HindSight 33

Human and organisational factors in operations

EUROCONTROL

DIGITALISATION AND HUMAN PERFORMANCE

FLIGHT DECK HUMAN FACTORS AND DIGITALISATION: POSSIBILITIES AND DILEMMAS

A conversation with FAA's Kathy Abbott

WE NEED TO TALK ABOUT ENGINEERING

Steven Shorrock

FALLIBILITY AND BRILLIANCE

Sarah Sharples

THE MANY MEANINGS OF AI

Erik Hollnagel

BUILDING ADAPTIVE CAPACITY: AMPLIFYING THE COMBINED STRENGTHS OF HUMANS AND MACHINES

Rogier Woltjer and Tom Laursen

Plus much more on digitalisation and human performance in aviation, healthcare, manufacturing, and beyond.

Winter 2021-2022

WELCOME

Welcome to issue 33 of EUROCONTROL's *HindSight* magazine, the magazine on human and organisational factors in operations, in air traffic management and beyond.

This issue is on the theme of **Digitalisation and Human Performance**. It includes a wide variety of articles from front-line staff and specialists in technology, change, safety, human factors, and human and organisational performance in aviation. There are also insights from healthcare and pharmaceutical manufacturing. The articles reflect the possibilities for digitalisation and human performance, and the challenges for individuals, teams, organisations, regulators, industries, and societies.

The authors present a variety of perspectives, some of which are quite different. This is an important aspect of *HindSight* magazine. Some focus more on the possibilities, while others focus more on the pitfalls. It is important that we consider and reconcile these perspectives. As noted in the Editorial, each of us has different attitudes and favoured strategies when it comes to the development and deployment of advanced technology in operations. Taking just one narrow perspective is likely to be problematic.

Digitalisation and human performance are interdependent. We know from decades of research and practice that the two cannot be separated. Ultimately, the success of efforts toward digitalisation depend on people in many roles – technical, operational, human factors, safety, quality, security, training, recruitment, and change management, to name a few.

Special thanks are extended to the authors and the operational reviewers, who help to ensure that *HindSight* magazine is relevant, interesting and useful. While the primary readers are operational staff, especially those involved in air traffic management, it is read much more widely, by different people in different sectors.

We hope that the articles trigger conversations between you and others. Do your operational and non-operational colleagues know about *HindSight*? Please let them know. Search 'SKYbrary *HindSight*' for all issues, covering a wide variety of themes.

The next issue of *HindSight* will be on the theme of **Handling surprises: Stories from the sharp end** (see inside back cover). When surprises happen in operations, many people in different roles are critical to ensuring that things go as well as possible. What's your story? Let us know, in a few words or more, for Issue 34 of *HindSight* magazine.

Steven Shorrock, Editor in Chief of HindSight

Tony Licu
Head of Safety Unit, EUROCONTROL
Network Manager Directorate

DIGITALISATION 2.0

At the time of writing this foreword I am preparing myself to take over the Digital Transformation Office (DTO) of the Network Management Directorate of EUROCONTROL. I feel very honoured, but at the same time I feel a great challenge and responsibility. As part of my preparation, since I had my first conversation on the subject with my Director Iacopo Prissinotti, I wanted to understand what (ATM) digital transformation is. Is it a new buzzword?

Digital transformation means *"adapting an organization's strategy and structure to capture opportunities enabled by digital technology"* (Furr and Shipilov, 2019). This has been happening for decades in all industries. As part of the ATM/ANS ecosystem, we follow the same general pattern.

Computers today – whether in your pocket, in the ops room, or on the flight deck – assist our work and increasingly enable the automation of tasks traditionally done by humans. Digital technology is now inseparable from the world as a whole and how we as people work. And the change is accelerating, whether we like it or not.

Digitalisation 1.0

But for me, this is Digitalisation 2.0. In the 1990s I witnessed and was involved in Digitalisation 1.0 with my previous employer (ROMATSA – the Romanian ANSP), together with colleagues and friends, inspired by the 'ODID IV' EUROCONTROL simulations.

The ODID IV study simulation evaluated the HMI aspects of a modern (at that time) ATC system using colour, graphical displays and a mouse input device within an expanded ATC environment, including approach control, lower and upper airspace sectors. And there were no paper strips. This was back in 1993.

