EUROCONTROL

White Paper
Human Factors Integration in ATM System Design

Joint Design Teams
User-Centred Design Rationale
User-Centred Design Process
Objective HF/E Criteria
Prototyping
Conditions for Evaluating Prototypes
Problem-solving
Problem-setting
Purpose-Orientated View of New Technology

SUPPORTING EUROPEAN AVIATION

FOUNDING MEMBER SESAR JOINT UNDERTAKING

NETWORK MANAGER

FOREWORD

by Prof. David D. Woods

Automation provides powerful capabilities, but capability, however advanced, is not a solution by itself to system goals. These capabilities need to be integrated with responsible human roles to create a joint system that can adapt fluently to handle inevitable occurrences of exceptions, anomalies and surprises. Human experience and expertise are critical for robust and resilient performance even as technology advances enable operations at increasing scale to achieve economic and throughput goals. As technologies that are more powerful are deployed, human roles change emphasising more sophisticated forms of coordination and supervision of technological assets.

As technology grows more powerful, it is clear that the risks from complexity penalties also increase. When disruptions, anomalies and surprises occur, effects can cascade more quickly or widely, the tempo of operations increases, quickly challenging the ability to keep pace with changing situations, uncertainty can grow, undermining the ability to reconfigure resources or re-plan decisively, workload on human roles can spike suddenly, coordination across roles and scopes of responsibility become more difficult.

Solutions to manage complexity penalties that accompany technology advances depend on utilisation of human-centred system design techniques and principles. Fundamentally, this means designing technology to be a cooperative partner in shared activities so that the human-machine team can be highly responsive to handle disrupting events. This white paper provides a guide to facilitate the design of technology and automation that supports the human contribution to robust and resilient system performance.

Contents

EXECUTIVE SUMMARY

In aviation, Human Factors/Ergonomics (HF/E) is traditionally closely linked to safety. The way safety is understood in the discipline of HF/E determines how HF/E approaches system design. Today, safety is often measured by its absence, by recording and evaluating critical events, for example. A safety report then usually contains the number and severity of incidents that have occurred in a specific period. However, it rarely describes the actual safety status of the organisation.

For several years, progressive safety experts and scientists have been developing new and pro-active approaches to capturing and understanding safety in complex systems. It is not so much a question of recording when the system is not functioning but rather of understanding successful operation. This is where HF/E needs to question whether they want to design safety or just prevent unsafety. A pro-active design of safety in this new perspective goes far beyond prevention and risk mitigation.

An active role for HF/E in system design is becoming even more important, considering that the degree of automation is increasing with each system generation. New technologies, digitisation and artificial intelligence (AI) are considered as a reliable source for more capacity and efficiency. However, confidence in technology alone without further investment in HF/E will likely result in less safety, capacity and efficiency. To achieve the anticipated benefits through more technology, it is all the more important to understand the overall system with its complex interactions and dependencies. Who, if not HF/E can provide a significant contribution to this? Currently, however, HF/E seems not well integrated in the actual design process of air traffic management (ATM) systems.

This whitepaper proposes basic principles for a better integration of HF/E in system design. These are:

1. Build **joint design teams** and do not treat HF/E as a mandatory add-on
2. Make a coherent **user-centred-design rationale** your HF/E product
3. Strive for a short, iterative **user-centred design process**
4. Derive **objective HF/E criteria** instead of relying on user opinions
5. Evaluate as early as possible with the help of **prototypes**
6. Select appropriate **conditions for evaluation**: Evaluate day-to-day operations as well as critical situations
7. Support the **problem-solving** process during implementation by facilitating trade-offs
8. Do a proper **problem-setting** in the first place whenever possible to understand your actual problem and the underlying mechanisms and needs
9. Be ready to participate in strategic decisions and introduce a **purpose-orientated view of technology**

The application of these principles supports organisations in better integrating HF/E into practice, which is urgently needed for the challenges to come: Not just for better user acceptance, but also to ensure that the anticipated benefits through more automation and technology are effectively realised.

HUMAN FACTORS, DESIGN AND SAFETY RELATIONSHIP

Design-Safety Relationship

"People create Safety"

In the meanwhile, this sentence has been adopted by many organisations, air navigation service providers (ANSP), EUROCONTROL and CANSO. Alongside the phrase "Safety First", they represent the core values of a modern safety management.

A relationship between humans and safety therefore seems obvious. The conclusions drawn from this relationship depend on the safety theories applied.

The way we understand safety affects how we consider Human Factors in an air traffic control (ATC) environment. Therefore, it is important to have a definition of safety in the first place before discussing how Human Factors can contribute in this very specific domain.

Traditionally, safety is defined as the absence of unwanted outcomes such as accidents or loss of separation. ICAO puts it this way: Safety is "the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level" and that "the elimination of aircraft accidents and/or serious incidents remains the ultimate goal" (ICAO, 2013).

It is relatively easy to recognise unsafe events once they have occurred, which makes a negative term definition attractive. This does not require defining the actual characteristics of a safe system. It is like defining brightness as the absence of darkness. The downside of a negative term definition is that it limits the space for safety improvements because it takes safety as given as long as no risks have been identified. Safety is measured by its absence not its presence. Consequently, the safety reports are rather a measure of *unsafety* than safety.

This perspective is also reflected in many accident reports. They usually include a huge compilation of all investigated causes and contributing factors that undermined safety and led to the unwanted consequence. The underlying assumption is that the system is basically safe and the human operator is seen as the weak and unreliable part in it.

Understanding human error and improving human performance are the reason why traditionally Human Factors is located in the safety management department and safety and HF/E are closely connected in the ATC domain. Human Factors became very popular because the discipline is concerned with cognitive work in general and human error in particular. The idea of Human Factors integration in this perspective is that if human errors are analyzed and understood by Human Factors experts in a systematic manner, adequate actions can be taken in order to avoid human errors or at least reduce the risk of occurrence.

One example of this is the accident of Air France Flight 447 (AF 447), a flight from Rio de Janeiro to Paris, which experienced a stall situation and crashed into the Atlantic. An obstruction of the pitot probes by ice crystals led to an inconsistency between the measured airspeeds, autopilot disconnection and a reconfiguration to alternate law. According to the report, the accident resulted from the following succession of events (BEA, 2012):

- Temporary inconsistency between the measured airspeeds, likely following the obstruction of the pitot probes by ice crystals, which led in particular to autopilot disconnection and a reconfiguration to alternate law
- Inappropriate control inputs that destabilised the flight path
- The crew not making the connection between the loss of indicated airspeeds and the appropriate procedure
- The PNF's (pilot not flying) late identification of the deviation in the flight path and insufficient correction by the PF (pilot flying)
- The crew not identifying the approach to stall, the lack of an immediate reaction on its part and exit from the flight envelope
- The crew's failure to diagnose the stall situation and, consequently, the lack of any actions that would have made recovery possible

These findings are an expression of the same safety understanding as given by ICAO: In general, all flights are safe. There were specific events, especially triggered by the crew that made AF 447 exceptionally unsafe. If the crew had made the appropriate control inputs, the right connection between the loss of indicated airspeed and the appropriate procedure, an in-time identification of the deviation in the flight path, had carried out sufficient corrections and diagnosed the stall situation, this flight would have been safe as well.

This shows the consequences of a negative term definition of safety: A lot can be said about why systems are unsafe,

but little about what actually makes systems safe. This is where HF/E needs to question whether they want to design safety or just prevent unsafety. The design of safety goes far beyond the prevention of unsafety. Design is something that necessarily happens before any risk evaluation or incident. One key question is how operators can be supported in making safe decisions and carrying out adequate actions in hazardous situations.

The "Miracle on the Hudson", US Airways Flight 1549 is an interesting example in this context, because the incident had a positive outcome. After a loss of thrust in both engines, the pilots were able to ditch the Airbus A320 on the Hudson River. All passengers survived. Obviously, not the absence but the presence of something led to a positive result. The final report names the following contributing factors to the survivability of the accident (NTSB, 2010):

1. the decision-making of the flight crew members and their crew resource management during the accident sequence;
2. the fortuitous use of an airplane that was equipped for an extended overwater flight, including the availability of the forward slide/rafts, even though it was not required to be so equipped;
3. the performance of the cabin crew members while expediting the evacuation of the airplane; and
4. the proximity of the emergency responders to the accident site and their immediate and appropriate response to the accident.

This case apparently included several aspects that produced safety. Human Factors needs to be better in understanding these aspects in order to design the conditions and circumstances of safety-related working environments. Besides dealing with probabilities, risk assessment and risk mitigation, this document promotes a new understanding of safety, which actively analyses how the system produces safety in day-to-day operations and how this "production process" can be supported.

The idea is not new, but is currently being discussed under the term "Resilience Engineering" and "Safety-II". Just as Safety-I was defined as a condition where as little as possible went wrong, Safety-II is defined as a condition where as much as possible goes right. The absence of failures (of things that go wrong) is a result of active engagement. In order to ensure that a system is safe, we need, therefore, to understand how it succeeds rather than how it fails (Hollnagel, 2014). Consequently, safety is something a system does rather than something it has (Hollnagel, Woods, & Leveson, 2006).

As soon as we use the concept of Safety-II as a basis, safety seems quite naturally linked to design, especially if we do not restrict the term "design" to technological systems, but working systems as a whole. Design can complement and steer the behaviours of operators in everyday situations as well as in critical situations.

For this, US Airways Flight 1549 is a suitable example, as well. According to the report, the pilot suffered task saturation resulting from the emergency situation. Fortunately, the captain started the auxiliary power unit with the result that the airplane remained in normal law and maintained the flight envelope protections. Among other things, the flight envelope protections aid the pilot to maintain a safe angle of attack and prevents the aircraft from stalling. Stalling is a serious danger, especially at low airspeeds. Due to this support feature, the captain could focus on maintaining a successful flight path while the system managed the risk of stalling. This example supports the idea that well-elaborated design can directly support safety.

As soon as the human contribution to safety is acknowledged, it becomes apparent how workplace and process design can reinforce safety. To do this, a deep understanding of the work and interactions involved is essential. Only if we better understand the mechanisms behind how people exactly create safety in day-to-day operations we are able to induce safety by design.

Design-Human Factors Relationship

At this point, this white paper deduces the interrelation between design and safety. Beyond that, how is design inter-related with Human Factors? For all Human Factors experts, this should not be a question at all, as the answer is part of the discipline's self-conception.

The International Ergonomics Association (cf. IEA, 2018) and ISO 6385 (2016) use Human Factors and Ergonomics synonymous and define both as follows:

"Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance."

This definition directly emphasises the importance of design as an integral part of the discipline.

Dul et al. (2012) deduced three fundamental characteristics of HF/E, i.e.:

1. takes a systems approach
2. is design driven
3. focuses on two closely related outcomes: performance and well-being

The postulation of a systems approach aims for an integrated perspective of ergonomic aspects. Its meaning remains unclear and is currently controversially discussed within the community. There is no common understanding of which characteristics denote a systems approach in HF/E. Thus, no models or methods have been established that can ensure the application of a systems approach. As a starting point, Wilson (2014) suggests the following definition for a system:

"A system is a set of inter-related or coupled activities or entities (hardware, software, buildings, spaces, communities and people), with a joint purpose, links between the entities which may be of state, form, function and causation, and which changes and modifies its state and the interactions within it given circumstances and events, and which is conceptualised as existing within a boundary; it has inputs and outputs which may connect in many-to-many mappings;

Or as Meadows (2008) puts it: "*The basic principle of a system is that it is something more than a collection of its parts. Systems thinking consists of three things: elements, interconnections, and a function (for non-living systems) or purpose (living systems). The least obvious part of the system, its function or purpose, is often the most crucial determinant of the system's behaviour*".

Even though the exact structure of a systems approach remains unclear, there seems to be broad agreement that such an approach should focus on the interdependencies among different system components rather than single system elements in isolation (cf. Wilson, 2000; Carayon, et al., 2014).

