Safety and Airspace Regulation Group

ATM Automation: Guidance on human-technology integration

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Foreword

For the foreseeable future, humans are expected to play a key role in the delivery of Air Traffic Management (ATM), and the maintenance support of the technical systems used. However, it is expected that the tasks, roles and means of the human delivering these services will evolve through the deployment of a broad range of complex automation.

The aim of this document is to provide guidance on how to address the relationship between humans and automation within the framework of a contemporary safety management system. The direct scope is ATM; therefore including the domains of: Air Traffic Services (ATS); Airspace Management (ASM); Communication/Navigation/Surveillance (CNS); Meteorology; and Air Traffic Flow Management (ATFM). Consequently, the publication is primarily intended for:

- Air Navigation Service Provider (ANSP) managers and safety practitioners, in meeting their legal requirement to manage the safety of their services.
- Competent Authorities in meeting their legal requirement to exercise safety oversight of air navigation services.

The publication also provides information for:

- Aerodrome operators, in considering infrastructure and technology procurement that has an impact on the provision of aerodrome ATS and CNS.
- Equipment manufacturers and design authorities, to ensure their awareness of the needs and expectations of the ANSP. This includes consideration by large-scale regional programmes such as Single European Sky ATM Research (SESAR).
- Any other users outside the scope of ATM who may wish to assess the utility of the guidance in their own operation.

The contents of this publication would not have been possible without the collaborative work of the collective project partners. We are also very grateful for the external review of this guidance material provided by:

- Professor Don Harris - Coventry University;
- Dr Kathy Abbott – FAA;
- Mr Richard Parker – Director RDFP Consulting Ltd.

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Chapter 1

Introduction

Background

Human interaction with technology and automation is a key area of interest to industry and safety regulators alike. In February 2014, a joint CAA/industry workshop considered perspectives on present and future implementation of advanced automated systems. The conclusion was that whilst no additional regulation was necessary, guidance material for industry and regulators was required.

Development of this guidance document was completed in 2015 by a working group consisting of CAA, UK industry, academia and industry associations (see Appendix B). This enabled a collaborative approach to be taken, and for regulatory, industry, and workforce perspectives to be collectively considered and addressed. The processes used in developing this guidance included:

- review of the themes identified from the February 2014 CAA/industry workshop[1];
- review of academic papers, textbooks on automation, incidents and accidents involving automation;
- identification of key safety issues associated with automated systems;
- analysis of current and emerging ATM regulatory requirements and guidance material;
- presentation of emerging findings for critical review at UK and European aviation safety conferences.

In December 2015, a workshop of senior management from project partner organisations reviewed the findings and proposals.

EASA were briefed on the project before its commencement, and Eurocontrol contributed through membership of the Working Group.

[1] S Quercioli-Torrens, Hertfordshire University, 2015

Terminology

Throughout this document, the following terms are used:

System	The complete socio-technical system
Technology	A piece of equipment
User	Those interaction with the ATM automation including Air Traffic Control Officers (ATCO), Air Traffic Safety Electronic Personnel (ATSEP), pilots, etc.

What is meant by Automation?

Automated systems come in many different forms with a broad scope of system characteristics and capabilities. Therefore the word 'automation' as a noun captures a complex blend of technology interacting with human operators, each carrying out a wide range of tasks, in support of human goals. However, 'automation' can also be used as a verb describing the process of fully or partially delivering or augmenting a function or service previously carried out by the human.

The terms 'automation' and 'autonomy' are often misused and mixed up. 'Autonomy' relates specifically to self-determination and independence of decision-making; however, whilst forms of automation can include such independence, the scope of automation is broader than this and captures a wide spectrum of functions.

Socially what we consider to be categorised as automation changes over time. What is thought of as automation today may not be in future when it becomes accepted as routine. For example, home central heating thermostats and electric kettles are not today thought of as forms of automation. Other such examples are a car's automatic choke control and electric windows. Yet all of these functions fit the definition and would have been socially considered as being examples of technology augmenting human functions when first introduced.

ATM already has a wide variety of technology and systems that provide automation support to humans, with some key examples as follows:

- Radar Data Processing,
- Electronic data displays,
- Electronic flight strips,
- Mode S down-linked airborne parameters,
- Safety nets such as Short Term Conflict Alert,
- Medium Term Conflict Detection,

- Arrival and Departure Manager,
- Time Based Separation support tools,
- Aeronautical Message Handling Systems,
- Aeronautical Information Management.

Figure 1: Automation in contemporary visual control room, including electronic flight strips. Picture courtesy of NATS.

There are also a number of new ATM automation technologies currently being deployed. Remote Tower systems include the ability to enhance the tracking of aircraft and provide 'heads up' information and warnings to the controller. Through the integration of Advanced Surface Movement Guidance Control Systems, airfield lighting systems, and controller workstations, there is now the capability to automate aerodrome ground control applying what is known as a 'follow the greens' concept. Whilst there has been very little automation of decision-making, when workload increases and users become more confident in the systems that provide possible solutions and advice, automation can and perhaps already has surreptitiously become a decision maker by proxy.

In the immediate future, SESAR functionality mandated by the Pilot Common Project relies on various types of automation as the core means of delivery. Examples include:

- Extended Arrival Manager,
- Departure management synchronised with pre-departure sequencing and integrating surface management constraints,
- Automated assistance to controllers for surface movement planning and routing,
- Airport safety nets,

- Flexible airspace management and free route airspace,
- Automated support for traffic complexity assessment,
- Initial System Wide Information Management (SWIM),
- Initial trajectory information sharing.