ODID IV included a set of conflict detection aids based on through sector aircraft profiles, updated according to the controller's plan, a dynamic interactive radar label for notation and data input, STCA, en route sequencing assistance for inbound approach traffic, system assisted coordination, colour planning states, a flight leg providing conflict information, and text windows for advance planning information.

This is what we were saying back in 1993: *"Forecast traffic …requires that powerful computers and display systems are introduced to help the controller plan and monitor a continuously evolving and complex traffic situation. Such systems can only assist the controller if they are provided with accurate information, and this requires that the controller updates the system with his/her current traffic plan.*

"The introduction of high-resolution colour raster scan displays together with powerful computers and fast graphic generators has pushed the upgrading of air traffic control systems into the high technology era. Research into the controller-system interface and its use of technology of this nature is required if we are to ensure its successful introduction into the operations room."

Does this sound familiar? Of course, there have been changes. Some of our applications were in DOS! (Some readers will not even know what this means.) We borrowed from MS Windows-type configurations of the screen, moving from the plan position indicator (PPI) radar screen technology to 2Kx2K computer screens. But even then, the controller could – via keyboard input and roller ball or touch input – amend aspects of the current flight plan information and aircraft profiles for purposes of visualisation and inter-sector data transfer. In fact, aside from the replica of the paper strips that were abandoned, the HMI in Bucharest looked the same for over 20 years.

The planned replica of paper strips in electronic form – like you see in Figure 2 – did not fly with our air traffic controllers. Despite slick algorithms for moving the electronic strips and sorting them in time or by level, the controllers just closed them and developed new ways of controlling the traffic. Work-as-imagined proved quite different to work-as-done (see *HindSight* 25), and we had to develop jointly a different way to do the planning and tactical control once we moved to Digitalisation 1.0. In the end, we used sector lists, and the radar screen became less cluttered.

Now, the days of Barco screens with dedicated air conditioning in the consoles are over for many centres. We have more powerful computers and functionality, taking less space, with farm servers and cloud infrastructure in some cases, providing exponentially more computing power.

