the situation awareness, visual scan patterns [21]. Itself these eye-tracking studies are serious candidates to cover the cells 1 (na) and 2 (na) of the HOAC matrix. Nevertheless the impact of the eye-tracking use may be broader. Indeed eye-tracking could be used as a tool supporting the progress of student pilots through training programs at a meso level.

Complexity Simulator. In the frame of a Human Oriented approach of interactions with complexity, the HF factor specialist or at least its argumentation may need methods or study at the macro level. This is especially the case when the HF specialist has to deal with the design of new ATM concept with apparently few evolution compare to existing operations. In this type of projects the acceptance of the different actors are difficult to reach at a meso level and usually this is because the perception of benefits of the concept should be viewed on the long term and at a traffic level. Therefore the perception of benefits is almost impossible for designer because these benefits are the results of a long and complex overall system (e.g. positive impact on CO_2; traffic predictability. In such cases the HF specialist needs to access to study using specific tools able to simulate the result of numerous small operational micro modifications that can have an important macro benefit due to the complexity of local interaction on long term period. These kinds of simulations (usually named fast time simulation) can be performed, so far, only by specific ATM agencies such as Eurocontrol, Mitre or NATS. But their results are really important to ensure and deals with of transition factors such as the acceptability of the new ATM concept. In this way the HOAC matrix can locate this kind of specific activities 2 (ma)/4 (ma) and guide the HF specialist to understand the importance of such complexity simulation for his/her own HF activity.

5 Discussion and Limits

We describe in this paper the HOAC matrix able to support a big picture of HF specialist dealing with aeronautics complexity. The aim of this matrix is to objectively classify the HF methods, tools and specialist actions. We illustrate with few examples some cells of this matrix. Obviously this matrix can be viewed as a predictive structure able to develop activities and tools supporting the entire Human Oriented Approach of interactions with complexity. This contribution is a first attempt to structure and integrate the HF specialist activity in this area, that is an actual great challenge. Nevertheless our approach is mainly based on a theoretical study. In this sense our proposal includes different flaws and should be completed and structured with a set of studies assessing the overall utility of this matrix and its efficiency to structure the HF specialists. Furthermore our study focuses solely on the interactions between the tasks and the vertex of the pyramidal model. Obviously this theoretical study should be extended to the entire pyramidal model and the HOAC matrix should be completed with other methods and activities in future works.

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