According to the second fundamental characteristic, HF/E is design driven, which means that real-work systems are examined. There are no "theoretical" work systems. This "action view" (cf. Helander, 1997) separates HF/E from many other disciplines.

Norros (2014) assumes that the design orientation is the largest challenge for the discipline. The specific demands of practitioners regularly collide with the scientific idea of a general validity. Therefore, she suggests that researchers should only be concerned with practitioners' questions, if available general knowledge is not sufficient.

This perspective neglects the high complexity of today's work systems: In most cases, the application under given restrictions and boundaries is the crucial part of system design. Salas (2008) and Meister (1999) argue that scientific findings often lack clear implications for practice. Furthermore, many findings from research papers cannot be directly transferred to problems in practice. Especially in laboratory studies, the controlled factors are often of higher interest to practitioners than the actual investigated variable (cf. Wilson, 2000; Chapanis, 1988; Chiles, 1971). Therefore, the application in practice is accompanied by many uncertainties, which makes the relevance of this knowledge questionable for many practical problems. The difficulties of knowledge application in practice are discussed under the term "researcher-practitioner gap" (cf. Salas, 2008; Dekker & Nyce, 2004; Buckle, 2011; Chung & Shorrock, 2011).

Ultimately, the application of HF/E in design is still connected with several problems. If, however, HF/E is to be a design-driven discipline as depicted by Dul (2012), foundational research is not sufficient. Instead, methods and approaches are needed that help to address specific HF/E challenges in complex organisations such as ANSPs. The pure production of new knowledge will not help to tackle the practitioners' problems, which arise from complexity rather than from lacking knowledge. As a design-driven discipline, methods should be provided that help to deal with this complexity.

The third characteristic of HF/E is that it focuses on two closely related outcomes: performance and well-being. It sets the overall objective of HF/E and splits it up into a performance goal and a humanitarian goal.

The performance goal is not formulated as "human performance" or "work performance". Instead, the definition uses the term "overall system performance" to reflect the idea of a spanning systems approach.

Complex projects typically have several conflicting goals from very different disciplines that need to be managed. Subsequently, one task of HF/E is to contribute to finding a proper solution, having overall system performance and all its interdependencies in mind. In Europe, the high-level measurements of overall system performance are often categorised into safety, capacity, environment and cost efficiency. While the impact on capacity, cost efficiency and environment can be measured, it remains unclear how to include safety in this equation. In the sense of Safety-I, it would be the absence of incidents. This again does not seem very attractive for a complex organisation like an ANSP and is particularly not in line with the idea of Safety-II. A qualitative safety approach could be more appropriate for this. However, this discussion leads far beyond the scope of this study. For this, more research is needed on how to integrate the idea of Safety-II into organisational safety management systems.

The humanitarian goal of optimising human well-being seems difficult to operationalise as well. This is particularly true if it is to go beyond the pure physical integrity of workers. There are some frameworks available that address human well-being, but they are more suitable for manual workers than cognitive workers. Hacker & Sachse (2014), for example, suggest four different levels: On the lowest level, the work has to be performable within the limits of human capabilities. The next level requires that the work can be performed without physical harm to the person. The third level demands that the work is not unreasonable (with respect to the payment, for example). Finally, the possibility for the individual development is placed on the fourth level. This model, however, seems not very suitable for cognitive work, as only the uppermost level seems relevant, while the lower three can be (more or less) neglected.

Newer concepts try to figure out why people go to work at all and what motivates them beyond payment and other extrinsic factors. The basic assumption is that well-being requires the job to produce individual meaning for the worker. The literature discusses different universal human needs that can induce meaningful experiences for workers. Based on Sheldon, Elliot, Kim, & Kasser (2001), Hassenzahl, Diefenbach, & Göritz (2010) describe and define six needs that can address human well-being. These are Autonomy, Competence, Relatedness, Popularity, Stimulation and Physicalness. Marc Hassenzahl elaborates this perspective of human well-being further in his contribution below. Although overall system performance seems to be a more tangible HF/E objective, the six needs nicely illustrate that human well-being is still a relevant matter that goes far beyond occupational healthcare and work-life-balance.

The following table gives an overview of the conceptual framework for a better HF/E integration into design. With this in mind, HF/E can contribute to addressing both: overall system performance and human well-being.

Conceptual Framework for HF/E in Design

		HF/E…
What	Scientific discipline	… develops theories, principles, knowledge and methods … investigates approaches to deal with increasing complexity … develops approaches to integrate Safety-II into practice
	Profession	… applies theories, principles, knowledge and methods … manages complexity within a specific domain … mediates among different disciplines in a design project
How	Systems approach	… focuses on the whole work system across different units instead of single elements or aspects … analyses interrelations and interactions between the elements
	Design driven	… has an action view … has the purpose to improve something and any analysis is just an instrument for that
Why	Safety	… knows and understands the key factors that produce safety in day-to-day operations … looks at safety as an product of human adaptations and well-working interactions … supports safety by adequate design
	Overall system performance	… knows and understands the main drivers for the overall system performance … considers the whole joint system with its technological, cognitive, social, cultural and environmental aspects … is convinced that this joint perspective is crucial for any successful change
	Human well-being	… considers work as a meaningful part of life where people come together, develop and express themselves … understands the contribution of technology to meaningful work … places human experience in the centre

A Perspective on Human Well-Being and Meaningful Work and its relevance to the ATC world

by Prof. Marc Hassenzahl

Technology plays a crucial part in our daily working lives. For example, air traffic controllers use a plethora of devices, software and physical arrangements to carry out their daily routines of guiding, communicating with and safeguarding aircraft. Of course, we expect these technologies to function properly, to be efficient and easy to use. Overall, the goal is to create a socio-technical system made of humans and technologies to allow for the most trouble-free air traffic possible. Automation is a key ingredient for this.

Understanding the contribution of technology to meaningful work

In general, automation substitutes know-how-intensive and allegedly error-prone human activity with technology. What is often overlooked in the endeavour to streamline work is the impact on the human in the system. In fact, the negative consequences of automation on work satisfaction are already well-understood: People feel alienated, they de-skill and feel less responsible for the outcome of a system, they are actually meant to supervise and steer. This is just one example of an important insight: Technologies are not just neutral ingredients of a work arrangement – they shape work practices as well as the subjective meanings people derive from work. Even subtle changes can have great impact. For example, when air traffic controllers insist on using tangible artefacts, such as flight strips, to manage flights, this tangibility might be crucial for feeling in control of an otherwise quite abstract work, where blips of light represent hundreds of people, whose lives depend on the work of the controller. From a narrow perspective of instrumentality, it does not necessarily matter in what exact manner certain information is presented and handled. From a broader perspective of experience and meaning, controllers might especially care about certain details, such as tangible flight strips, since they impact how work "feels" and whether it remains "meaningful" to them. As a consequence, insisting on particular aspects of a given technology should not be equated with stubbornness or a general resistance to change on the behalf of the user. Quite the contrary, it is often a consequence of short-sightedness on behalf of technology design and development, which has an impoverished view of the actual richness of human experience created through technology.

Placing human experience in the centre

If we place human experience in the centre of technology design, crucial questions will change. While organisations strive towards more efficiency, they must balance efficiency with creating meaningful jobs. What is important is a good understanding of what makes certain work practices meaningful and enjoyable for practitioners. While many organisations have substantial descriptive knowledge about work procedures, tasks and regulations, they often dismiss experienced meaning and enjoyment as too subjective, far outside their influence. In addition, they lack methods to actually explore meaning of work in detail. However, only if an organisation is aware of which particular elements of work practices are satisfying can the impact of a novel technology on work truly be assessed. To give an example: Assume that informal exchanges between air traffic controllers and pilots via radio add to meaningful work, since they fulfil air traffic controllers' need for social exchange. In this sense, pilots become "co-workers" or part of the "team", and it is only natural to know their names, to make some light jokes and to wish them a good flight. Strictly speaking, this exchange is not "necessary" from an organisational point of view and could be automated or more heavily restricted. However, for the humans in the system this element of their work practice might fulfil an important psychological need, which strongly adds to their work satisfaction.

Designing for Well-Being

While it is good to scrutinise changes in the technological arrangements with regard to their impact on people's experience of work before actually introducing a new technology, it is better to pro-actively design technology with human experience in mind. An approach is Experience Design, often also called Design for Well-Being (Diefenbach & Hassenzahl, 2017; Hassenzahl, et al., 2013). In a nutshell, Design for Well-Being (DfW) starts from positive, that is, meaningful and/ or enjoyable, everyday experiences. Think for a second and try to remember a moment during the last week, when you enjoyed work and thought that it contributed to your personal growth. On a closer look, those moments will be linked to a small number of particular psychological needs. Humans experience joy and meaning in work, when they master a challenging task (need for competence); when they can make their own choices (autonomy); when they feel close to other people, they care about (relatedness); when they discover interesting and stimulating new things (stimulation); when they influence and inspire other people (popularity); when they have calming routines (security); or when they experience their body, feel healthy and agile (physicalness) (see figure).

Broaden the scope

Any technology inevitably shapes work practices. Its particular design facilitates particular ways of thinking and doing and obstructs others. Typically, technology design focuses on ways to make work more efficient, overlooking many other ways to improve work through technology. Organisations that care about their human capital and the health and well-being of their workforce should thus focus on the role of technology in increasing well-being. Take the workplace of air traffic controllers as an example: They almost entirely work through technology – they "see" through displays and perceive work through abstract representations of planes; they "act" through phones and radios. Any introduction of a new technology, be it automation, artificial intelligence or digital flight strips, will impact work and its meaning tremendously. A human-centred design of those technologies, which is sensitive towards the experiences, emotions and motives of the humans involved, can ensure that the technology will actually contribute to the well-being of the most crucial elements of a socio-technical systems: people.

Competence
"I'rn good in what I do"

Autonomy
"I can do what I want the way I want it"

Popularity
"I have impact on what others do"

Relatedness
"I feel close to the people I care about"

Security
"I'rn safe from threats and uncertainties"

Stimulation
"I was experiencing new activities"

Physicality
"That my body was getting just what it needed"

PRINCIPLE 1: JOINT DESIGN TEAMS

Build joint design teams and do not treat HF/E as a mandatory add-on

HF/E is often seen as something separate to design. Organisational and methodical conditions even reinforce this fragmentation.

Make HF/E an integral part of the design process instead of a mandatory add-on and let engineering and HF/E act as a joint team.

Although HF/E claims to be design driven and strives for an active role in ATM system design, HF/E is often treated as something separate. Usually, there are distinct HF/E departments, HF/E processes, HF/E assessments, and even separate HF/E requirements as if HF/E is just an addendum to the regular design work. This separation is maintained in the whole aviation industry but especially in ATC. Other industries do not pursue this separation between design and HF/E. Instead, HF/E experts are employed in the relevant unit, such as cockpit design at a car manufacturer. In this setting, HF/E experts, engineers and designers meet as equals in an interdisciplinary team.

Why did HF/E integration evolve differently in ATC? Probably because a close linkage of HF/E to safety has a long tradition. In a world where human error is perceived to be the main source of incidents, it makes perfect sense to maintain a separate organisational capacity that exclusively deals with this phenomenon. In this role, HF/E has the expertise to explain human error and to develop adequate prevention strategies for new systems and procedures. HF/E's role is to assess a given design with respect to the likelihood of human error occurring and to assess if potential human error may undermine safety in later operations. This perspective, however, is not in line with the idea of Safety-II, as it still understands safety as the absence of incidents. In consequence, HF/E is often reduced to a simple hazard analysis, with a focus on humans instead of technical components. Design units are likely to adopt this perspective and perceive HF/E as an additional item on the to-do list in order to receive HF/E blessing. However, one cannot expect others to accept HF/E as an integral part of design as long as the self-concept of HF/E in ATM remains caught in this perspective.