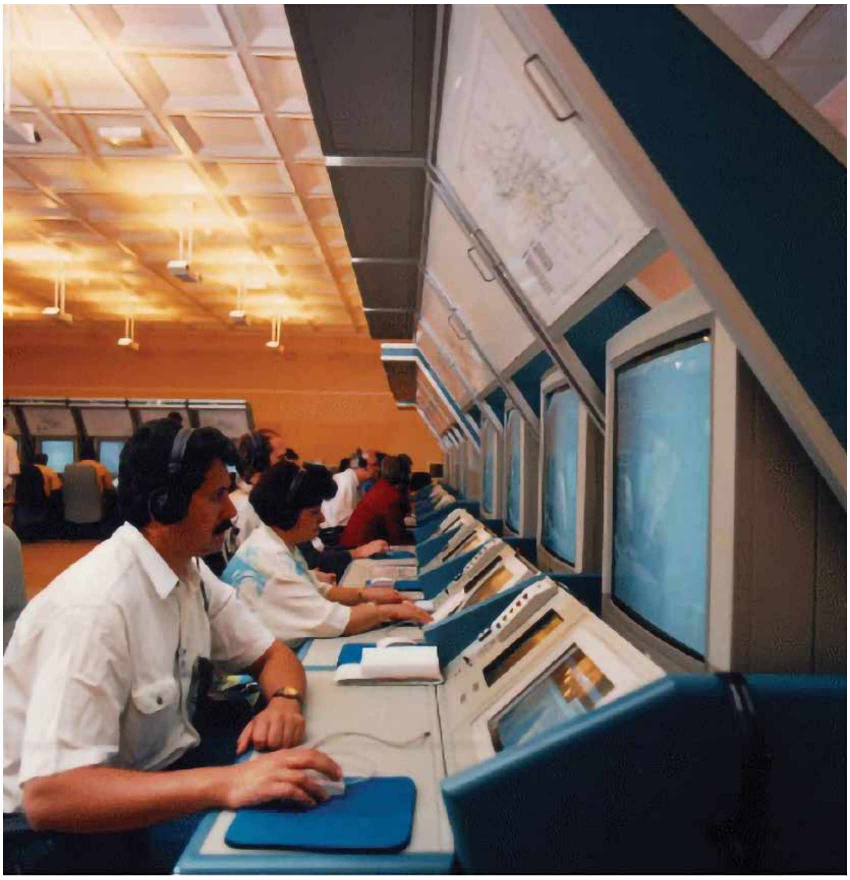

Figure 1. The Romanian 1997 real-time simulation operations room in Brétigny

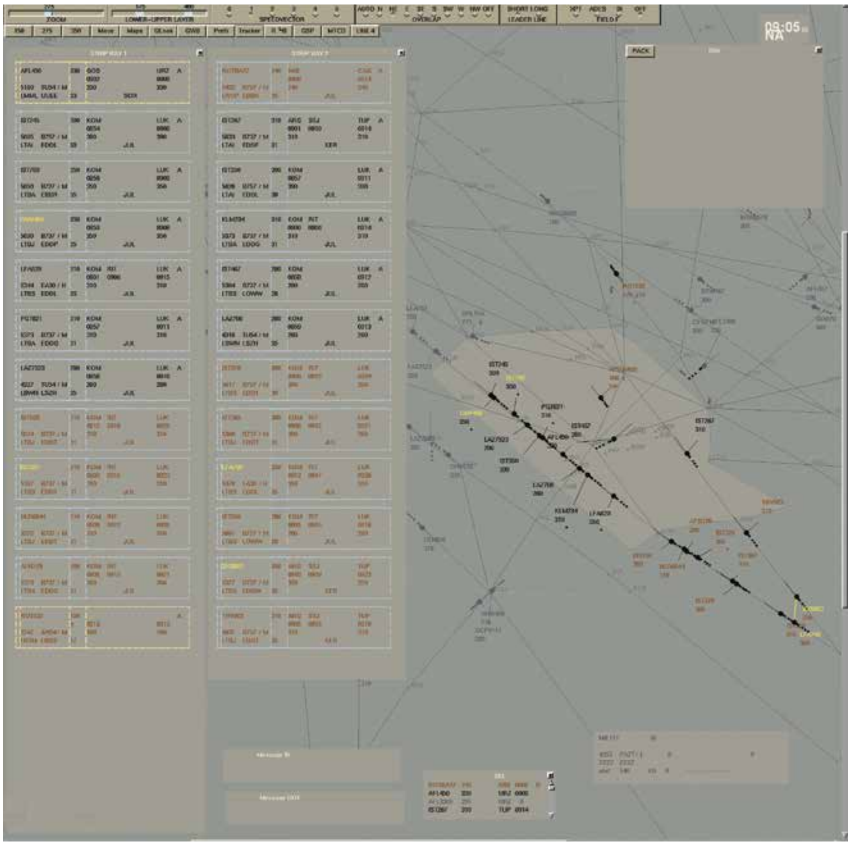

Figure 2. En-route planning display with electronic strips during Romania 1997 simulation in Brétigny

So what is different?

In the 1990s the technology was expensive and inflexible. Change was relatively slow and did little to disrupt how ATCOs, flow controllers, AIS specialists, ATSEPs, and others worked. Partly for those reasons, Digitalisation 1.0 did not shake up ANSPs too much.

Now, as noted by Wessel et al (2016), cheaper and more flexible IT infrastructure have aided newcomers to the market. Not only has technology changed, business models and the whole sector is unrecognisable from the 20th century (e.g., unmanned aircraft system traffic management or UTM providers). These innovators, they argue, *"often seek to displace rather than support legacy organisations, making it critical that older businesses pay close attention to what's changing and adapt when necessary".* The ATM world needs to embark quickly on Digitalisation 2.0, if not already, or else risk being disrupted and losing the market.

Can we adapt?

But can we adapt? *"Many executives have little faith in their employees' ability to survive the twists and turns of a rapidly evolving economy"*, wrote Fuller et al (2019). The head of strategy at a top German bank told them, *"The majority of people in disappearing jobs do not realize what is coming … My call center workers are neither able nor willing to change".*

This kind of thinking is sad but common. There is a perception of the ATM world is that it is conservative, overprotective, and does not want to change and adapt. My experience from the inside is different, but we have a long way to go to prove to external parties that we too are adaptable and resilient.