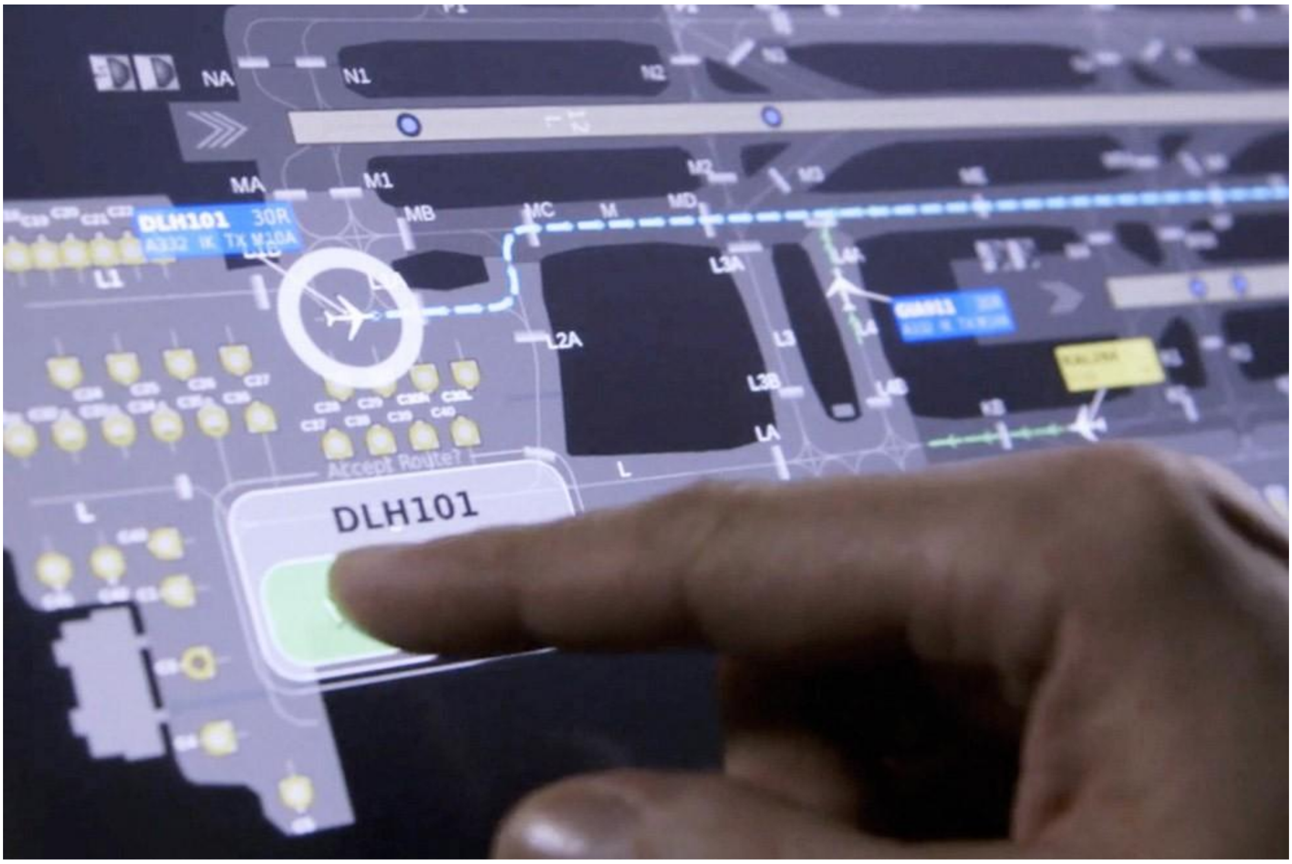

Figure 2: Integrated aerodrome control user interface. Picture courtest of ATRiCS.

Levels of Automation

At the present stage of ATM technological development, a taxonomy that supports the understanding of the spectrum of automation can be a helpful tool, and can be a useful concept for communicating ideas about automated systems. The taxonomy can help identify the degree to which a function is delivered by technology, on a continuum from a low level (no assistance from technology) to a high level (completely automated system). However, it should be remembered that even a very high level of automation involves some human interaction, for example maintenance where the operational engineers are the ‘users’.

Research by SESAR identified that previously developed taxonomies could not fully meet the demands of classifying ATM technology examples, mainly due to the lack of inclusion of the full scope of cognitive functions. Consequently, SESAR developed a new Levels of Automation Taxonomy (LOAT), inspired by previous work, which:

- addresses specific functions rather than the complete system;
- recognises that a technical system can support multiple cognitive functions.

The SESAR LOAT is grouped by the four cognitive functions:

- Information Acquisition,
- Information Analysis,
- Decision and Action Selection,
- Action Implementation.

For each cognitive function there are a number of levels from Level ‘0’ (manual task accomplishment) through to Level 8 (full automation). The condensed SESAR LOAT is as shown in Figure 3.

As future ATM systems increasingly interact, share data, and operate across interconnected and closely coupled ‘systems of systems’ this will lead to the concept of ‘levels of automation’ becoming blurred as it becomes less realistic to assess specific functions for their particular ‘level’. Furthermore, the notion of levels of automation does not address the requirements for human–technology integration; recent developments in this area have pointed out that a lack of effective activity to address this aspect might not only challenge effectiveness but also the safety of operation.

