HOW AUTOMATION MAY TRANSFORM THE WAYS IN WHICH CREW MANAGE PEAK WORKLOAD AND INCAPACITATION

Nick McDonald
Alison Kay
Rabea Morrison
Margaret Ryan
Centre for Innovative Human Systems, Trinity College Dublin, Ireland

A 'Crew Manage the Operation' concept was developed as a unifying framework to analyse the combined role of diverse technologies in supporting the management of peak workload and incapacitation. Multiple-crew configurations mean that many of the same technologies are supporting quite contrasting instantiation of crew roles. While Proactive and Immediate modes support the independence of the crew in their cockpit, both reactive modes of workload management pose questions about the information flow between the cockpit and ground control, and in turn about the level of support or, in the final mode, effective intervention that could be provided from the ground. These issues are not just about the flow of information but about responsibility and accountability. Thus the technologies are neither determinate of the way they are operated nor are they bounded by cockpit environment; therefore a profound discussion about crew roles and the philosophy of automation is required.

New technologies on the flight deck are transforming the nature of automation to provide novel solutions to core issues concerning human performance such as the management of peak workload and pilot incapacitation. ACROSS was a large integrated European project established with the goal of designing technology systems that alleviate crew workload in current two-pilot operations to improve operational safety (ACROSS, 2016). Three main objectives were set out to guide the design, development and testing of new cockpit solutions: Objective 1 - Addressing peak workload situations; Objective 2 - Addressing reduced crew operations; and Objective 3: Identifying open issues for possible single-pilot operations. This paper simply outlines the development of concepts concerning workload and automation through the project workprogramme. Other papers will describe in more detail the methodologies used and present the analyses of results of the various studies involved.

The Project comprised more than 30 partners spread across Europe, involving multiple organisations, nationalities and large number of diverse technologies being developed in parallel and tested and evaluated in a range of separate test beds. The technology work packages were organised around the classic pillars: Aviate, Navigate, Communicate, Manage Systems, with additional technology workpackages for Crew Monitoring and Crew Incapacitation. Human Factors was one of several transverse workpackages designed to provide a coherent integrated approach across the project. While the project was driven by the development of technologies, its core philosophy always emphasised Human Factors as core to delivering its operational objectives.

In the absence of a physical integration of technologies at project level, the Human Factors team had to deliver a conceptual framework to address the technology scope for each flight function as well as their overall integrated assessment. The objective was to deliver an integrated concept of the crew and their activity with technology at three levels: 1) the operational process, 2) crew tasks, and 3) Human-Machine-Interface. the challenge was to manage the integration of human factors throughout the project ensuring the achievement of operationally valid solutions.

The Initial Workshop

The first Human Factors workshop to address the global operational level was attended Technology development leads, HF experts and the operational representatives in the project. A core purpose was to ask Technology development leaders to link the contribution of their technology to the crew maintenance of the Situational Awareness (SA) bubble. SA refers to the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1988). The term "Situational Awareness bubble" is used commonly to emphasise both the time and space aspects of SA. Technology leaders were asked to conceptualise the situational awareness bubble in terms of the situational dependencies that need to be managed by crew and the discussion centred around the following questions:

> How are the operational dependencies organised in time and sequence (e.g. flight phases)? How do they relate to each other? How should they be organised and prioritised? How should multiple dimensions be represented in the HMI? How to balance demand against capacity? How to transfer authority when capacity is limited?

The answers to these questions linking operational dependencies to technological functions led to the following general observations:

> 1) The crew should be at the centre of the flight operations process and pilots should always be the ones to make the final decision on the flight-deck. 2) There is a clear difference between managing a flight (gate-to-gate) and managing the flight operations process in terms of both system and stakeholder input and output required. 3) There is a need for an integrated crew support function on the ACROSS flight deck. 4) The technology interfaces and functions, considered individually, could not deliver a solution to crew maintaining the situational awareness bubble. 5) The crew should receive decision support to manage the tasks of Aviate, Navigate, Communicate, Manage Systems and Crew Monitoring. This decision support should be in the form of prioritised recommendations for action. 6) It would be advantageous if the recommendations could give an idea of what potential consequences of those actions would be.