"Despite slick algorithms for moving the electronic strips and sorting them in time or by level, the controllers just closed them and developed new ways of controlling the traffic"

“The ATM world needs to embark quickly on Digitalisation 2.0, if not already, or else risk being disrupted and losing the market”

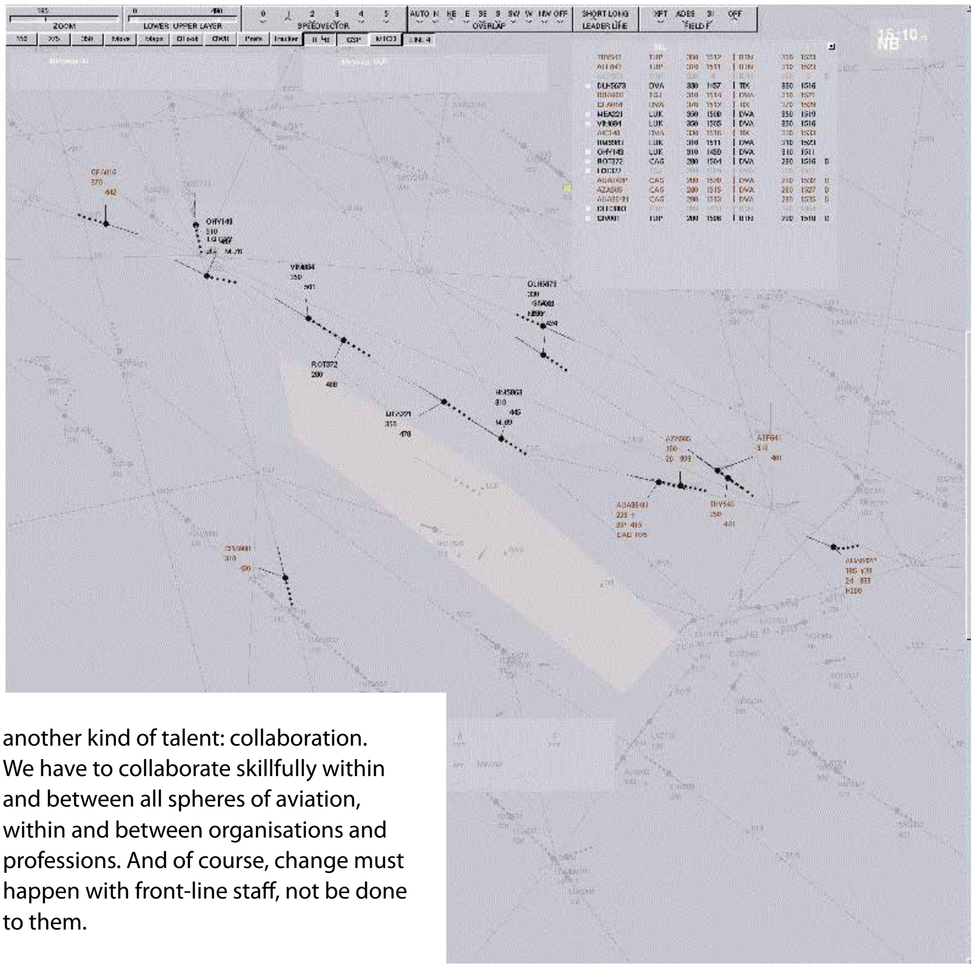

Figure 3. The final radar display after the simulation validation without electronic replica of paper strips

Digital transformation: Talent in four key areas

According to Davenport and Redman (2020), success in ‘digital transformation’ requires bringing together and coordinating talent in four interrelated domains – technology, data, process, or organizational change capability. To put it in aviation terms, they wrote that *“Technology is the engine of digital transformation, data is the fuel, process is the guidance system, and organizational change capability is the landing gear. You need them all, and they must function well together.”* And for that, I would add another kind of talent: collaboration. We have to collaborate skillfully within and between all spheres of aviation, within and between organisations and professions. And of course, change must happen with front-line staff, not be done to them.

This issue of *HindSight* is dedicated to *Digitalisation and Human Performance*. As you read the contents, I invite you to reflect on the changes that have occurred, pay attention to the changes that are occurring now, and get involved in the changes that are coming.

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TENTS

CONTACT US

HindSight is a magazine on human and organisational factors in air traffic management and related sectors. The success of this publication depends on you. Please tell us what you think. And even more important, please share your experiences with us. We would especially like to hear from front-line personnel (the main readership) with a talent for writing engaging articles.