From information to action →

Increasing automation ↓

A INFORMATION ACQUISITION	B INFORMATION ANALYSIS	C DECISION AND ACTION SELECTION	D ACTION IMPLEMENTATION
A0 Manual Information Acquisition	**B0** Working Memory Based Information Analysis	**C0** Human Decision Making	**D0** Manual Action and Control
A1 Artefact-Supported Information Acquisition	**B1** Artefact-Supported Information Analysis	**C1** Artefact-Supported Decision-Making	**D1** Artefact-Supported Action Implementation
A2 Low-Level Automation Support of Information Acquisition	**B2** Low-Level Automation Support of Information Analysis	**C2** Automated Decision Support	**D2** Step-by-Step Action Support
A3 Medium-Level Automation Support of Information Acquisition	**B3** Medium-Level Automation Support of Information Analysis	**C3** Rigid Automated Decision Support	**D3** Low-Level Support of Action Sequence Execution
A4 High-Level Automation Support of Information Acquisition	**B4** High-Level Automation Support of Information Analysis	**C4** Low-Level Automatic Decision Making	**D4** High-Level Support of Action Sequence Execution
A5 Full Automation Support of Information Acquisition	**B5** Full Automation Support of Information Analysis	**C5** High-Level Automatic Decision Making	**D5** Low-Level Automation of Action Sequence Execution
		C6 Full Automatic Decision Making	**D6** Medium-Level Automation of Action Sequence Execution
			D7 High-Level Automation of Action Sequence Execution
			D8 Full Automation of Action Sequence Execution

Figure 3: Condensed SESAR LOAT

ATM Automation Benefits, Issues and Challenges

The benefits of ATM automation can be categorised at a high level as providing potential improvements to:

- Safety,
- efficiency[2],

[2] Through reduced cost, increased reliability and consistency.

- capacity,
- security,
- environment,
- passenger comfort.

However, automation can also create unintended consequences. Hence, it is vital to identify and understand the benefits and risks at a total system level.

Automation introduces a challenge for human–technology integration, as whilst the automation often has the ability to perform routine tasks, there is often an enduring need for a human to be in the loop to deal with the novel and unexpected. Human reliance on the automation to perform routine tasks means that if the automation fails, they may not be able to detect this, and even if they do so, they may not have the competence to resolve the situation manually.

Automation creates new human weaknesses and amplifies existing ones. Human error does not vanish; automation changes its nature. The key to success lies in automation supporting and co-operating with users, not only in normal operation but also during novel and unusual circumstances[3].

The following captures the high level grouping of human-automation interaction issues and challenges:

- Inadequate understanding by those that procure and design such systems of the current operation and the real need for technology.
- Technology designed, developed and deployed without sufficient attention to human performance.
- Revised roles, responsibilities, and accountabilities resulting from the introduction of technology are not appropriately bounded or reasonable.
- Weak technology interfaces and dependences.
- Insufficient planning conducted for technical failures and fallbacks.
- Training focused on how to operate but not how to understand the technology.
- The adaptation and normalisation of new technology is not appropriately managed.
- The emergent properties and human behaviours are not identified and acted on in service.

[3] On Your watch: Automation on the Bridge, M H Lutzhoft and S W A Dekker, Journal of Navigation (2002), 55, 83-96

ATM Automation Needs

Recognising and balancing the specific needs of industry, regulatory authorities, and the workforce has been a key aspect in developing this guidance material. These needs, whilst having variations in priority, were complementary and could be reconciled. The key needs of each community were identified as:

Industry

- Automation is necessary to help to ensure safe and resilient services, delivered more cost-effectively, and in a manner that delivers capacity to meet demand.
- Automation is a key enabler for the deployment of SESAR.
- Automation provides opportunity to bring together and share data with airports, airlines, and other ANSPs. This can enable delivery of services and solutions that were previously impossible, and by removing the silos, it will deliver benefits to the passenger.
- Automation must be delivered safely. There is a need to ensure that the system is designed for human interaction.
- Guidance material is required to provide a framework for automation, which ensures that the right balance is achieved between 'the manual and the 'automated' and to achieve appropriate human-technology integration.

Regulatory

- Automation needs to be introduced in a safe manner and one that delivers benefits for all users of the ATM system by ensuring that all aspects of the change are assessed primarily from a safety perspective using a standardised approach.
- Human performance aspects should be fully considered from initial concept design and continually through the operational life of the system, using processes defined as an integral part of the ANSP's safety management system.
- Recognition is needed of the need for increased emphasis required on in-service safety monitoring and identification and management of emergent human and system behaviours.
- Guidance material should support and be aligned with current and predicted regulatory requirements.
- Processes should be compatible with large-scale European programmes such as SESAR.

Workforce

- The human is a key element of the overall ATM system and has a fundamental role in its performance, safety and resilience.
- When automating any aspect of the ATM system, a human-centred design approach should be used. The users should be involved in all stages of the design and implementation.
- Automation should aim to simplify the user's tasks but, at the same time, keep them aware of the decision-making and system state.
- The workforce must receive appropriate training to perform safely and effectively with automation. This includes regular training on fallback procedures to ensure competency in the event of system failure and to prevent the degradation of skills needed in such an event.
- Since the introduction of automation has the potential to modify the user tasks, the roles and responsibilities of the human must be clearly identified.
- The availability, accuracy, integrity, and continuity of advanced technology must be clearly identified, both from a technical, professional and legal point of view.
- Engineers have a key role at the intermediate deployment stage where they have to maintain the legacy system whilst simultaneously learning the intricacies, modes and states of the new system.
- The networked nature of new ATM automation using SWIM will require that the Systems Monitoring and Control (SMC) suites provide comprehensive and holistic situational awareness of a complex system of systems environment.

Chapter 2

Overview of ATM automation themes and principles

When and how to use the guidance

This guidance material provides a number of themes and principles, intended to act as a guide and crosscheck for the safety assurance and oversight of the human performance aspects of the design, development, transition and in service operation of ATM automation. They need to be considered in their totality, as they are inter-dependant and are not intended to be used sequentially. They should also be considered recurrently through life from initial concept design through to decommissioning, as shown in Figure 4.