The general conclusion of the integration meeting was that the technologies, on their own, cannot deliver an autonomous progressive automation concept, moving from one level of automation to another according to the level of workload, or an entirely reliable and valid incapacitation decision leading to automatic recovery of the aircraft. This also implied that the normative model of workload expressed as a function of demand over capacity (e.g. Fuller, 2000) would not be adequate to address the core function of crew as 'managers of the operation', including, of course, being active managers of workload and incapacity.

The Relationship between Technology and Operations

This conclusions begged the question: what is the relationship between advanced technology and operational performance? Generating an answer to this question was stimulated by a radical analysis of cognitive HMI by Hourlier and his colleagues which formed the basis of the Thalis ODICIS cockpit (Hourlier & Suhir, 2014; Lini et al., 2012; Lini, Favier, Servantie, Vallespir, & Hourlier, 2011). In this framework there are four cognitive HMI principles that enable a rupture between classical fly-by-wire technologies and the next generation of cognitively enhanced cockpits. Briefly, these principles suggested the following questions about the ACROSS technologies:

> Schematise: what schematic representations can be supported by technologies that are critical to the management of workload by crew?
>
> Anticipate: what advanced information can technologies support/provide that support proactive management of workload?
>
> Delegate: What functions can be delegated (to other crew or technology) through technologies to support the crew in managing workload?
>
> Routinise: In what way do technologies support management of workload to render them simple, intuitive, easily learned and reducing overall cognitive training effort?

These cognitive HMI principles tie into the cognitive behavioural cycle of operations that deals not only with separate technologies but with how these enable the management of concurrent tasks, taking into account both the past and projections for the future. These principles highlight what the technology can do for the crew. This then helped to focus the question: what can the crew do with the technologies?

The ACROSS Workload Management Concept

This approach led to the formulation of a generic workload management concept, as outlined in Table 1.

Table 1. ACROSS Workload Management concept

Workload Management Concept	Definition
Proactive Workload Management	Managing workload using timelines and other schematisations. This enables anticipation, which in turn enables planning and allocating resources along the timeline. This enables crew to spread the anticipated workload better and also to be more prepared and more capable of absorbing unexpected spikes in workload.
Immediate Workload Management	In ACROSS immediate workload management is achieved through the use of automation, which reduces demand and together with enhanced decision support reduces crew workload in the here-and-now.
Reactive Workload Management	Managing workload by reacting to events/situations after they have happened. The main focus of reactive workload management in ACROSS is the Crew Monitoring System, which can detect pilot incapacitation and suggest mitigations.

In the final phase of the project this workload concept was tested in a series of workshops involving operational and human factors experts following a set of operational scenarios deploying the technologies enbaling a focussed discussion of the operational aspects of the technologies under the different configurations envisaged by the project (full crew; one crew member incapacitated; both crew incapacitated).

The following provides a short schematic summary of the core relationships of each mode of managing workload, based on the analyses of the workshops with key stakeholders. The purpose of this exercise was to consolidate a model of how the ACROSS technologies could support the management of peak workload and pilot incapacitation, and to point to some basic issues that need further examination.

Proactive Workload Management does not stand on its own, it is a precursor to the other modes. It provides a barrier to peak workload through advanced information in relation to alternate airports and their characteristics, the weather, frequency changes, overall system status, amongst other things. This enables crew to, for example, plan and select alternates or to adjust the mission in the light of system status. It reinforces current crew roles and could have a strong input to crew briefing. The outcome is to spread workload more evenly and to ensure crew a both prepared for things that are foreseen, and ready to tackle unforeseen demands.

Immediate Workload Management operates through reducing demand in a number of ways: providing specific information to assist decision-making, actuation of decisions by use of automation, new HMI design which co-locates system status and action actuation, and interaction design which supports a check process. These barriers to escalating workload in turn support a number of mechanisms: making a decision (selecting nearest airport, for example), deploying automated systems, going through fault identification and rectification sequences that manage the systems' status. Again these mechanisms reinforce both crew roles. The outcome is easier and less demanding decisions, delegating tasks to automation, including automated checks on system status. The objective is an optimal division of labour in a highly demanding situation.