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Jan-Gunnar Pedersen
CEO Avinor ANS

Human performance in the context of digitalisation has gained more importance as ATM undergoes major developments. Over the last decades ATM systems have developed from manual paper-based systems with no or little system support, to digitalised systems providing more advanced support. This redefines the role of the human and how the human interacts with other parts of the ATM system.

The ATM world has witnessed significant changes around every 30 years. The last big change was the implementation of radar to support the ATM system, improving safety and efficiency. Now, new concepts such as interoperability and self-separation are becoming operational reality. Technology provides benefits of improving capacity, efficiency and safety as well as bringing new challenges for human performance. The tasks of ATCOs will change, and they must rely on the system in a completely different way than before.

As part of the iTEC alliance and in collaboration with ANSPs across Europe, we are on the way to modernise our en route ATM system. With this system, the role of the ATCO will be transformed to a supervisory role in detecting conflicts, relying on sophisticated system support. However human skills will still be needed to assess and resolve conflicts that automated systems will detect. A monitoring role will for example bear the potential for out-of-the-loop performance issues, making it more difficult for the human to detect and take action to recover from unforeseen situations.

Paradigm changes in technology like i4D and self-separation concepts call for new or modified skills and competency requirements for the human in the ATM system, parallel to recent developments in cockpit automation. The aviation industry must have learned from those developments that it is critical to make sure the user is in the centre of the design. Realistic assumptions on human behaviour, and knowledge of human capabilities and limitations need to be considered in design. It is critical to understand the extent of the change. Risk assessment methods must account for 'systems in systems' and greater interdependencies between people, technology, and all other elements.

Part of the operational staff in Avinor ANS was temporarily laid off last year due to the situation with Covid-19. As traffic increases again, most ATCOs are now back in operations. We do have experience and measures in place to train personnel returning to work, but the pandemic has shown us new challenges. There is also a need to focus on those that continued to work operationally and now need to adjust their practices to new demands. The consequences of COVID-19 represent added layers of complexity to be tackled by management and the operational environment. There are lessons to consider, now and in the future.

Avinor ANS is implementing a considerable strategic initiative with remote towers in corporation with Avinor AS (mother company). Technology and digitalisation are central strategic areas at corporate level. In ANS en route business area, the development of the future ATM system is a major ongoing programme.

Key digitalisation initiatives are also ongoing for support functions, which operations strongly depend on. One example was to deploy iPad applications that digitalise previously paper-based information for ATCOs. The goal is to optimise the resource demand for administrative tasks. Another example is the development of resource management tools in-house, to optimise management of ATCO resources in production.

The major change toward more automation in air traffic control – shifting from controlling to monitoring the traffic from a human perspective – is as much a cultural change as a change of tools and the human role. As an ANSP we need to foster such a cultural change and as top management we should be aware of the critical role we are playing in building a new culture. The more technology advances, the more important it is to focus on the human dimension in the overall system, for the sake of our employees, our customers, and safe and efficient services.

As from 1 January 2022 Jan-Gunnar Pedersen will be the CEO of Avinor ANS, Norway. Since 2014, he has been the Director of the Business area Enroute. One of his main achievements has been to unify the enroute organisation, from separate ACC units to one organisation operating the ACCs as one virtual ops room. Jan-Gunnar holds an MBA in Aviation Management and has been in Avinor most of his professional career, in various management positions since 2005. Jan-Gunnar was born in the Northern part of Norway in 1969. Although he moved to the Oslo area in 1994, he enjoys spending time in the beautiful landscape above the polar circle.

SKYclips

SKYclips are a growing collection of short animations of around two minutes duration which focus on a single safety topic in aviation. Created by the industry for the industry, they contain important messages to pilots and air traffic controllers with tools for safe operations.

There are SKYclips on the following topics

- Aimpoint selection
- Airside driving
- Airspace infringement
- Airspace infringement and aeronautical information
- Callsign confusion
- Changing departure runway while taxiing **NEW**
- Changing runways
- Conditional clearance
- Controller blind spot
- CPDLC
- Emergency frequency
- En-route wake turbulence
- Helicopter somatogravic illusions
- Immediate departure
- In-flight fire
- Landing without ATC clearance
- Level busts
- Low level go around
- Low visibility takeoff
- Mountain waves
- Pilot fatigue
- Readback-hearback
- Runway occupied medium term
- Sensory illusions
- Shortcuts and unstable approaches
- Speed control for final approach
- Startle effect
- Stopbars
- TCAS - Always follow the RA
- TCAS RA high vertical rate
- TCAS RA not followed **NEW**
- Unexpected traffic in the sector
- Workload management

Each SKYclip is developed by aviation professionals from a variety of operational, technical, and safety backgrounds.