HF/E should rethink its role and clarify its nature in ATM: Does it actually want to be an integral part of design or is the task of HF/E more or less the evaluation of predefined technical descriptions? HF/E at least claims to take an action view and to be an active part of system design. A clear commitment to design is indispensable to be recognised as a key player for usable system design by other experts and departments.

Existing methods even facilitate the asymmetry between analysis and design. This is because HF/E methods rely very much on already finished "products" that can be evaluated in situ (in operation or at least in simulation environments). Essentially, HF/E methods collect either user feedback in one form or another, or they measure users' (involuntary) responses. Examples of the former are questionnaires, subjective workload assessments or scoring situation awareness. Examples of the latter are eye tracking, eye blink frequency or heartbeat irregularity.

The problem, of course, is that for a long time during a new development, there is no finished product to evaluate. Rather there is a great need for input in terms of requirements and implementation ideas long before a first prototype exists. HF/E falls short on methods that can be used before a prototype is available.

This limitation has a couple of implications.

- First, HF/E input is often handled and perceived as an afterthought. That means HF/E requirements or considerations are simply placed on top of existing requirements and concepts. This leads to additional effort for integration, or it might not be possible to integrate them at all. Within an organisation, HF therefore is seen more as a hindrance than as a contributor.
- Second, even if there are HF activities taking place early during a project, there is no defined interface between them and the typical engineering design and/or project management processes. This is true on the organisational level and the methodical level. Teams are not integrated and work separately with their own tools and, more importantly, worldviews and jargons.
- Third, HF requirements themselves are not usable from an engineering perspective. Most methods have a lot of explanatory power but lack the transfer into clear design implications. Requirements need to be (among many other qualities) specific and verifiable. Typically, HF requirements are not specific due to their link to HF/E concepts instead of engineering entities and are not verifiable either, or are only verifiable with the finished product. There are practically no modelling or simulation tools around that allow the checking of the impact on workload or situation awareness of competing concepts before implementation.

It is the task of HF/E science to overcome those methodical limitations. Salmon (2016) names several potential improvements for HF/E methods. Two proposals among others are that prospective ergonomic methods should, firstly, be based on system thinking and, secondly, directly inform design. He also points out that there remains a paucity of reliability and validity evidence for ergonomic methods: The extent to which some ergonomic methods actually work and thus are fit for purpose remains unclear. Shorrock & Williams (2016) identified accessibility constraints, usability constraints and contextual constraints as limiting factors for HF/E methods. They suggest a close linkage of HF/E methods to the user-centred design process in order to make methods fit for purpose.

ANSPs, as practitioners, on the other hand, need to make sure that HF/E is incorporated into the organisation and ATM development processes. Not as a mandatory add-on, but as an integral part of the overall design proposition.

Nevertheless, the question remains how HF/E could contribute if analysis and evaluation alone are not sufficient in ATM design. What could be a significant HF contribution from an engineering perspective? This whitepaper suggests promoting a coherent user-centred design rationale as a distinct HF product. Principle 2 will illustrate this idea in more detail.

PRINCIPLE 2: USER-CENTRED DESIGN RATIONALE

Make a coherent **user-centred-design rationale** your HF/E product

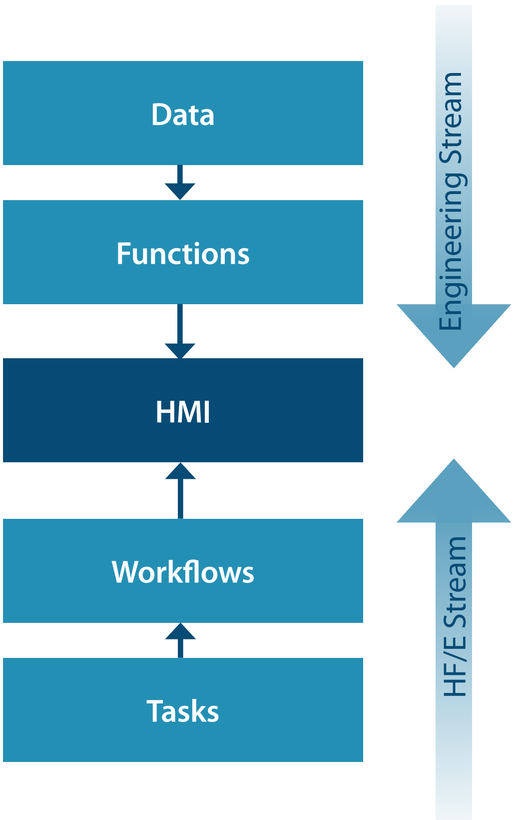
A clear user-centred rationale is often missing in ATM development. Today, system design mainly follows functional considerations.

Make a coherent user-centred design rationale your HF/E product that can be seamlessly integrated into early phases of the engineering process.

HF/E is design driven and therefore not limited to evaluation and analysis of existing workflows and systems, regardless of whether they are prototypical or already in operation. The question remains what HF/E can contribute to a product that does not yet exist. In the early stages of a design process, little is determined, leaving a lot of freedom to HF/E experts to incorporate their ideas and principles. But how? The lack of a clear-cut HF/E product makes a seamless integration into engineering processes difficult.

One such product could be to provide a design rationale from a user perspective. This rationale guides all concept development in early phases and can be used for all the trade-off studies and open questions during the ongoing development.

If we look at today's ATC workplaces, a clear user-centred design rationale is often missing. Usually it is rather unclear why a controller working position and its human-machine interface (HMI) look the way they do. The design mostly follows functional considerations, mainly from an engineering perspective: There is a certain amount of data in the system that needs to be conveyed to the user for manipulation. Consequently, there is a need for inputs to keep the software processes going. It is not that these data and inputs are displayed completely arbitrary; they just follow other (mostly technical) paradigms, which are not necessarily user centric. The result is an HMI that theoretically provides everything that is needed but does not reflect real workflows in practice. It hampers performance and may lead to potentially unsafe situations.



Who, if not HF/E experts could and should provide such a user-centred design rationale? Typically, any HF/E activity starts with a thorough examination of the underlying goals and tasks. Without a clear understanding of the underlying tasks, needs, constraints and strategies of the users, there is no way to achieve a match between the intentions of the users and the possibilities the software offers. This is what Don Norman (1986) describes as the gulf of execution. This is also true for the opposite direction, the gulf of evaluation: How well is the system state represented and does it fit the mental model the user has of the system and its processes?

In this role, HF/E prepares, discusses and evaluates different design alternatives and interaction modes through the application of a user-centred design process. Furthermore, HF/E experts ensure the adherence to design standards and best practices in order to avoid the use of (too many) colours, small-sized fonts, low contrasts and to prevent high information densities and inconsistencies between different displays, etc.

Engineering and HF/E may perfectly complement each other. Although they come from different directions (feasibility vs. usability), they both target the HMI as the final product for the end user. Therefore, both streams should not work independently from each other. What matters is that both streams are well integrated (see principle 1). A coherent user-centred design rationale then develops its full potential.

PRINCIPLE 3: USER-CENTRED DESIGN PROCESS

Strive for a short, iterative user-centred design process

Complexity in ATM makes it impossible to get a system design right the first time. Linear design processes make it more difficult to revise misconceptions and to implement changes.

Strive for a short, iterative user-centred design process that gives you room to adapt. Integrate this approach into your existing processes, even though they are supposedly linear.

The previous principle suggested a user-centred design rationale as a specific HF/E outcome within ATM design. This chapter proposes the user-centred design process as a suitable approach for its development.

Typically, ATM deals with particularly long-term strategies and plans. There are system roadmaps laid out for years, sometimes decades. These are necessarily linear in nature, for example, which feature comes after which enabler. When this is broken down into the implementation projects, the linearity is kept. The typical project management plan deals with a string of milestones with few parallel phases. This is supposed to keep the risks low, as there are only few interactions between the phases. The archetypical product/software development process, the waterfall model, follows the same pattern. Nevertheless, there are some major drawbacks.

Most of the time, the product has to be fully specified in order to commence the implementation phase. The implementation phase ends with an almost complete product, which is then tested against the requirements. After that, there will be user tests (at best) before training and introduction. Unfortunately, experience shows again and again that the specification is never fully right and complete. Sometimes it was built on wrong premises. Experience also shows that truly fixing this is staggeringly expensive and in the worst case impossible (cf. Alexander & Albin, 1999). The product is already there and was designed and built with a lot of effort, after all.

In complex systems such as ATM, it is impossible to identify every possible situation and circumstance upfront. Thus, a certain amount of information is necessarily overlooked during the concept and planning phases and often during development. The surprises – unexpected situations, unexpected behaviours, unexpected side effects and interrelations – only come to the surface during transition and operational use. With linear approaches, it is almost impossible to react then, because the requirements and implementation phase are long over. Flexibility is lost very early when complexity is still low.

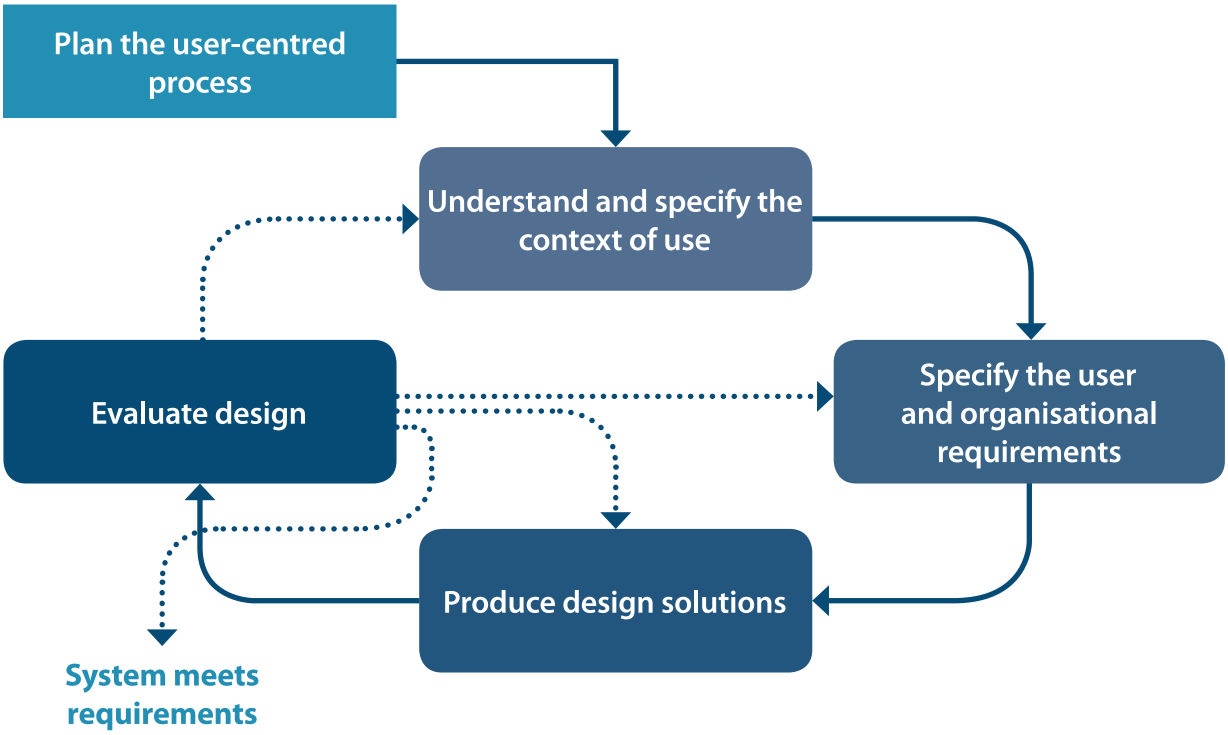
HF/E acknowledges this reality of complexity and emergence. That is why established HF/E processes such as user-centred design (DIN EN ISO 9241-210, 2010) are highly iterative. Since you cannot know everything in the beginning, you base the design on what you know, implement it via rapid prototyping, and evaluate it. Do this several times until you have learned enough to be confident that there are only minor surprises left.