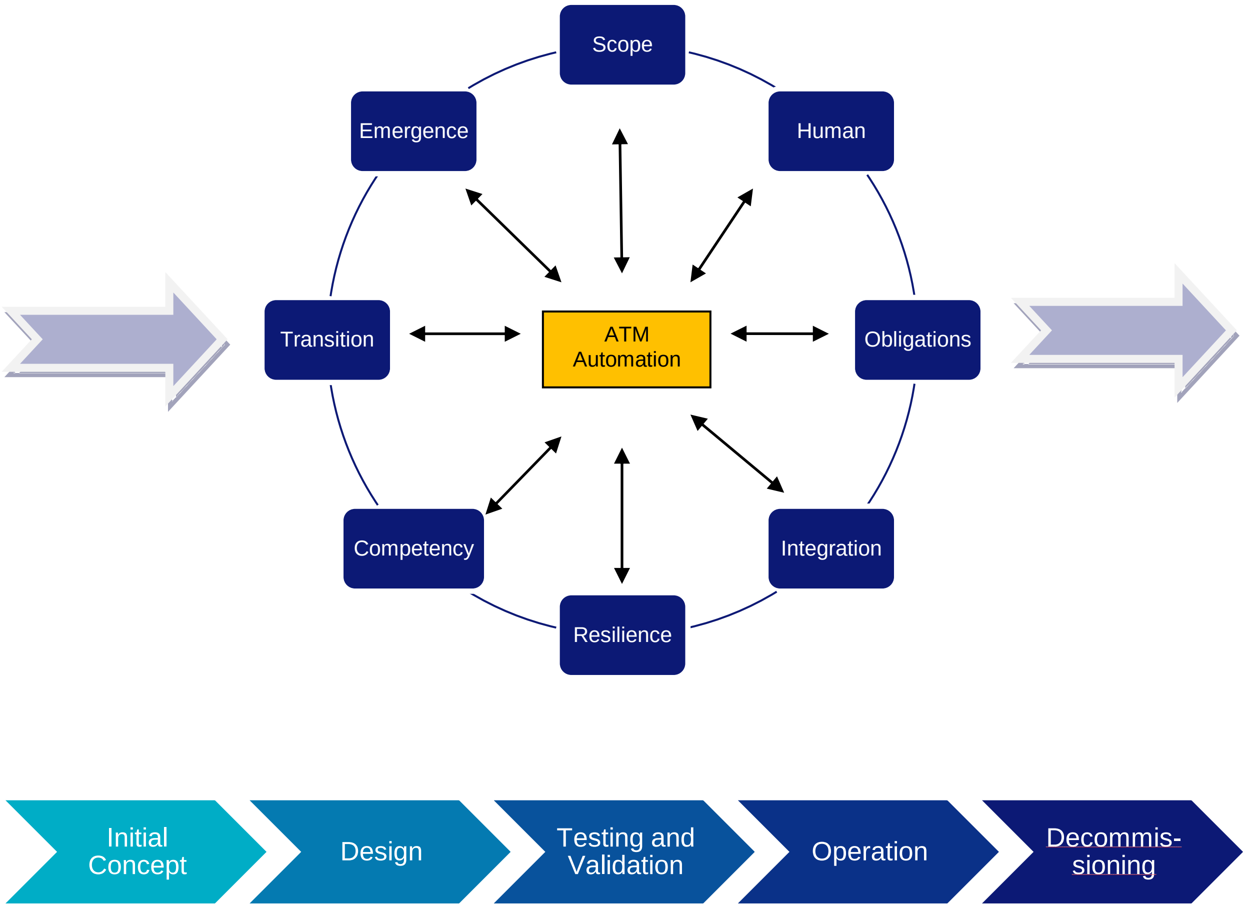

Figure 4: ATM automation human-technology Themes used through a project life

The themes and principles support a performance-based approach to safety management by enabling risk and need driven solutions rather than specifying prescriptive measures. ANSPs should use these themes and principles within their own safety management systems, in particular in the following areas:

- Policy on human-technology integration and the ANSP's means of addressing and implementing this guidance material within their management system.
- Safety assurance of change. Showing evidence of achievement for each principle appropriate to its novelty, complexity, and safety risk as an integral part of the change management process will enhance the safety argument provided and is likely to result in improved operational performance. Early application of the guidance material will give more freedom to make adaptations at lower cost. Later application will reduce flexibility to address the identified issues by design, thus increasing costs and reliance on procedural mitigations or work-arounds.
- Safety achievement. Used iteratively within a project's lifecycle, to ensure that assumptions, findings, and conclusions reached are reappraised as the project develops. For example, the themes and principles could be used as a framework for audit, review, or survey and to seek evidence for achievement or otherwise.
- Setting customer safety requirements on suppliers of equipment and providers of project safety assurance. For example, by requiring evidence to be provided on how the themes and principles in this document have been considered and addressed in a contracted project.

The UK CAA will use the themes and principles as a means of testing the adequacy of the safety management arrangements and outputs provided by the ANSP. For example, as a potential framework to assist in audit, approval and oversight of ATM systems and technology.

Chapter 3

Theme 1 – Scope

Overview

Understand the current operation and identify the real need for automation.

Understanding the current operation and the need for automation is fundamental to ensuring that the design is appropriate and benefits are achieved without creating unforeseen adverse consequences.

Failure to address this subject at the planning stage is likely to significantly inhibit the ability to resolve the issues at a later stage without significant cost or impact. This activity should also be routinely revisited during the lifecycle of the project.

Principles

1.1 Clearly identify and articulate the need, aims and aspired benefits of the automation on the system as a whole.

Explicitly identifying the need ensures that automation is deployed for clear and rational benefits rather than just because it is available. This avoids ‘automation for automation’s sake’, which can lead to a disjointed system, or failure to identify alternative potentially more efficient or effective ways of achieving the result.