Changing departure runway while taxiing

TCAS RA not followed


Airspace infringement

Mountain Waves

Runway occupied medium term


Unexpected Traffic in the Sector

Find the SKYclips on SKYbrary at https://skybrary.aero/tutorials/skyclips

Steven Shorrock
Editor in Chief of HindSight

DIGITALISATION AT SEA: ALL HANDS ON DECK

In all industries and aspects of society, 'digitalisation' has become a watchword – an idea for directing the way that things are to be done. But people have quite different attitudes about this. How far should we go with digitalisation? What are the implications for human and system performance, and life more generally? In my own experience working on digitalisation projects and reviews with people in operational, technical, safety, and management roles, I tend to notice some distinct groups of 'like-minded people', each of which disagrees with one or more of the other groups. They don't see the world, with all its problems and opportunities, in the same way, nor on the best way to progress.

Related to this, Karnofsky (2021) recently proposed some nautical metaphors for the "different ways of working toward a better world", including the voyage of digitalisation. It is probably fair to say that each of us, and our like-minded colleagues, has different attitudes and favoured strategies when it comes to the development and deployment of advanced technology in operations. As you read on, you may even see yourself and others in one of the nautical metaphors below.

Rowing

Rowing involves helping the ship to reach its current destination more quickly. Advancing technology, or taking advantage of technological developments, is the primary focus, with an emphasis on speed. Rowing tends to be the preferred strategy of *technological solutionists*, who have most understanding of hardware and software (e.g., engineers), are more familiar with it (e.g., operational superusers), or who favour digital solutions for other reasons (e.g., entrepreneurs).

Rowing is obviously necessary for progress, and to gain competitive advantage. As the saying goes, *"Time and tide wait for no man."* There are indeed advantages to be gained from the now-familiar cloud computing and speech recognition technologies, and less familiar artificial intelligence and virtual and augmented reality technologies. But we should not assume that all technological development is good. Hazards are harder to see at speed, and a focus on speed – like 'press-on-itis' in piloting – brings new risks. For instance, there can be insufficient opportunity or willingness for necessary checks and coordination. Overconfidence, simplifications, and assumptions can prevail. As multiple different technologies are developed and connected at speed, technological complexity grows, along with unintended consequences.

Steering

Steering involves navigating toward or away from a destination or points along the way. Steering tends to be the preferred strategy of *technological sceptics* and those with a more long-term and systemic perspective, who are not against digitalisation *per se*, but who question the claims of technological solutionists. This group tends to have

"Each of us, and our like-minded colleagues, has different attitudes and favoured strategies when it comes to the development and deployment of advanced technology in operations"

more understanding of complexity and the wider context within which technology is introduced (e.g., safety scientists, complexity scientists, systems practitioners), but not always (e.g., policy-makers). The group is also likely to have a greater understanding of history and lessons from the past (e.g., major accidents or failed programmes).

From this perspective, speed is secondary to direction and route when it comes to advanced technologies. What might be the unintended consequences of advanced technologies, and are the intended consequences well thought out? Some of these consequences may only be evident after deployment, while others are more foreseeable, with the right expertise. Karnofsky argues that *"'steering' has become a generally neglected way of thinking about the world"*, as the primary focus is on rowing.

Anchoring

Anchoring involves holding the ship in place, or attempting to maintain the status quo. In terms of digitalisation, anchoring tends to be the preferred strategy of *technological conservatives*, who are more likely to oppose continued digitalisation or see significant threats. But there are downsides to staying put. Karnofsky notes that there has been enormous change in the last two centuries and huge improvements in life quality for people (but not animals) on most known measures. There have also been remarkable improvements in safety-critical sectors with technological advancements.

So-called rosy retrospection – our tendency to recall the past more fondly than the present – can be problematic. Many of us seem to think the music of our youth was the best, and some have similar attachments to technologies and worldviews. We may even wish to row backwards (forming another strategy – *reverse rowing*).