At its core, it is a flexible, highly iterative process. It consists of four main phases as shown in the figure below, which are run through repeatedly until the product satisfies the needs.

At first glance, a linear project management and an iterative design might seem mutually exclusive. Yet, there is no fundamental incompatibility. Several iterations can be planned into the classical project phases. However, this has to be done during the proposal phase. Otherwise, the necessary resources (such as software programmers for early concept prototypes) will not be available in the early project phases.

User-centred design should not be confused with agile methods of software development, such as SCRUM. Some characteristics are similar (strong focus on iterations and user involvement), others are not. A core element of most agile methods is to quickly implement isolated features of the software to operationalise and review them with users. On the surface, this sound like the user-centred design idea, but there is no mechanism to ensure the big picture, with all features combined, actually makes sense in the end. The HF/E design rationale and concepts have to be defined to a degree of certainty before the actual implementation of features starts. The similarities, however, make it easy to reconcile user-centred design and agile methods if the respective strengths and weaknesses are acknowledged.

User-centred design process according to DIN EN ISO 9241-210



PRINCIPLE 4: OBJECTIVE HF/E CRITERIA

Derive objective HF/E criteria instead of relying on user opinions.

Opinions and anecdotes are not an adequate basis for professional system design, because they tell us little about underlying needs and mechanisms.

Translate user feedback into meaningful requirements and validate with the help of objective measures, which can be found within HF/E, but also other disciplines.

When developing a new product, system or interface under the user-centred design process, one has to determine how to involve users. This is can become a delicate matter. Type and extent of involvement significantly impact the final product, efforts and costs.

The easy way out is to pass on the responsibility for fixing the front-end design to the controllers themselves, since "they know best". While this statement holds some truth, it is a grotesque distortion of the idea of user-centred design. In short, user-centred design strives for user integration into the design process but in a structured manner with clearly defined roles. Although controllers are experts in their field, they lack knowledge about engineering design, requirements elicitation and the state of the art in terms of interface and workplace design. The resulting products tend to be overly conservative and more of the same – most often reproductions of the current system with a slightly different look and labels.

A second misleading approach is to ask about user opinions ("how do you like it"). Opinions are highly volatile. Involving different groups of users at different times during the development might lead to completely different views on supposed "facts". All in all, opinions and anecdotes are barely adequate for professional system design.

The elicitation of user opinions originally comes with good intentions: An incorporation of user opinions into design is supposed to increase controllers' acceptance. Controllers' acceptance, however, can become a misleading criterion, especially if it is purely opinion based. There is a fundamental difference between a professional domain, such as ATC, and consumer products. Websites and apps face a lot of competition and the users are free to choose those they like best. Ease of use and joy of use may trump functional scope and sophistication. Safety, reliability and productivity are not the main concerns. The opposite is true in a work domain, especially in ATC. Any software here has to provide a specific set of crucial functionalities in a reliable way to enable the controllers to handle traffic in a safe and efficient manner.

In short: Users can tell the HF/E experts what they think they want but rarely what they actually need.

It does not mean that one should avoid users' opinions completely. Opinions can be a suitable starting point. However, they should be treated as symptoms of underlying needs and mechanisms. What helps in digging for the actual needs and mechanisms is translating all the user input into objective constructs and criteria. These can be used during an engineering approach that relies on measurable, quantifiable requirements. The two examples below illustrate this idea.

The translation of user feedback into HF/E design criteria is difficult. It requires broad knowledge, not only about the state of the art of the scientific research in the own discipline but also in related fields. If HF/E wants to contribute meaningful requirements for design, it needs to interlink with other disciplines and adapt existing methodologies into the HF/E toolbox. The challenge is to make the connection. Inter-disciplinarity has always been a key virtue of HF/E.

Example 1: rework of colour set on radar screen

Problem symptom:
From incident investigations, there were indications that controllers were overlooking certain targets on the radar screen. The controllers themselves demanded more and more vibrant colours for certain states (warnings, alerts). They were very vocal about the need for more highlights and visual cues.

Problem-setting:
There were a large number of different warnings and alerts. Analysis showed that there was no concept behind the selection of colours. Additional colours had been added based on controller suggestions. There were large discrepancies in colour reproduction between screens. A complete redesign of the colour set was necessary.

HF/E construct(s):
In order to come up with a new colour set, the habit of suggesting and discussing colours needed to be broken. Instead, only the function of the colour-coded items and their relative priorities were discussed. This led to an ordered list of items. With some additional comparisons, this list was amended based on their relative importance ("distances" between the entries). Based on recommendations from HF/E literature, this list was divided into groups that justified the use of different information coding options – not only colours. The construct used to actually assign colours to the remaining items was the CIELUV colour space (Schanda, 2007). This 3D representation of colours is meant to have perceptual uniformity, i.e. the Euclidian distance of colours in the colour space represents the contrast as perceived by humans (Schader, Perott, Heister, Leonhardt, & Bruder, 2012). Working from the starting point that the STCA alert (short-term conflict alert) should have the largest contrast to the background colour, the relative importance could be mapped to the Euclidian distances. This resulted in colours that represented the required visual prominence of the colour-coded states.

Conclusion:
Instead of discussing colours, the importance of the colour-coded items was established. This importance could be mapped to contrasts, which led to a colour set accurately representing the items' importance, thus fulfilling the users' needs. The discussion was shifted away from a design solution to needs and an adequate, objective construct (colour space) was used to come up with the colour set.

Example 2: acoustic optimisation of control room

Problem symptom:
Controllers complained about high noise levels in the control room. They maintained they understood the conversations of other controllers in the distance better than the conversations of their own neighbouring coordination partners. After some measurements, several local measures were taken with dubious results.

Problem-setting:
A new control room was being built and the acoustics were to be optimised. The conditions were supposedly going to be quieter thanks to modern air-conditioning and the lower thermal loads of the computers. It was unclear what the ultimate perception of the controllers would be if the problems were solved and whether optimisations were necessary.

HF/E construct(s):
Prototypically, reverberation time and sound pressure levels (SPL) are the fundamental constructs for the acoustic design of rooms used by engineers. However, they did not capture the problems described. Research yielded another psycho-acoustic construct, the speech transmission index (STI). It describes how well speech is intelligible. As such, it was the measurement of choice. Controller input was utilised to understand the communication needs (who talks with whom) and to define scenarios, i.e. which working positions are staffed during daytime peaks and during night-time lows. SPLs of typical controller conversations were measured. With all these variables known, simulations of the room and the resulting STIs for the different scenarios could be run. The result was a STI map of the room representing which working position was audible for which working position. Corrective actions could be taken.

Conclusion:
Instead of relying on conventional engineering constructs and reworks after the initial operational use of the control room, literature research led to a new psycho-acoustic construct. This enabled the connection of the subjective impressions of the controllers with measurable physical quantities. Controller input was used to generate requirements and simulation scenarios. Potential areas of optimisation could be identified.

PRINCIPLE 5: PROTOTYPING

Evaluate as early as possible with the help of prototypes.

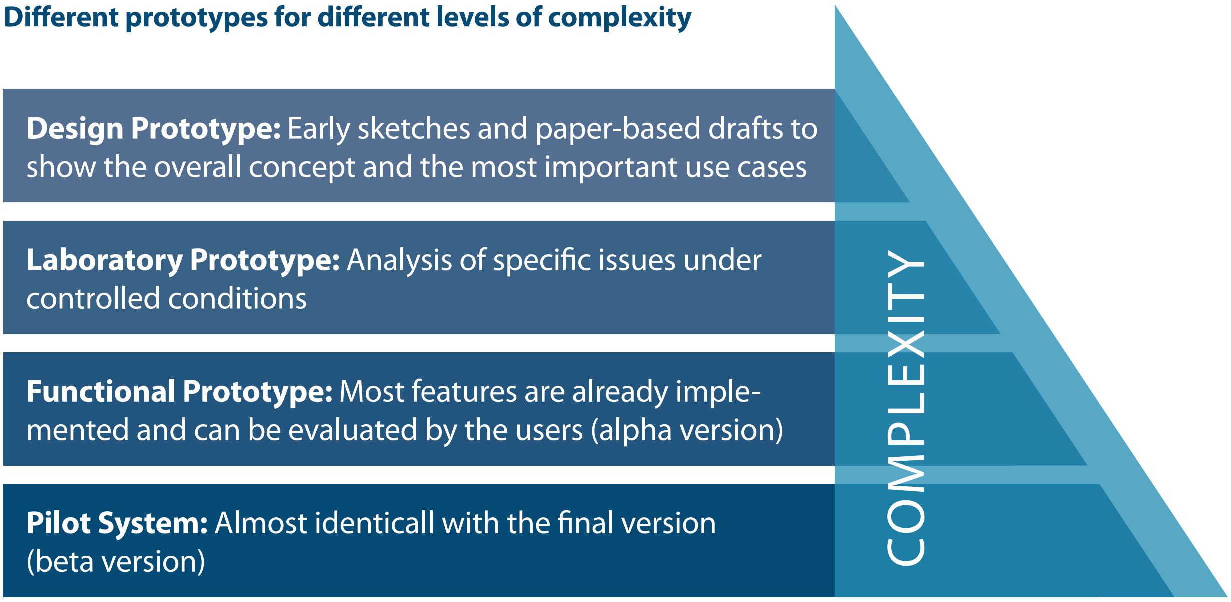
Design projects start with limitless possibilities but little knowledge about the context of use. When finished, the context of use is very well known, but changes come at high-cost.

Evaluate as early as possible with the help of prototypes, which range from pen & paper to beta versions to overcome this dilemma.

One key feature of iterative user-centred design is that each cycle yields a product: the design solution. Experts and users alike can evaluate the product to determine whether and to what degree the requirements are fulfilled. Under realistic circumstances, this is never the case during the first iteration. However, it also should not be the goal. Instead, the iterative approach should be fully embraced. That means features and functionality should be introduced gradually during multiple cycles. This way, complexity can be increased in a controlled fashion. Any mistake can be fixed before it becomes too entangled with other aspects of the product. Dead ends can also be identified early and the development can take another direction without severe loss of time and budget.

We call these early and intermediate design solutions prototypes. They are somewhat different from a prototype in a typical industrial setting. There, prototypes are almost ready for production and thus almost the final "thing". They are expensive to produce and thus hard to change or even reject. As such, they produce lock-in effects. The project is bound to specific decisions. Even though ATM systems are mostly software, the same thing happens in ANSPs. After the requirements phase, a demonstrator or alpha version is programmed. Most often, this takes so long that there is no room for substantial changes even when they are necessary. This leads to workarounds and training issues.

Different prototypes for different levels of complexity



For our purpose, prototypes can take many forms and evolve together with the design solution they represent.

In the beginning, they might represent initial concepts without much need for form or finesse. Here, it is easiest to use pen & paper methods. Such prototypes are easy to produce and modify (even during user workshops) and are cheap and disposable. Since it is easy to modify this kind of prototype, as many use cases as possible should be considered and tested. It can also be worthwhile to develop multiple different solutions and compare them at this stage. The most viable variants should then be transferred into a digital format for easier reference.

Once there is enough trust in the viability of the overall concept, the specifics have to be fleshed out. When developing a user interface, this would be the time to start using a dedicated rapid prototyping tool. This allows for a more realistic representation and some interactivity while retaining flexibility for rapid changes. Accordingly, cycles can be kept short and there is still enough room to explore different options. However, one should keep in mind that the conditions under which this kind of prototype is evaluated remain idealised and controlled. It might not run on the same hardware at the real workplace (which might not exist yet). This means not all possible side effects and influences can be seen during tests. At best, the influences are known from the context-of-use analysis and their impact can be estimated.

Depending on the prototyping software and how the final interface is to be implemented, it might be necessary to switch the prototyping environment to something that offers more interaction opportunities or can mimic some limited backend operation. This can be useful to evaluate more sophisticated workflows that involve more operations or coordination between different people.

The resulting final prototype should represent the design and behaviour of the product. This is why it can actually be used in addition to, or even to replace, written specifications. The software engineers can refer to the prototype to develop a better understanding for the product.