The needs and the potential solutions are likely to differ depending on the type of operation (location, task etc). What fits for one airport or air traffic control centre may not be appropriate for another.

Being aware of needs, aims, and benefits, assists in avoiding scope creep beyond what is actually required, supports change management processes and assists in gaining stakeholder buy-in.

1.2 Identify the complexities of the operating environment, its boundaries and dependencies, and the strengths and weaknesses of the current ATM system (people, processes, technology). Protect the strengths and address the weaknesses.

It is easy to fall into the trap of using automation to address a perceived need, and in doing so inadvertently losing positive attributes of the old system or process that may be taken for granted. For example in deciding to implement electronic flight strips, it is important to understand and retain the benefits from traditional paper flights strips such as simplicity, ability to manipulate and offset strip holders, the physical act of passing a flight strip to gain attention etc. Automation is also designed to operate to strict rules using predefined algorithms; this makes automation unable to take account of new factors or novel situations. The ability of humans to take account of thousands of variables and adapt to novel situations is what creates a safe system.

Understanding the current system enables implementation of appropriate technological solutions. Automating complex human tasks can result in the simpler components of the task delivered by the technology, but leaving disjointed complex tasks to the human with the added complexity of liaising with the automation. This may result in an overall increase in workload and reduced efficiency.

1.3 Decide on the degree and level to which the automation will supplement or replace human functions, balancing business needs and resilience with reliability, and necessary human competency.

It is vital that the type and level of automation provides the technical reliability and operational resilience needed to deliver business needs. It should be expected that at some point the technology will degrade, fail, or have a credible corruption. If in such circumstances business continuity needs require the human to take over, then the user must have the competence to do so.

Therefore, there is a fundamental decision to be made on how to achieve the right balance between the business needs, technical reliability and human competence. This might result in a lower level of automation being chosen, enabling appropriate residual human competence to be maintained, but perhaps at lower capacity. However, if the business needs are such that high levels of automation are required, there needs to be an acceptance of no possible human capability to provide fallback.

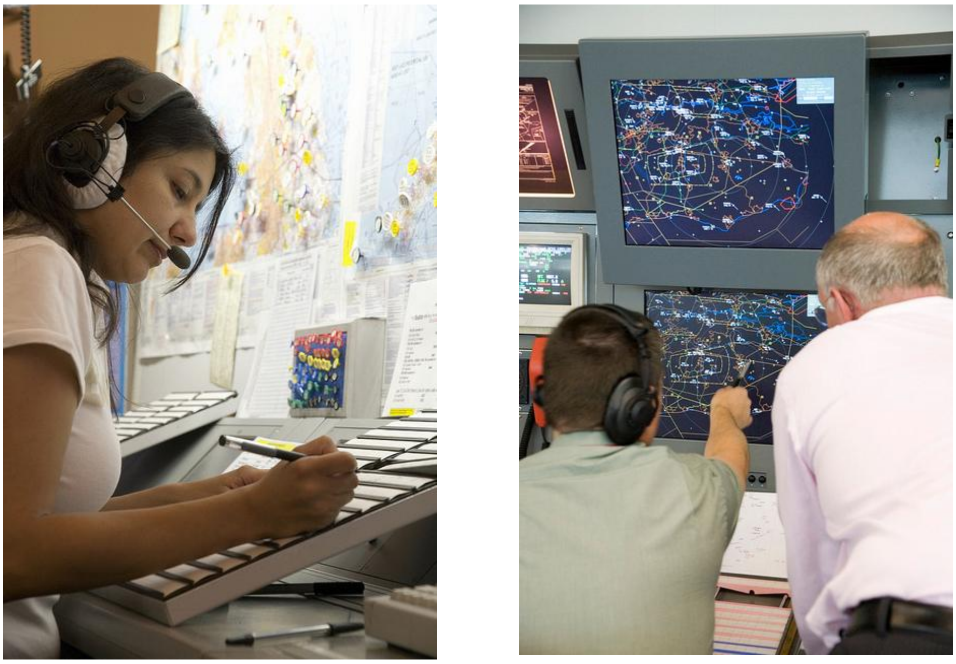

Figure 5: Varying Air Traffic Control (ATC) task needs

1.4 Identify and consider the effects of the proposed change on the organisation and the workforce.

ATM automation has the potential to generate workforce issues by changing or redistributing roles, responsibilities, methods of work or places of employment.

The workforce often fear that they will be forced to use a system they are not comfortable with and that they will lose control of their destiny. People have concerns that automation will lead to reduction in staffing or de-skilling. Early staff involvement can allay these fears, ensure buy-in to the solution, and make use of their operational experience leading to efficient design solutions and acceptance.

Figure 6: NATS Swanwick Area Control Centre. Picture courtesy of NATS.

Chapter 4

Theme 2 - Human

Overview

Design, develop, deploy and operate automation with human performance in mind.

Although the interaction between humans and technology will continuously change, the human will remain an integral part of the overall ATM system as the most critical source of its safety, performance and resilience.

Humans are often responsible for preventing incidents and averting disasters by detecting situations that are outside the norm and managing those situations. They have the unique ability to identify new or unusual ways to react to abnormal situations and circumstances in a manner that reflects current and emerging situations. They are able to detect subtle changes in a situation, diagnose problems, adapt and create innovative ways to solve problems, using a wealth of knowledge and experience.

The introduction of automation may have an unforeseen impact on user tasks and working methods. These changes may inadvertently lead to an increase in the operators' workload or reduce their situational awareness and negatively affect human performance especially in terms of efficiency and safety.

Explicit consideration of human performance should aim to protect the role of the human as an asset whilst minimising the potential for human error.