Reactive Workload Management in Single Crew Incapacitation involves the key barriers of monitoring information about the crew and about the aircraft operational status. These are also accompanied by all the other technologies we have just described in the previous two paragraphs – both information and actuation. The monitoring information enables on-going monitoring and decision-making, but the other technologies are crucial in reducing the demand on the remaining pilot in continuing the operation (for example in automated go-around). The focus here is on consolidating both crew roles in one pilot, though some of the experts referred to some automated functions as a potential co-pilot. A big question that arose in the workshop discussions concerned the sharing of information with ATC and Flight Operations Control. The outcome here is reasserting effective control over the operation, with some questions about the type of support that could be received from the ground.

Reactive Workload Management when all crew are incapacitated involves the critical barriers of constant crew monitoring, together with the availability of emergency support systems for the aircraft controlling all the automation options that can return the aircraft safely to the ground. The mechanisms centers around a clear signal that initiates transfer of control to the emergency support systems. This then potentiates functions like automated navigation and landing. The Ground Station is in strategic control. Again the question was raised about the level of sharing cockpit information with the Ground Station and ATC. The outcome is a safe landing. An issue that arose concerned the responsibility and capability of the ground support to deal effectively with any malfunction of the emergency support systems.

Conclusions

Two things stand out from this analysis:

Firstly, the Proactive and Immediate Workload management modes both reinforce the current crew configuration and their roles which make sense in terms of optimizing all resources in managing a demanding situation. On the other hand crew incapacitation involves transforming those roles – consolidating in one crew or transferring to an automated pilot and ground control. Thus many of the same technologies are supporting quite contrasting instantiation of crew roles.

Secondly, while the Proactive and Immediate modes support the independence of the crew in their cockpit, both reactive modes pose questions about the information flow between the cockpit and ground control, and in turn about the level of support or, in the final mode, effective intervention, that could be provided from the ground. These issues are not just about the flow of information but about responsibility and accountability.

The ‘Crew manage the operation’ concept has provided a unifying framework through which it is possible to see the combined role of these diverse technologies in a crew-centric way. It has enabled the exploration of the role of advanced technologies, and most particularly the ‘rupture’ in technology development that is typified by the ACROSS technologies which bring both rich meaningful content and dramatically expanded connectivity.

However that rupture demonstrates the need to rethink the philosophy of automation. In referring to Tarnovsky (2002), the question is raised whether or not this is still an authoritative comment on automation philosophy in the light of the cockpit technologies represented in ACROSS. Simplistic thinking along the lines of classic automation is no longer sufficient – it is not just a question of replacing one function after another with an automated system until one gets rid of a crew-member. The implications of technological step changes must be addressed in depth.

Trust in technology is core to trust in the future system. Some confidence was placed in this during the workshops – with use, people will learn to trust the new technology and exploit the functional benefits it brings. However single crew operation is for many a threatening concept viewed with great suspicion if not hostility. Crew monitoring raised questions about how future systems would “handle” data associated with crew and fatigue. There must be clear guidelines for data protection whilst ensuring safe practice for crew. The dynamics of system transformation by new technology is not a deterministic process and there are real choices to be made about the relative role of people and technologies. These choices need to be made in an informed way.

All of this will require new procedures and new training to capture reinforce the optimal relationships between new technology and operations and how to cope when the technology fails.

A new paradigm for system integration has emerged with new flight deck technologies together with the SESAR and Next-Gen mega-projects; however this has yet has to generate a new operational paradigm. The issues can no longer be resolved on the flight deck or at the controller's workstation - they increasingly concern the relationship between flight deck and ground control (both airline and ATC). It is not just the technology interface with the human that is important but the connectivity to the rest of the system. Because of this complexity the driving operational concept should be clearly embedded in a rich understanding of operational reality. This involves a capability for 'System Design for Operations' (McDonald, Morrison and Grommes, 2007). The development of new technologies pushes us further to consider not just the transformation of roles at local level where new automation can enhance human functioning as well as supplanting it; it forces us to consider how relationships are transformed across the system and it puts clearly on the agenda the requirements for effective and accountable governance of the next generation of operational systems

Acknowledgements

The authors appreciate the financial support for this research by the EC through the ACROSS project (Contract No ACP2-GA-2012-3141501).

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