PRINCIPLE 6: CONDITIONS FOR EVALUATING PROTOTYPES

Select appropriate conditions for evaluation: Evaluate day-to-day operations as well as critical situations.

Usually, prototypes are tested under "lab" non-operational conditions to prove the concept and the potential rise in capacity. Equally important, however, is to demonstrate robust system performance under degraded conditions.

Evaluate day-to-day operations as well as critical situations

While principle 5 suggested the usage of prototypes in general, this section discusses the conditions under which these prototypes should be tested.

Usually, prototypes are tested under "lab" non-operational conditions to validate new functions but also to demonstrate a rise in capacity to management and the project sponsor. This is absolutely reasonable, as every system design is an investment for the company. Therefore, the project should demonstrate that anticipated and actual benefits match. This is often done with a normal traffic volume where standard procedures apply, when all systems are working properly and when all positions are staffed. Under such conditions, it is relatively easy to demonstrate almost anything.

Actually, the real world is far from idealised. The main question for HF/E is: Is the system still able to put those anticipated benefits into effect, once confronted with the ruthless complexity that we experience in day-to-day operations? Therefore, prototypes should also be tested under abnormal conditions like extreme (high or low) workload, emergency situations, system failures and short-staffed situations.

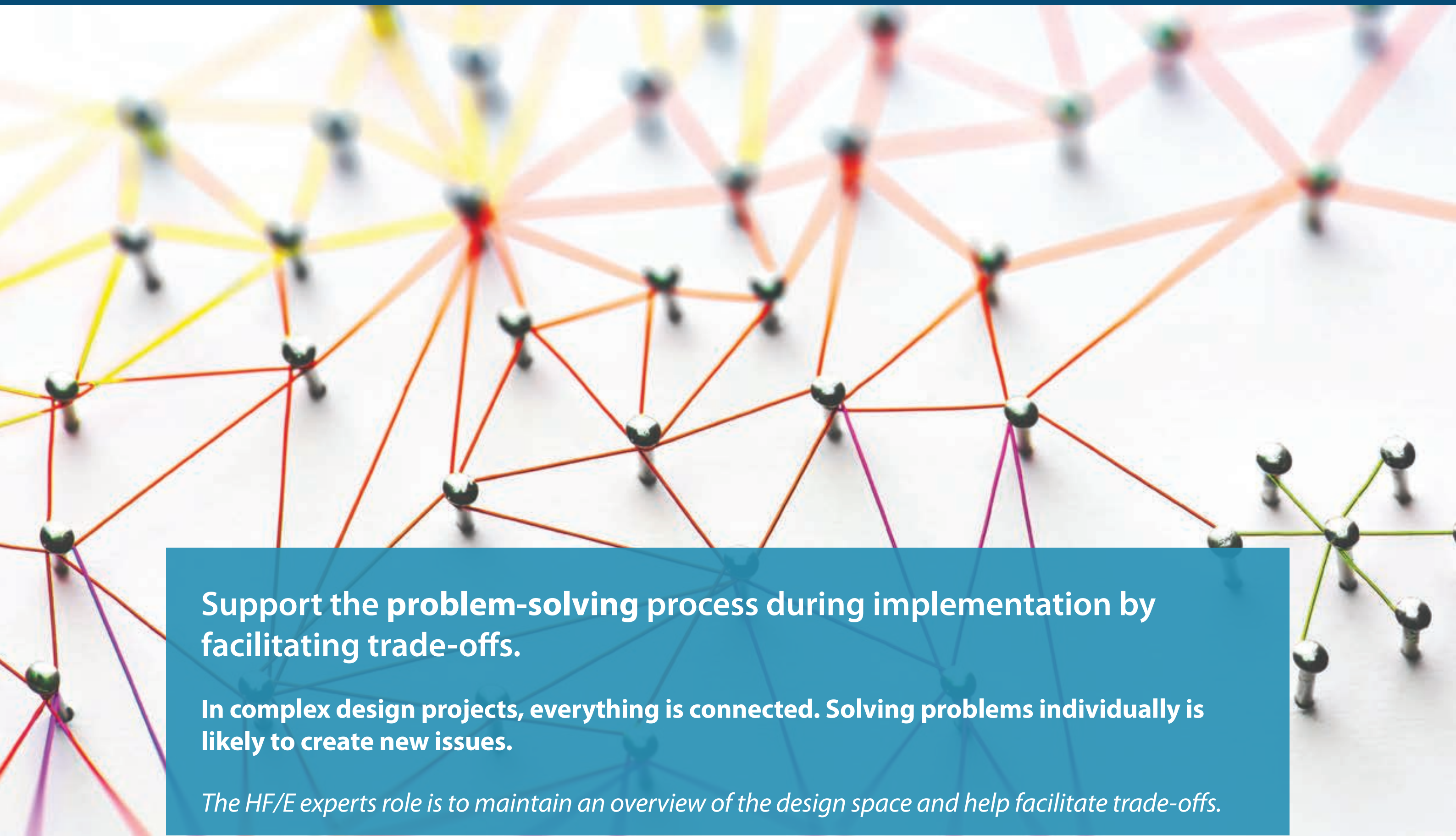
However, a test under degraded mode or abnormal operations should not be conducted under a safety case perspective, i.e. to identify what might go wrong. It is far more interesting to see how controllers adapt in these situations and how they are able to manage the growing complexity with the help of the system. What mechanism and strategies do controllers apply? Which redundancies are most important? Which workarounds become crucial? Does the system support or impede these workarounds? The system should provide enough resilience to gracefully extend the performance and safety boundary. Vice versa, the system should not act as if still in normal operation by enforcing workflows or delivering information that are not valid in exceptional situations.

Even under normal conditions, a design only works well if it allows the operators to continually adjust what they are doing to fit the situation (work-as-done). Unfortunately, the workflows implemented in the system often have a tendency to emphasises work as it should be done (work-as-imagined). Problems arise if there is a mismatch between work-as-done and work-as-imagined (cf. Hollnagel, 2014). An evaluation under varying conditions can help to make these human adaptations visible and identify possible gaps between work-as-imagined and work-as-done. These findings are very valuable for system design because they enable the system design to support the operators in situations where they need it the most: in high workload situations, with lots of uncertainty, exceptional situations and degraded system support.

Characteristics of normal and abnormal operation modes

Normal operation	Abnormal operation / degraded mode
• Normal amount of traffic	• Working under extreme (high or low) workload
• Standard procedures apply	• Emergencies and exceptional situations
• All systems are working properly	• Failure of primary and secondary systems
• All positions are staffed	• Working under production pressure and short-staffed situations

PRINCIPLE 7: PROBLEM-SOLVING



Support the problem-solving process during implementation by facilitating trade-offs.

In complex design projects, everything is connected. Solving problems individually is likely to create new issues.

The HF/E experts role is to maintain an overview of the design space and help facilitate trade-offs.

The design of ATM systems is a complex undertaking with many interdependencies. Almost every design element has influence on at least one other. This is not a problem per se, but these interdependencies need to be acknowledged and managed. The required expertise in all the design areas is usually not concentrated at one point but scattered throughout the organisation. Because of this, there is a danger that business units work in isolation from each other and adopt the solution that reflects their viewpoint and boundaries. The sum of these adaptations, however, is highly likely to not be optimal for a controller working position as a whole.

It might occasionally happen that people synchronise beyond their boundaries in order to build a coherent user experience. Unfortunately, that is not the norm.

This lack of synchronisation occurs when the organisation is in *problem-solving* mode. Problem-solving usually refers to a specific issue that emerges unexpectedly (such as incidents). These issues often occur in projects at short notice and in the late stages, for example when users are involved during an evaluation. Typical examples are poor user experience, insufficient font sizes and an inconsistent usage of colours. HF/E experts are then called into the project and requested to address the problem identified.

In order to break the cycle of mal-adaptation and creation of new issues, HF/E experts have to have two key competences:

the ability to withstand the urge to quickly "solve" the alleged singular issue and the ability to create an overview of which design elements influence the one currently in focus and which are influenced by it.

Thus, the role of HF/E experts is to define achievable goals and to find a possible solution given the project's boundaries, such as budget, time or technological limitations. Other experts in the project are loyal to their specific professional ethos as well, which requires HF/E experts to coordinate among different domains. The outcome is frequently a compromise that at least does not contradict any professional convictions.

HF/E could make a significant contribution for organisations that are in a problem-solving mode by embracing the systems approach and putting it into action. The challenge is to withstand the quick fix, take a holistic perspective and mediate among different disciplines, issues and requirements. In this role, HF/E acts as a mediator within an organisation, weighs different requirements from different departments against each other and facilitates trade-offs. Furthermore, HF/E is able to recognise incoherencies in the overall user experience caused by fragmented problem-solving before consequences emerge.

PRINCIPLE 8: PROBLEM-SETTING

Do a proper problem-setting in the first place whenever possible to understand your actual problem and the underlying mechanisms and needs.

HF/E regularly acts as a problem-solver. In most cases, it also makes sense to draw a bigger picture and question the purpose of a given development.

HF/E should emancipate for strategic decisions and constantly refine the problem-setting: What problem are we going to solve from user perspective?

For sensible problem-solving, taking a step back and looking at the entire design space with its interdependencies is the way to go. This view is still quite narrow, as it is focused on that one specific problem. Whenever possible, one should ask: For what are we doing this? What is the underlying goal the system should achieve?

Therefore, HF/E in design should act on an additional level: problem-setting.

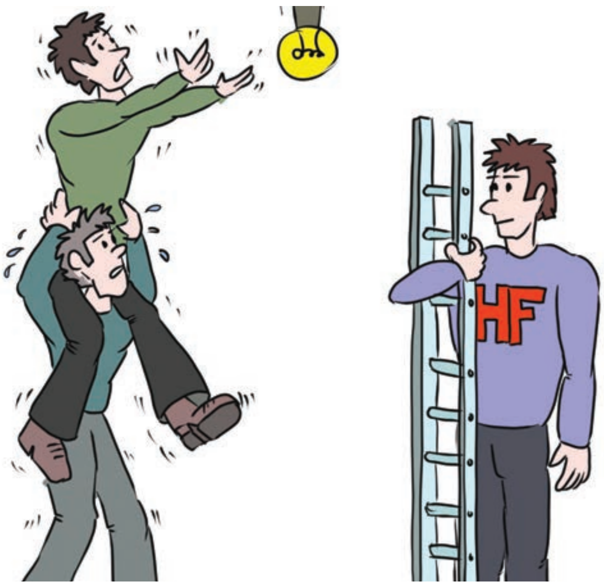
Problem-setting happens on a strategic level, as it does not define the achievable, but the desired goals of HF/E within a project or organisation (cf. Béguin, 2011). It draws the "big picture" and affects the overall design strategy. In problem-setting, HF/E actively manages the coherence of system requirements, instead of just coordinating several interdependencies to facilitate a feasible compromise as in problem-solving.

Characteristics of problem-setting & problem-solving (cf. Béguin, 2011)

Setting	Solving
• Task for a strategic HF/E	• Task for an operational HF /E
• Define desirable goals • Define a design strategy • Decide on analysis and diagnosis • Coherence of requirements • Project planning	• Define achievable goals • Searching the best solutions given the constraints (budget, time, human) • Coordinate interdependences • Requires specific knowledge about HF/E in design
• Confrontation between required HF/E quality in ATM system and deadlines & cost criteria	• HF/E as integral part of the project

Today, the technical side of the work system is often designed first, whereas the human side is identified later and mitigated. However, solid and structured problem-solving requires a solid foundation in the first place as guidance. Relevant non-technical questions are:

- Which (HF/E) problem are we going to solve?
- What is our mechanism to achieve more capacity and efficiency?
- What are the bottleneck in today's work that we want to address?
- Do we need to consider other aspects such as teamwork, procedures, current role models, training, or personnel selection?
- What analysis and which methods do we need to carry out in order to answer these questions?