Principles

2.1 Involve users in all stages of design and development, facilitated by systems engineering, human factors, and safety expertise.

User involvement in design and development captures the complete system, including the technical architecture, its functionality, the operational procedures applied, and training needed.

User involvement throughout the design process is important to make use of their knowledge and experience. However, automation is complex and specialist expertise is required to facilitate such involvement.

Users must be comfortable interacting with the technology and incorporating its use into the overall workflow. It is essential that where technology fundamentally relies on the human user to take action to maintain safety, such reliance is shown to be realistic based on the limiting user rather than maximum human performance.

A fundamental prerequisite for successful delivery of this principle is for an effective and appropriate safety culture to be in place.

2.2 Ensure that the technical performance, availability and accuracy meets the trust needs of the users, taking account of the natural human tendency to over rely on highly reliable automation and be biased by large data sets.

Humans are susceptible to ‘automation complacency’ or ‘automation bias’. If technology appears reliable, humans will trust it. This may become over trust when they stop questioning information presented to them, even when it doesn’t look quite right.

Users’ trust in automation affects how it is used. If user trust exceeds the technical capabilities, problems of misuse or complacency can occur. Alternatively, if user trust is insufficient, reduced utilisation will adversely affect the expected benefits from the automation.

Information presented in a digital form tends to appear more credible to users. There is a natural tendency for humans to believe and act on large data sets without understanding the source and its accuracy. Even when automation is telling the user something that is not correct, they are likely to believe it anyway.

If a system is highly reliable, users are less likely to have the skill and vigilance to spot the rare anomaly. Therefore, safety arguments based on assumptions that the user will detect corrupt information may not be sound.

2.3 Design the human machine interface (HMI) to optimise situational awareness and workload.

The design of the HMI has a direct influence over situational awareness and user workload, and therefore the possibility for human error. For example, SMC suites need to provide the ATSEP with comprehensive and holistic situational awareness of the status of the system of systems.

User ability to cope with complex situations is reduced when using automation for the routine and mundane tasks. Good user decisions require good situational awareness and optimal workload. Therefore, while the user remains directly responsible for the end outcomes, they need to be appropriately engaged in the core task.

More information does not necessarily equal more situational awareness. Users should be presented with the right information, in the right place, at the right time and in the right format. Technology should not misdirect user attention through high numbers of alerts.

Although automation is often intended to result in reduced work load, this is frequently not as significant as originally planned. The primary reason for this is that the act of automating a task or sub task often places an extra burden upon the human in terms of monitoring or integrating actions with the technical system.

2.4 Ensure appropriate team resource management principles are in place to support new or changed interfaces, roles or responsibilities.

Automation can result in new or changed roles and responsibilities. Team resource management programmes should reflect this to ensure that all roles that interact in the delivery of ATM are assessed prior to the implementation of the automation.

Figure 7: Remote Tower technology. Picture by Stefan Kalm, copyright Saab AB.

Chapter 5

Theme 3 – Obligations

Overview

Roles, responsibilities, and accountabilities resulting from the introduction of technology need to be bounded and reasonable

Regardless of the technology implemented, people will remain accountable for the safety of ATM. Humans will still have to take responsibility and accountability for the unintended consequences of their interactions with automation.

Principles

3.1 Minimise reliance on the human as a monitor and ensure human task engagement is appropriate to intervention needs.

Humans are naturally poor at monitoring tasks, both in high and low workload situations and particularly in highly reliable systems where the need for intervention is low. However, human monitoring capability can be good when the task is an intrinsic part of the user task involvement.

The user needs to be appropriately engaged in the core task and this requires careful consideration of the effect of giving routine tasks to the technical system. Users need to stay appropriately engaged in order to exploit the human as an asset in the system.

3.2 Do not hold users responsible for taking reasonable decisions based on information that is incorrect but credible.

Information presented in a digital form, based on a complex algorithm, using live information feeds, will appear to be highly credible. Designers must assume that users will rely on automation and make operational decisions based on the information presented to them. The ANSP is responsible for ensuring the system provides information that neither biases user decisions nor leads the user to overestimate the accuracy of information.

This principle accords with the application of a just culture.

3.3 Ensure that new or transferred accountabilities, responsibilities and roles are appropriate and unambiguous to the individuals concerned.

‘Appropriate’ means that the accountability, responsibility or role is fair and able to be met by the individual. ‘Unambiguous’ means that it is explicit and not open to interpretation.

ATM automation is likely to redistribute responsibilities of pilots, ATCOs and ATSEP. New system complexities will also involve differing combinations of humans and technology working together.

Although the technology or a computer cannot be held to account, those who design, code, assure, maintain and operate the system, can be held accountable.

Figure 8: Controller Pilot Data Link Communications at Maastricht UAC. Picture courtesy of Eurocontrol.

Chapter 6

Theme 4 – Integration

Overview

Automation interfaces and dependences must be robust

ATM technology must be safely and efficiently integrated into the total aviation system. Assumptions and dependencies on systems and processes outside the ANSP's direct control can significantly impact on the safe and efficient provision of their services.

ATM technology is reliant on large quantities of data and complex databases. Some will come from automatic sensors such as meteorology or from Mode S transponders, others from look up tables, or from third party databases such as the Base of Aircraft Data (BADA) model.

The transition towards 4D trajectories results in significant increases in data sharing across ANSP's and the flight deck. An increased reliance on fast accurate ground to air communication is also expected through the deployment of SESAR technologies including Downlinked Aircraft Parameters and Datalink.

Cross-border actions and data transfer as well as ownership and modification of data across borders are expected to become increasingly prevalent in support of delivering SESAR.

Principles

4.1 Ensure that new or changed technology works in a coherent and collaborative way with other internal and external systems.

Technical solutions must fit within the overall ATM architecture of the ANSP. However, ATM automation is also resulting in more integration across the whole ATM system as well as with the aircraft flight deck; therefore, there is a need to understand and manage the interdependencies across the total aviation system e.g. the output from one technical function can be the input to a different function.

Hazard identification, risk assessment, and mitigation can only be complete through cross aviation domain collaborative assessment. Safety risks are likely to be hidden or sub optimal solutions implemented unless all domains (aircraft, ATM, airport etc) affected by the change work together to share their assumptions, dependencies, needs, and relative risks.

4.2 Ensure compatibility and consistency of the procedural interfaces.

ATM automation is resulting in more integration across the entire aviation industry and is breaking down the barriers between the traditional hierarchical aviation domains. This results in an increased need for operational procedures and processes to interface.

Current ATM-flight deck interaction is already generating challenges, for example:

- The downlink of Mode S selected level provides valuable data to the controller on pilot vertical intent, but does not always reflect true pilot intent in certain modes of flight management on step climb SID and step descent STAR. Attempts to resolve this by encouraging pilots to use a particular mode of flight can create disproportionate risk through operations differing from aircraft manufacturer intent.
- The replacement of ATC headings to fly with defined Area Navigation (RNAV) arrival routes can in some circumstances generate effect on the flight crew through Flight Management System fuel warning messages being generated due to the technology not being able to take account of ATC intent on the extent of the RNAV arrival to be flown.
- The introduction of new technology is enabling new ways of communicating between different operators. For example, data exchanges between air and ground will be increasingly performed by data-link, while voice is expected to remain as back-up in time critical circumstances. Failure to anticipate the impacts of these communication modes on user situational awareness and workload may generate new forms of error or limit the expected performance and safety benefits.

Figure 9: Airline, ATC and airport – highlighting need for increased cross aviation considerations for the integration of ATM automation. Picture courtesy of NATS.

- The SESAR Pilot Common Project (PCP) includes the deployment of initial trajectory information sharing. This relies on target times and trajectory information, and use of aircraft on-board 4D trajectory data by the ground ATC and Network Manager systems. Such data sharing is increasingly safety critical and places potentially significant impacts on the roles of ATM personnel.

Chapter 7

Theme 5 – Resilience

Overview

Plan for technical failures and fallbacks

As systems become more complex, with more interdependencies, and more lines of code, the potential for technical failure of some degree is greater. When a failure happens there is likely to be commercial pressure to achieve short notice workarounds in order to ensure continued operation. These have the potential to create safety risk if not considered as part of a managed contingency plan.

Principles

5.1 Design technical systems such that failures are obvious and graceful to the user.

'Obvious and graceful' means that failures are easy to recognise and do not present immediate safety criticality. This can be achieved through appropriate user task involvement and transparent HMI design. This enables users to detect early 'drift' in the system performance and commence safe shut down or apply pre-defined and safety assured contingency measures.

Failures that are not obvious can escalate and result in inappropriate actions. Confusion and uncertainty as to what the system is doing, or immediate corruption or total loss of critical data or functions lead to the failure not being 'graceful'.

Whilst good design can ensure safety in the event of failure, the measures applied to achieve this may not meet business needs for service continuity. Continued operations in degraded operation or using contingency or fallback must be safety assured in advance.

The SMC system should give the ATSEP the opportunity to adjust and mitigate potential risks and failures of their systems. In addition it can provide continuous monitoring enabling assessment of the safety level achieved and identifying areas for future improvement.

5.2 Ensure that processes and technology are available to provide the required levels of contingency and that necessary human competencies are maintained.

We have to assume that at some time, something will fail and if service continuity is required, we must build in resilience through redundancy or fallbacks. Therefore, planning for fallbacks and contingency allows appropriate processes, tools and procedures to be in place in advance.

5.3 Ensure that fallback processes place reasonable demands on the capability and capacity of users.

When technology fails, it is often the user who is relied upon to take remedial action to maintain a safe service, or as a last resort close down the service safely. However, this may require the user to have a level of skill and situational awareness that has been lost through the introduction of the automation.

Figure 10: ATSEP SMC. Picture courtesy of Entry Point North.

Chapter 8

Theme 6 – Competency

Overview

Ensure people understand the technology, not just how to operate it.

Training is often focused on 'which button to press'. However, where the users' task interfaces with the technology e.g. where the technology provides support and advice for a user function, there is a need for deeper understanding.

Principles

6.1 User training in the use of automated systems should include:

a) **Clarity on the underlying system logic, functions, modes, design assumptions and data fusion.**

Users need to understand what the automation is doing and why it is doing it.To work effectively as a team, each member needs a good understanding of each other's strengths and limitations. Similarly, users need to understand the logic of the technology, what it is trying to achieve, what affects it, its strengths and limitations, the different modes in which it operates, and have the ability to mitigate any un-serviceability and degradation of the service.

b) **How to evaluate the information and solutions provided by the technology in situations where the technology does not recognise the entire operational context.**

Users need to evaluate the solutions generated by the technical system against wider contextual information that the automation may not have considered.

c) **How to adapt cognitive and physical work flows to incorporate the information and solutions offered by the technology.**

Technology changes the order and routine in which tasks are completed. Consideration of both cognitive and physical activity changes is necessary. For example, the implementation of electronic flight strips fundamentally changes the brain, eye, hand activities conducted to deliver what is an identical end function. Additionally, automatic coordination can reduce awareness of aircraft approaching the sector and so controllers must adapt their workflow to ensure they widen their visual scan and make a conscious effort to anticipate potential tactical conflicts.