The development of a proper problem-setting inevitably leads to the involvement of the operators and the analysis of their primary task, performance goals and working environment. This, in turn, is crucial for design and technical decisions during the problem-solving process. Without problem-setting, problem-solving is lost in the woods and stuck in trial and error.

Often, however, HF/E is constrained in a way that problem-setting just doesn't seem reasonable. Instead, it is worthwhile to pick the low hanging fruit in a problem-solving process and treat the urgent symptoms first. Especially in a rather sceptical environment towards HF/E it makes sense to convince project owners with practical solutions before returning with a problem-setting proposal. Problem-setting and problem-solving are closely connected anyway: During problem-solving you learn about your problem-setting (e.g. whether you asked the right questions) or vice versa: Once you develop a proper problem-setting you might recognise, that best practices for problem-solving from the past just make no sense anymore.

With proper problem-setting, HF/E has the potential to integrate different disciplines by providing a coherent view and thus design objective. Overall system performance and human well-being are well suited for treating conflicting goals and facilitating trade-off discussions, as they allow a qualitative discourse beyond schedule and costs.

PRINCIPLE 9: PURPOSE-ORIENTATED VIEW OF NEW TECHNOLOGY

Be ready to participate in strategic decisions and introduce a purpose-orientated view of technology

Technology is often perceived as increasing productivity and efficiency without further investment. In complex systems like ATM, however, the anticipated benefits are easily hijacked by complexity. As a result, the realised benefits fall short of expectations.

Confidence in technology does not makes a strategy. It is task of HF/E to introduce a purpose-orientated view of new technology and to describe the mechanisms for an increase in system performance and well-being.

Traditionally, there is a strong focus on technology as a lever for more productivity and efficiency. Historically, this is understandable. Technological advancements on the ground and in the cockpit led to massive increases in safety and capacity in air travel. Primary and secondary radar, ground proximity warnings, traffic alerts and collision avoidance are only a few of these remarkable feats of engineering. For these, the benefits were self-explanatory and almost immediate. This led to the notion that the introduction of more technology would always be beneficial, as if it was an end in itself. "Tech" is perceived as increasing safety or capacity without any further investment – you just have to introduce it. Hardly surprising, there are many ideas and concepts floating around that follow this worldview: multi-touch, speech recognition, augmented reality, etc.

Simulations further bolster this almost magical thinking. It has become relatively easy to demonstrate desirable results using laboratory studies and rapid prototyping, provided you can idealise the context just enough to avoid the pitfalls of real-life complexity.

Alternatively, as Doyle & Alderson put it: "Computer-based simulation and rapid prototyping tools are now broadly available and powerful enough that it is relatively easy to demonstrate almost anything, provided that conditions are made sufficiently idealised. However, the real world is typically far from idealised, and thus a system must have enough robustness in order to close the gap between demonstration and the real thing" (quoted in Woods, 2016).

In operational use, more often than not the anticipated benefits from new technology never come at all. At best, they emerge whenever the real situation is actually like the idealised laboratory setting for a limited amount of time. However, most of the time, it is not – there are numerous quirks and workarounds in the current system that were not considered in the design. Situations are not as described in procedures and checklists. People use artefacts very differently from their intended purpose. New behaviours and unforeseen consequences emerge and undermine the anticipated benefits ("Artefacts shape cognition" (Woods, 1998)). In the end, controllers might even feel misunderstood and perceive the new features as a waste of resources, which then is projected negatively onto the organisation.

It is essential to close the gap between demonstration and "the real thing". Technology alone cannot guarantee gains in safety or capacity. There has to be a very good understanding of how the work is actually carried out by the operators in the real world. Technology and the people using it form a joint cognitive system (cf. Woods & Hollnagel, 2006) with its cognition being situated, meaning it can only be understood and replicated in situ – not in the laboratory.

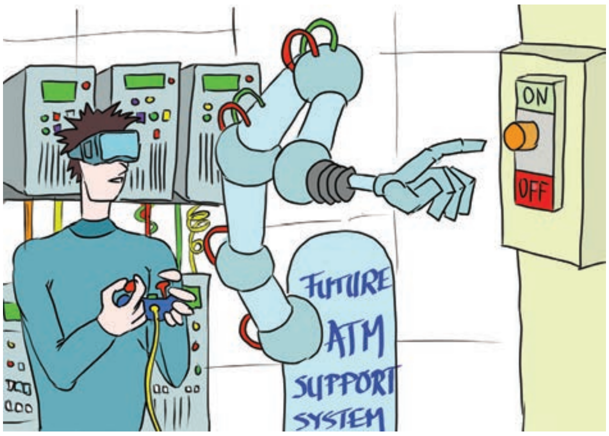
Management is under pressure to react to the emergence of new technologies and approaches. In order to achieve supposed competitive advantages, it seems appealing to implement new technologies as fast as possible. However, there is no such a thing as a free lunch. Technology is likely to create new problems that lead to additional effort and costs that exceed the original budget by far in the long term. Therefore, new technologies cannot be implemented without further investment in HF/E.

Organisations should exercise caution from temptation to quickly jumping on new technologies because they are fashionable and a strategic decision should be taken after sound consideration of further HF/E considerations.

This may even be the case if previous concept studies proved the high potential of certain technologies in the first place. The actual challenge is not to be the fastest but to make technology work in a complex system. The first organisation that implements well-elaborated and balanced automation that works in a complex environment will be the actual global leader in technology. This, however, requires a paradigm shift that goes beyond a pure technology-centred perspective.

It is not new technologies that should be the focus of ATM strategies. Instead, a deep understanding of current operations, bottlenecks, inefficiencies and latent potentials should be the starting point for strategic considerations. A comprehensive description of operational drivers for safety, capacity and efficiency as well as an honest description of organisational weaknesses help to achieve the best fit between real operations and new technologies. Then, strategic considerations do not just focus on new technologies, but on the operational purpose of technology. A definition of purpose finally becomes a management tool that helps to select the right pieces of technology out of thousands of potentially misleading possibilities.

Therefore, HF/E should be a careful advisor whenever problems are intended to be solved by more technology. Do we really understand the underlying mechanisms in the system? Are there other ways to do it? A purpose-orientated view helps to facilitate the implementation of more automation and new technologies. In addition, it avoids unwanted consequences, including skyrocketing costs, due to an improper implementation.



NEXT STEPS

This white paper takes an optimistic stance on the role and prospects of HF/E integration into system design in ATM. The application of the principles may serve as a starting point to tackle current challenges and close the gap. It is up to the reader to determine how exactly those principles should be implemented. Nevertheless, it is possible to give some general suggestions for ANSPs as well as for the scientific community.

Suggestions for ANSPs

All the European ANSPs face the same fundamental challenge of how to cope with increasing traffic with fewer people in an ever more competitive environment. Operational complexity is reaching new heights and so are the promises of technology and automation. In the process of the ensuing changes, safety must not be compromised.

The nine principles offer some answers to the question of how to approach this. The key message is that HF/E can contribute significantly under the right circumstances. Four implications for immediate action are suggested for ANSPs:

1. The ANSPs have to take the idea of **safety by design** seriously. This is a logical consequence of Safety-II and System thinking. The makeup of each ANSP as a socio-technical system enables or prevents the adaptations necessary for an acceptable performance under ever changing conditions. To contribute actively to system design, HF/E departments have to change their roles from risk mitigators (for human error) to safety designers. They need to change from being critics of others to becoming designers of tasks, roles, circumstances, and technology, themselves. This implies becoming more involved in decisions on different levels, from strategy to concrete engineering. With this comes much bigger responsibility and the potential for contributing by providing a cohesive user-centred design rationale, which is missing today. HF/E departments of ANSPs need to question whether they actually want to become a decisive, integral part of ATM development or just evaluate predefined technical descriptions. A clear commitment to design is indispensable.

2. The **interface between HF/E and systems engineering needs to be defined** by elaborating ways of cooperation and the exact division of labour. There could still be a separate HF/E department but with full integration of its members on a project-based level. Another possibility is merging HF/E together with other areas into one or more new departments that are responsible for development on different abstraction levels, such as concept development and interface development. Whatever the organisational structure, the tasks of problem-setting and problem-solving need to be adequately addressed. Knowledge transfer between the individual HF/E experts has to be ensured. The blurring of traditional HF/E and engineering is desirable when working on concrete tasks, but overall the unique worldview of HF/E must not get lost and problem-setting should be established on a regular basis to synchronise among different projects and propositions.

3. A successful integration of HF/E in design is difficult with today's processes. They need to change, as does the attitude that comes with them. As long as there is a technological core and then the mitigation of some Human Factors along the way, it will not be possible. **User-centred design** has to become the standard practice. It changes the perspective on design as it puts the users and their needs in the focus. The question becomes what the design projects are actually trying to achieve on a system level, with the technological means as a way to get there. This requires a different approach to project management. Space has to be created for various iterations and the phases and milestones have to be planned more flexibly. Users have to be available throughout for evaluations, which is a wise investment but not easy to achieve when only a few controllers are available.

4. Fourthly, the systems approach should be utilised for **strategic management decisions** and the assessment of new technologies. HF/E is able to contribute a deep understanding of current operations by identifying bottlenecks and mechanisms, e.g. for capacity growth, by analysing the entire socio-technical system. This may happen independently of specific technologies. Based on that, a purpose-orientated perspective on technology can be introduced, which helps to select the alternative out of many possibilities that fits operational conditions best. For this, HF/E needs to be fit to participate in strategic decisions and to take responsibility for a smooth human-machine-integration; not just to ensure an improvement in system performance, but also to actively manage human well-being so that the resulting work and environment will keep an attractive and meaningful character even with more automation.

Suggestions for the scientific community

Practice and research are closely related in HF/E. It is the latter's task to provide new insights, data, and methods to inform design in practice in order to optimise the overall system performance and human well-being. There have been numerous publications bemoaning the theory-practice gap (e.g. Chung & Shorrock, 2011; Buckle, 2011; Salmon, 2016; Shorrock & Williams, 2016). This whitepaper further verifies this gap and suggests six implications for the scientific community based on the previously described principles.

1. Even though HF/E claims to be design driven, there is a **lack of adequate design methods**. Traditionally, there is a strong focus on fundamental research and associated methods for analysis but only little is available that actually help practitioners to design workplaces in complex environments. User-centred design forms a solid foundation but there is a lack of proven methods to actually flesh out two of its four phases, namely requirements specification and the production of design solutions. Since these are part of any product development process and thus well established, HF/E has to either provide its own interpretation that can be adopted by the other stakeholders in a design project or specify how the existing ways need to be complemented. Additionally, the transfer between different stages within a user-centred design does not work seamlessly. The difficulty often is not to outline a fist design but to maintain a coherent user-centred design rationale through the whole development. Therefore, the transfer between the phases of a user-centred development is by far more challenging than the actual work within each phase. Methods are needed that help to commute between these phases and bring them in coherence with each other. For example, this includes the question how to convert the results of a task analysis (as part of a context of use analysis) into subsequent user requirements.

2. Especially delicate is the question of **how to integrate users** in a sensible manner. General approaches like questionnaires, interviews or observations might be appropriate but are not structurally embedded in the user-centred design framework. Therefore, there is the risk that user involvement in practice becomes arbitrary concerning when to ask, whom to ask, what to ask and how to ask. As a result, HF/E input is shrugged off as "feel good" measures because of the impression it only passes on users' unfounded wishes concerning workplace design. Actually, user opinions should only be a starting point and need to be substantiated. Some methods already address rather objective measures like the operators workload or situational awareness. In practice, however, it is difficult to transfer these findings into meaningful system requirements that can

be engineered eventually. Although the methods may have explanatory power (detailing why a certain solution is good or bad), they clearly lack specific design implications. It is up to the scientific community to provide adequate methods that steer user integration within a user-centred design and are able to affect the engineering process effectively.