Automation requires more (and different) learning for users. Users need to be re-skilled to be able to interface with it appropriately.

d) **Tasks and actions required in the event of equipment failures, and to deliver required fallback capability and continuation of service.**

Users need to be appropriately skilled and competent to operate in fallback and contingency.

Skills and functions required only in contingency are likely to need refresher training to maintain an appropriate level of capability. Where there is reliance on skills that are not routinely used, training to maintain these competencies is likely to increase as skills fade, or new staff arrive without the old competencies. Where the training requirement to maintain the required level of competency is deemed to be excessive, the system may need to be redesigned such that necessary skills are frequently used and therefore maintained to an appropriate level.

Figure 11: ATC classroom training. Picture courtesy of NATS.

Chapter 9

Theme 7 – Transition

Overview

Manage the adaptation to and normalisation of the automation

There are specific safety and business risks relating to the change from one system or process to another. Transition planning is the key to ensuring the safe, seamless change from one system or process to another. Drawing on the experience of present users and training them for future systems will enable an efficient and safe transition.

Transition can be carried out in several phases from pre-operational training, validation trials, live shadowing, and limited operational service prior to full operational service. It is important to manage the overall schedule of change to prevent multiple changes causing ‘the perfect storm’.

New equipment, interfaces, procedures and skills all take time to bed-in and contingency is needed to ensure any late breaking issues can be resolved before the next change occurs.

Principles

7.1 A transition plan for each deployment should address:

a) **The workforce dimension of the technology deployment.**

Depending on the scale and type of technology deployment, there could be significant effects on the workforce. Tasks and roles could change, jobs could be lost, people may need to relocate. Failure to manage these effects will inhibit the ability to involve users in the design and development, which is so necessary to ensure a safe and efficient system. This approach also supports achieving user understanding and buy-in.

b) **The effects on human performance.**

The introduction of new technology is likely to reduce or remove users’ adaptive capacity when it is first introduced. It could create an increase in workload and reduced capacity until workflows and processes become engrained.

Adaptations in human performance can occur as users refine their understanding of the technology.

c) **Interim capacity management.**

Regardless of how much training people are given, there is always a learning curve, as people get used to the new environment, perfect their new skills and fine-tune their focus of attention. Despite prior training, live operation may require a transition phase where workload and capacity is managed to cater for user adaptation.

d) **Reversion strategies.**

Validation under simulated conditions can be limited. It may be necessary to complete validation in live operation. Live operation may reveal unforeseen problems which require roll back to the original processes and systems.

7.2 For the deployment of multiple tools a longer-term roadmap and an incremental deployment plan should be considered.

A choice has to be made between incremental deployment and multiple simultaneous deployment. In some circumstances, it may be better to deploy multiple tools at the same time. However, this may not be the case in other circumstances where incremental steps are more appropriate. Consideration of the benefits and drawbacks of each approach is needed.

Particular technologies may be dependent on other systems being in place. Additionally, the potential for users to become overloaded by the amount of change needs to be considered and managed. In these circumstances, an incremental deployment may be required.

Figure 12: Manchester Airport new ATC Tower (2013). Picture courtesy of NATS.

Chapter 10

Theme 8 – Emergence

Overview

Monitor and act on emergent properties and behaviours

The deployment of innovative technology is likely to result in unpredictable and hard to foresee properties and behaviours of both the technology and the users. Therefore, intelligence needs to be gathered about how the technology is performing and being used, how it is changing the nature of work and to address any unintended consequences.

Principles

8.1 In-service safety and performance monitoring processes should be implemented to identify and address emergent behaviour from the human-technology integration.

Adaptations in human performance can occur as users/operators refine their understanding of the automation.

Humans use their experience, knowledge, training and intuition to detect cues and subtle changes, to diagnose problems, to adapt, and to create innovative ways to solve problems. Such variances, where positive, should be normalised and promoted. However, variations from intent that may have adverse consequences hidden from the user need to be addressed.

’Automation complacency’ or ‘automation bias’ can develop during operational use. These changes need to be identified as they are likely to undermine assumptions made in the design and early implementation stages.

8.2 Technical design and human performance assumptions and predictions should be routinely reviewed, assessed, validated and updated in service.

It should be assumed that technical and human performance will change over time, this may well undermine design assumptions and predictions.

Old skills, that have been assumed will be maintained, might not last as they are no longer practiced. These changes need to be identified, the consequences considered, and actions taken as necessary to reflect the reality.

ATM technology is reliant on large quantities of data and complex databases. Some of the data will come from automatic sensors such as meteorology or from Mode S transponders. Data may come from look up tables, which are manually updated, such as the BADA model. The databases and data feeds may be automatically or manually checked to mitigate the risk of latent errors that can be masked by the apparent speed and accuracy of the system.

Figure 13: Observation of normal operations is an effective way of identifying emergent behaviour. Picture courtesy of NATS.

APPENDIX A

Abbreviations

Abbreviations	
ANSP	Air Navigation Service Provider
ASM	Airspace Management
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
ATSEP	Air Traffic Safety Electronics Personnel
BADA	Base of Aircraft Data
CAA	Civil Aviation Authority (the UK Competent Authority)
CNS	Communications, Navigation, Surveillance
EASA	European Aviation Safety Agency
GATCO	Guild of Air Traffic Control Officers
HMI	Human Machine Interface
IFATCA	International Federation of Air Traffic Control Associations
IFATSEA	International Federation of Air Traffic Safety Electronics Associations
LOAT	Levels Of Automation Taxonomy
PCP	Pilot Common Project
RNAV	Area Navigation
SESAR	Single European Sky ATM Research
SMC	Systems Monitoring and Control
SWIM	System Wide Information Management

APPENDIX B

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APPENDIX C

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