3. Air Traffic Control happens in a complex environment. HF/E should acknowledge this complexity by following a **systems approach**. However, it remains unclear for practitioners how exactly a systems approach will be applied, which premises it follows and how it can be incorporated into design. Specifically, more research and methods are needed that enable organisations to actively manage complexity and interdependencies.

4. The objective of HF/E is to optimize overall system performance **and human well-being**. While it is relatively easy to demonstrate a rise in performance, human well-being remains difficult to operationalize. It becomes even more difficult, if the interest of HF/E goes beyond the prevention of physical harm and occupational healthcare. Newer approaches, that put the overall human-experience in the centre, seem more appealing with respect to design. More research is needed on how technology affects meaningful work or, even more interesting, how meaningful work can be shaped by design. HF/E should be committed to both objectives: Human well-being and overall system performance. For this, a better-suited concept for human well-being is urgently needed, which is able to compete with system performance as the dominant objective.

5. **Resilience Engineering** and **Safety II** are becoming more and more popular. They are especially attractive for system design, as they recognize safety as something that can be actively shaped. Human adaptability are seen as a main resource of safe systems. More effort needs to be spent on the question, how adaptability can be incorporated in the development of new systems. While the theoretical frameworks deliver the necessary foundation, more work is needed to transfer these ideas into practice.

6. Another problem of HF/E seems to be the multitude of **rival schools** of thought, such as: cognitive systems engineering, ecological interface design, computer-human interaction, computer supported cooperative work and many more that descend from different source disciplines, such as psychology, engineering, computer science or economics. On taking a step back, they are all concerned with the same thing, namely understanding and designing socio-technical systems, albeit with different key interests. Still, the wheel is being reinvented over and over again, as the disciplines do not necessarily interact. A separation starts during the education of HF/E experts, already. Although it depends on the academic traditions of the country of origin, HF/E courses, for example, originate mostly in psychology. This leads to an overrepresentation of cognitive aspects combined with a worldview focused on analysing and explaining. Actually applying what has been learned to produce something, be it a more abstract work process or a concrete interface, rarely happens. As regards interfaces, UX designers fill the gap. They are very good at aesthetics but lack a scientific foundation. This may work for the web, but fails for complex environments like ATM. A simple way forward would be to detach education from its historic origins (e.g. psychology and HF/E) and fuse the relevant areas of psychology, engineering, and industrial design to create a new interdisciplinary curriculum.

INSIGHTS FROM DIFFERENT DOMAINS

Even though no technology should be put into use "just because", the latest developments in mobile technology and augmented reality offer fascinating possibilities. Prof. Kluge provides insight into the current research of when and how to use these advances to empower the operator to become the "conductor" of industrial processes. To facilitate this, she proposes methods to analyse the work system as a whole and the implications on the cognition of the operators.

The Augmented Operator, Digital Assistants and Cyber-Physical Systems

by Prof. Annette Kluge

Future work is assumed to be embedded in cyber-physical systems (CPS). CPS are based on the latest developments in computer science, information and communication technologies, and manufacturing science and technology (MST). A CPS consists of autonomous and cooperative elements and subsystems that come into contact with each other depending on the situation. They cooperate across all operation levels, from the process of machines to the process of logistics and back again (Monostori, 2014). This is made possible through new forms of communication between people, machines and products.

CPS enables these new forms of communication between people, products and manufacturing technology. The production employee is connected to the CPS via multimodal human-machine interfaces and can act on these via voice, touch displays and gestures, for example.

In such a future work context, the "augmented operator" becomes the conductor of value creation (Bauernhansl, 2014). The augmented operator in CPS becomes an evaluative, decisive employee, who receives support from technical assistance systems and can cooperate "fencelessly" with robots. Mobile tablet computers, smart watches, smart glasses from the consumer sector already offer new possibilities here today (Vogel-Heuser, 2014). Smart mobile devices can be integrated into CPS via various interfaces (such as Bluetooth, USB, WLAN) and can be equipped with cameras and sufficiently high computing power.

There are already some vivid examples of applications for mobile operation (you can walk around the production area with the tablet and operate a machine remotely or via the Internet), as a mobile information platform (instead of fixed stations or computer terminals connected to a machine and providing information about it), in the form of augmented reality (computer-assisted fading or extension of a section of reality, e.g. a camera image, with additional information) (Vogel-Heuser, 2014) which can support the augmented operator.

Considerations are currently being formulated as to how the support of employees in the human-machine interface can look like on the basis of cyber-physical systems (Mayer & Pantförder, 2014; Schließmann, 2014; Spath, 2013). A relevant aspect here is above all to generate the useful information from the countless data available from the systems for the various work roles (such as role of operator, supervisor, trainee, experienced) and to present the newly acquired information in a suitable and integrated form with high expectation on functionality and user experience (Borisov, Weyers, & Kluge, 2018).

In this way, the processes in the process can be made transparent and comprehensible for people and the information can be suitably prepared for the different display sizes (smartphone, tablet, monitor, smart glass, smart watch) and made available for different operating systems (platform independence), such as through 3D process visualisation, touch interaction and gesture control, augmented reality or social network information systems.

In that respect, he aggregation and processing of information for humans (Vogel-Heuser, 2014) is a major challenge of CPS future work systems. This applies to the support in engineering by assistance systems as well as to the provision of the large amount of data for the operator, maintenance staff or plant managers of a production unit and the equipment operated in this production unit. It is therefore not a question of displaying all existing data, but of establishing connections between these data. The data should be filtered, clustered and presented in their context as information depending on the user (Vogel-Heuser, 2014).

The digital assistance systems should offer people suitable forms of interaction in which to search for information, prepare task-related decisions or plan interventions on the basis of this information. This data depends on the task that the person is currently performing, on the role in which he or she is doing this, and on the environment or peripheral information that is being processed and presented, taking into account individual personal differences (Borisov, Weyers, & Kluge, 2018). Individual personal aspects can be e.g. age-differentiated presentation and interaction concepts, as well as information processing depending on the experience or acceptance of mobile devices (Vogel-Heuser, 2014).

With regard to work and work design, questions such as how human-system interfaces must be designed in order to be conductors of production arise.

Dr. Michaela Kauer-Franz adds a practitioner view on workplace design and usability engineering. She particularly highlights the close relationship between tasks, users, and technology. In her contribution, the working environment is recognized as a key factor for successful implementations.

Design technology that fosters growth

by Dr. Michaela Kauer-Franz

In the development of new technologies in the working environments, an increase of efficiency and safety is often the goal of the main activities. We do fully agree with the idea that working with technology should be as efficient as possible, because we believe that the time of every human is precious. BUT we do NOT measure efficiency solely in the number of seconds until a task is performed error free.

In our work, we design good working environments. This means for us: understanding the task of the user, his personal needs and the physical and social environment. Starting from this understanding, we design technology that assists the user in performing his task in the best possible way. In our understanding, the best possible way means technology that assists the user in focussing on the task instead of struggling with the interface. Reaching that goal is so important to us that we even developed a new approach in our work (we call it Data Driven UX Design or short: 3DUX®) which formally integrates user data into the development of new systems during various stages of the design.

In our view, technology should be a means to an end instead of the end itself. The time spend with a system should be perceived as positive time by the users. Either because the task becomes the centre of attention and is enjoyed by the user or because the technology leads to positive emotions itself. This could be done by assisting people in developing competence, feeling connected to others or strengthen their autonomy (for more details on needs see Marc Hassenzahl section - A Perspective on Human Well-Being and Meaningful Work and its relevance to ATC world - within this White paper).

To be able to design technology that lives up to these expectations, it is a necessity to have joint design teams that respect the human perspective right from the beginning. It is necessary to design with the human in mind, because good design is not possible if technology dictates the conditions and humans have to adapt to the outcomes. As long as we want to have safe flights, we need to design working conditions that keep employees motivated and in the loop. Downgrade people to pure technology-sitters will lead to decreased safety because they will start working against technology due to boredom, due to anxiety, due to frustration. Increased safety comes from competent employees that feel responsible for the results of the process. Having a joint design team and a human-centred approach will reduce the number of senseless systems. To reach that goal, it must be clear that the first solution will not be the best solution but instead an iterative process is needed that helps to adopt system to the needs of the users and the environment.

LITERATURE

Alexander, D. C., & Albin, T. J. (1999). Economical justification of the ergonomics process. *The Occupational Economics Handbook*, pp. 1495-1505.

Bauernhansl, T. (2014). Die vierte Industrielle Revolution - Der Weg in ein wertschaffendes Produktionsparadigma. In T. Bauernhansl, M. ten Hompel, & B. Vogel-Heuser, *Industrie 4.0 in der Produktion, Automatisierung und Logistik. Anwendung. Technologie. Migration.* (pp. 5-37). Wiesbaden: Springer.

BEA. (2012). *Final Report on the accident on 1st June 2009 to the Airbus A330-203 registered F-GZCP operated by Air France flight AF 447 Rio de Janeiro - Paris.* Le Bourget: Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile.

Béguin, P. (2011). Acting within the Boundaries of Work Systems Development. *Human Factors and Ergonomics in Manufacturing & Service Industries, 6*(21), pp. 543-554.

Borisov, N., Weyers, B., & Kluge, A. (2018). Designing a Human Machine Interface for Quality Assurance in Car Manufacturing: An Attempt to Address the "Functionality versus User Experience Contradiction" in Professional Production Environments. *Advances in Human-Computer-Interaction*. doi:https://doi.org/10.1155/2018/9502692

Boy, G. A. (2013). *Orchestrating Human-Centered Design.* London/Dordrecht/Heidelberg/New York: Springer.

Buckle, P. (2011). The perfect is the enemy of the good - ergonomics research and practice. *Ergonomics, 54*(1), pp. 1-11.

Burns, C., & Hajdukiewicz, J. (2004). *Ecological Interface Design.* Boca Raton: CRC Press.

Carayon, P., Wetterneck, T. B., Rivera-Rodriguez, A. J., Hundt, A. S., Hoonakker, P., Holden, R., & Gurses, A. P. (2014). Human factors systems approach to healthcare quality and patient safety. *Applied Ergonomics, 45*(1), pp. 14-25.

Chapanis, A. (1988). Some generalizations about generalization. *Human Factors, 30*(3), pp. 253-267.

Chiles, W. D. (1971). Complex performace: the development of research criteria applicable in the real world. In W. T. Singleton, J. G. Fox, & D. Whitfield, *Measurement of man at work: An appraisal of physiological and physical criteria in man-machine systems* (pp. 159-164). London: Taylor & Francis.

Chung, A. Z., & Shorrock, S. T. (2011). The research-practice relationship in ergonomics and human factors - surveying and bridging the gap. *Ergonomics, 54*(5), pp. 413-429.

Cook, R. I., Woods, D. D., & Miller, C. (1998). A tale of two stories: contrasting views of patient safety. *The Foundation*.

Dekker, S. W., & Nyce, J. M. (2004). How can ergonomics influence design? Moving from research findings to future systems. *Ergonomics, 47*(15), pp. 1624-1639.

Dekker, S., & Woods, D. D. (2002). MABA-MABA or Abracadabra? Progress on human-automation coordination. *Cognition, Technology & Work*(4), pp. 240-244.

Diefenbach, S., & Hassenzahl, M. (2017). *Psychologie in der nutzerzentrierten Produktgestaltung.* Berlin: Springer.

DIN EN ISO 6385. (2016). *Ergonomics principles in the design of work systems.* Berlin: Beuth.

DIN EN ISO 9241-210. (2010). *Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems.* Berlin: Beuth.

Dombrowski, U., & Wagner, T. (2014). Mental strain as a field of action in the 4th industrial revolution. *Procedia Cirp*(17), pp. 100-105.

Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W. S.,... van der Doelen, B. (2012). A strategy for human factors/ergonomics: developing the discipline and profession. *Ergonomics, 55*(6), pp. 377-395.

Fitts, P. M. (1951). *Human engineering for an effective air navigation and traffic-control system.* Columbus: Ohio State University Research Foundation.

Hacker, W., & Sachse, P. (2014). *Allgemeine Arbeitspsychologie: Psychische Regulation von Tätigkeiten* (3. ed.). Göttingen: Hogrefe.

Hassenzahl, M., Diefenbach, S., & Göritz, A. (2010). Needs, affec, and interactive products - Facets of user experience. *Interacting with Computers*(22), pp. 353-362.

Hassenzahl, M., Eckoldt, K., Diefenbach, S., Laschke, M., Lenz, E., & Kim, J. (2013). Designing Moments of Meaning and Pleasure. Experience Design and Happiness. *International Journal of Design, 7*(3), pp. 21-31.

Helander, M. G. (1997). Fourty years of IEA: Some reflections on the evolution of ergonomics. *40*(10), pp. 952-961.

Hollnagel, E. (2003). The Role of Automation in Joint Cognitive Systems. *9th IFAC Symposium on Automated Systems Based on Human Skill and Knowledge* (pp. 9-11). Göteborg: Elsevier.

Hollnagel, E. (2005). Designing for joint cognitive systems. *The IEE and MOD HFI DTC Symposium on People and Systems - Who Are We Designing For (Ref. No. 2005/11078)*, (pp. 47-51). London.

Hollnagel, E. (2014). *Safety-I and Safety-II.* Farnham: Ashgate.

Hollnagel, E. (2014). *Safety-I and Safety-II: The Past and Future of Safety Management.* Farnham: Ashgate.

Hollnagel, E. (2014). *Safety-I and Safety-II: The Past and Future of Safety Management.* Farnham: Ashgate.

Hollnagel, E., Woods, D. D., & Leveson, N. (2006). *Resilience Engineering - Concepts and Precepts.* Aldershot: Ashgate.

ICAO. (2013). *Safety Management Manual (SMM) - DOC 9859 AN/474* (3. ed.). Quebec: International Civil Aviation Organization.

IEA. (2018, August 31). *Definition and Domains of Ergonomics*. Retrieved from International Ergonomics Association: https://www.iea.cc/whats/

Kinney, G., Spahn, M., & Amato, R. (1977). *The Human Element in Air Traffic Control: Observations and Analysis of Performance of Controllers and Supervisors in Providing Air Traffic Control Separation Services.* McLean: MITRE Corporation.

Mayer, F., & Pantförder, D. (2014). Unterstützung des Menschen in Cyber-Physical Production-Systems. In T. Bauernhansl, M. ten Hompel, & B. Vogel-Heuser, *Industrie 4.0 in der Produktion, Automatisierung und Logistik. Anwendung. Technologie. Migration.* (pp. 481-509). Wiesbaden: Springer.

Meadows, D. H. (2008). *Thinking in Systems - A primer -* . Vermont: Chealsea Green Publishing.

Meister, D. (1999). *The history of human factors and ergonomics.* Mahwah, NJ: Erlbaum.

Monostori, L. (2014). Cyber-physical production systems: Roots, expectations and challenges. Variety Management in Manufacturing. *Proceedings of the 47th CIRP Conference on Manufacturing. 17*, pp. 9-13. SystemsProcedia CIRP.

Norman, D., & Draper, S. W. (Eds.). (1986). *User Centered System Design: New Perspectives on Human-computer Interaction.* CRC Press.

Norros, L. (2014). Developing human factors/ergonomics as a design discipline. *Applied Ergonomics, 45*(1), pp. 61-71.

NTSB. (2010). *Aircraft Accident Report - Loss of Thrust in Both Engines After Encountering a Flock of Birds and Subsequent Ditching on the Hudson River - US Airways Flight 1549*. Washington D.C.: National Transportation Safety Board.

Rasmussen, J., & Vicente, K. (1989). Coping with human errors through system design: Implications for ecological interface design. *International Journal of Man-Machine Studies*(31), pp. 517-534.

Salas, E. (2008). At the turn of the 21st century: reflections on our science. *Human Factors, 50*(3), 351-353.

Salmon, P. M. (2016). Bigger, bolder, better: methodological issues in ergonomics science. *Theoretical Issues in Ergonomic Science, 14*(4), pp. 337-344.

Sarter, N. B., & Woods, D. D. (1991). Sitation Awareness: A critical but ill-defined phenomenon. *The International Journal of Aviation Psychology*(1), pp. 45-57.

Schader, N., Perott, A., Heister, R., Leonhardt, J., & Bruder, R. (2012). A user-centred approach to colour-coding in ATC. *Proceedings of the 30th European Association for Aviation Psychology (EAAP) Conference* (pp. 206-212). Sardinia: EAAP.

Schanda, J. (2007). *Colorimetry: understanding the CIE system.* (C. (.-I. Illumination, Ed.) Hoboken, N.J., USA: Wiley-Interscience.

Schließmann, A. (2014). iProduction, die Mensch-Maschine-Kommunikation in der Smart Factory. In T. Bauernhansl, M. ten Hompel, & B. Vogel-Heuser, *Industrie 4.0 in der Produktion, Automatisierung und Logistik. Anwendung. Technologie. Migration.* (pp. 451-480). Wiesbaden: Springer.

Shappell, S. A., & Wiegmann, D. A. (2000). *The Human Factors Analysis and Calssification System - HFACS, DOT/FAA/AM-00/7.* Washington DC: U.S. Department of Transportation - Federal Aviation Administration.

Sheldon, K., Elliot A. J., Kim, Y., & Kasser, T. (2001). What is satisfying about satisfying events? Testing 10 candidate psychological needs. *Journal of Personality amd Social Psychology*(80), pp. 325-339.

Shorrock, S. T., & Williams, C. A. (2016). Human factors and ergonomics methods in pracice: three fundamental constraints. *Theoretical Issues in Ergonomics Science, 17*(4), pp. 468-482.

Spath, D. (2013). *Produktionsarbeit in der Zukunft - Industrie 4.0.* Stuttgart: Fraunhofer Verlag.

Vogel-Heuser, B. (2014). Herausforderungen aus der Sicht der IT und der Automatisierungstechnik. In T. Bauernhansl, M. ten Hompel, & B. Vogel-Heuser, *Industrie 4.0 in der Produktion, Automatisierung und Logistik. Anwendung. Technologie. Migration.* (pp. 37-48). Wiesbaden: Springer.

Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics, 31*(6), pp. 557-567.

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics, 45*(1), pp. 5-13.

Woods, D. D. (1998). Designs are Hypotheses about How Artifacts Shape Cognition and Collaboration. *Ergonomics*, pp. 168-173.

Woods, D. D. (2016). The risks of autonomy: Doyle's Catch. *Journal of Cognitive Engineering and Decision Making, 10*(2), pp. 131-133.

Woods, D. D., & Hollnagel, E. (2006). *Joint Cognitive Systems - Patterns in Cognitive Systems Engineering.* Boca Raton: CRC Press.

PHOTO CREDITS

Cover: MR.Yanukit / Shutterstock 730170973
p. 5. PHOTOCREO Michal Bednarek / Shutterstock 393500134
p. 9. Marc Hasenzahl
p.10. Sergieiev / Shutterstock 626347238
p. 11. Daniel Avram
p. 13. Daniel Avram
p. 19. Daniel Avram
p. 22. optimarc / Shutterstock 588813473
p.23. Daniel Avram
p. 25. Daniel Avram
p. 26. Callahan / Shutterstock 109390016
p. 27. Daniel Avram
p. 28. belkos/ Shutterstock 268980527

AUTHORS

Dr. André Perott studied Mechanical Engineering and Business Administration at University of Technology in Darmstadt. He subsequently worked as a research associate at the Institute of Ergonomics. His research involved the role of ergonomic requirements in Air Traffic Control and their dependencies in complex design tasks. During his work, he acquired a doctoral degree in engineering. Since 2011, he is responsible for Human Factors/Ergonomics within DFS design projects, but also regularly consults other organizations in HF/E matters. andre.perott@dfs.de

Nils Tavares Schader has been working for DFS' HF/E team within the corporate safety management since 2011. He enjoys being involved in concrete ATM design projects as well as developing concepts and strategies on the organisational level. He holds a postgraduate degree in mechanical engineering with a specialisation in aerospace and human factors/ergonomics. nils.tavares.schader@dfs.de

Jörg Leonhardt is Head of Human Factors in Safety Management Department at DFS – Deutsche Flugsicherung – the German Air Navigation Service provider. He holds a Master degree in Human Factors and Aviation Safety from Lund University, Sweden. He co-chairs the EUROCONTROL Safety Human Performance Sub-Group and is the Project leader of DFS-EUROCONTROL "Weak Signals" project. joerg.leonhardt@dfs.de

Tony Licu is Head of Operational Safety, SQS and Integrated Risk Management Unit within Network Management Directorate of EUROCONTROL. He leads the support of safety management and human factors deployment programmes of EUROCONTROL. He has extensive ATC operational and engineering background and holds a Master degree in avionics. Tony co-chairs EUROCONTROL Safety Team and EUROCONTROL Safety Human Performance Sub-group. antonio.licu@eurocontrol.int

CONTRIBUTORS

Prof David D. Woods (Ph.D., Purdue, Cognitive Psychology, 1979) is Full Professor in Integrated Systems Engineering at the Ohio State University. He has developed and advanced the foundations and practice of Cognitive Systems Engineering since its origins in the aftermath of the Three Mile Island accident in nuclear power. This field combines concepts and techniques from cognitive psychology, computer science, and social sciences to study how people cope with complexity. His studies have focused on human systems in time pressured situations such as critical care medicine, aviation, space missions, intelligence analysis, and crisis management. He designs new systems to help people find meaning in large data fields when they are under pressure to diagnose anomalies and re-plan activities. His latest work is model and measure the adaptive capacities of organizations and distributed systems to determine how they are resilient and if they are becoming too brittle in the face of change.

Prof. Marc Hassenzahl is professor for Ubiquitous Design / Experience and Interaction at the University of Siegen, Germany. He combines his training in psychology with a love for interaction design. With his group of designers and psychologists, he explores the theory and practice of designing pleasurable, meaningful and transforming interactive technologies. Marc is author of "Experience Design. Technology for all the right reasons" (MorganClaypool), co-author of *Psychologie in der nutzerzentrierten Produktgestaltung. Mensch-Technik-Interaktion-Erlebnis* (People, Technology, Interaction, Experience) (Springer, with Sarah Diefenbach) and many peer-reviewed papers at the seams of psychology, design research and interaction/industrial design.

Prof. Annette Kluge is a psychologist and full professor for Work, Organisational and Business Psychology at the Ruhr-University Bochum, Germany. Before that, she was a professor for Work, Organisational and Business Psychology at the University of Duisburg/Essen, Germany. She also worked as a professor at the University of St. Gallen, Switzerland. She is editor of the online newsletter Complexity and Learning, the journal Wirtschaftspsychologie, the online journal Cognitive Systems and of the Journal of Work, Organisational and Business Psychology.

Dr. Michaela Kauer-Franz is CEO of Custom Interactions GmbH. Together with her husband she founded Custom Interactions as a Data Driven UX Company that focusses on designing great solutions for different working environments. With her team of technology-, design- and human-experts, she strives for a world in which technology assists humans and fosters growth instead of frustration. Michaela aims at changing the view of upcoming system developers on technology. To reach that goal, she is lecturer at the Technische Universität Darmstadt for the area of Human-Machine-Interaction and part of the working group ergonomics at DIN that is responsible for the German standards on ergonomics, usability and UX.

ACKNOWLEDGEMENTS

These principles have been discussed with many leading professional from the field i.e.: Eurocontrol Safety Human Performance Sub-Group, Eurocontrol Safety Team, CANSO (Civil Air Navigation Service Providers Organisation), ANSPs (Air Navigation Service providers), Academia – Glasgow University, University Politehnica of Bucharest, other industries than aviation e.g. automotive. The authors would like to thank them for their valuable input in the realisation of this White Paper.

NOTES

EUROCONTROL

SUPPORTING EUROPEAN AVIATION

www.eurocontrol.int