But Karnofsky argues that a weaker version of 'anchoring' can be constructive: *"asking that changes to policy and society be gradual and incremental, rather than sudden, so we can correct course as we go".* As Frischmann (2018) wrote, an anchoring strategy *"enables critical reflection and evaluation of the technological world we're building".* Anchoring allows time to think about our steering and the pace of our rowing. This can be the role of several stakeholders, such as regulators, professional associations, the media, and academics in certain disciplines.

Equity

Equity involves working toward fairer relations between people on the ship. For any voyage, there are people with different characteristics on board. It is helpful for harmony and effectiveness if resources and opportunities are fairly distributed, and the right conditions exist for people to contribute their expertise. With digitalisation, equity may seem less obvious as a strategy, but many groups are grossly underrepresented not only as employees but (and partly by consequence) in the products, as their needs are not met. This is eloquently explained in the context of big data by Caroline Criado Perez in her intensively researched book, *Invisible Women*.

The agile-minded approach

So which is the best approach for our voyage of digitalisation in safety-critical industries? The answer is "none", or rather, "it depends". As Karnofsky remarked, *"The details of where the ship is currently trying to go, and why, and who's deciding that and what they're like, matter enormously."* And there are also details that matter enormously about where the ship is now, who is on it, their expertise, and the many contexts of work (technical, physical, environmental, social, cultural, regulatory, etc.). Crucially, people's expertise concerns not only technology but also fields such as operations, complexity, systems, change, diversity, resilience, and human factors.

Even if we recognise 'favoured' strategies in ourselves or others, we rarely challenge our own interests and ways of thinking. It is problematic to get stuck in our ways, in our like-minded groups. We can become known for one mindset and one strategy. Our approaches can be in opposition, and a fifth strategy identified by Karnofsky can even emerge – *mutiny* (at least a soft form of it). There could be a variety of states that no-one wants, such as *drifting*, or worse.

To be more credible and useful in conversations about digitalisation and human performance, it is better to be agile enough to consider different worldviews and approaches, depending on the situation. The success of our voyage will depend largely on how well we communicate – negotiating and reconciling important differences – and the resulting choices that we make. Since digitalisation and human performance are inseparable, we need to come together to try to do the right things right. In the words of acclaimed transoceanic solo sailor Francis C. Stokes Jr., *"In the end, the sea finds out everything you did wrong."* S

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FALLIBILITY AND BRILLIANCE

For over 70 years, it has been recognised that people and technology need to be designed to work well together. **Sarah Sharples** explores some of the implications of introducing technologies into complex work settings.

In 1951, Paul Fitts, the first director of the Psychology Branch of the Aerospace Medical Research Laboratory at Wright Field, produced a list which compared the capabilities of people and technologies. This became known as Fitts' list, or MABA-MABA ('men are better at, machines are better at', in 1950s language). While much has changed since then, one of the things I often say to my students when describing my work as a human factors professional is that "humans are brilliant and humans are fallible". We need to minimise the impact of human fallibility, and maximise the opportunity for human brilliance. But the idea applies equally well to technology.

Integrating people and technology

Over the past two and a half decades, I've worked on projects that have explored the implications of introducing technologies into complex work settings. The range of ways that we have seen aspects of work designed to combine novel digital technologies and people is vast. This is especially true in manufacturing. An interesting example is the production of high quality mirrored metallic products, where the majority of the manufacturing process is automated. Despite the degree of automation in the process, one element depends on tactile feedback and skilled variation of pressure and movement – the metal polishing task. This remains best completed by an expert person.

In a healthcare context, medical image recognition, such as cancer screening, has benefitted from the gradual improvement in computer vision and algorithms resulting in technology to speed up scan interpretation processes. In rail transport, we see many examples of people and technologies working together on route setting tasks. The underpinning timetabling information enables the majority of routes to be managed through automated route setting, but in case of disruption or non-routine routes, the operator is required to maintain active control.

Each of these examples presents challenges. In metal polishing settings, the job can be lonely. The person is in a setting dominated by machines, and skills retention and succession planning for such a highly skilled and practised task can lead to concerns around system resilience. In the medical screening setting, questions are raised about accountability of decisions, and the impacts on learning and familiarity with the task of interpretation of images. And in the rail setting, we frequently see operators choosing to override automatic route setting technologies, not only to improve system performance, but also due to their own preference for the way that they complete the task, being keen to remain 'in the loop'.

The changing human role

A key lesson is that, very often, digitalisation does not completely replace a person. Instead, it changes their task, job or role. In her seminal paper 'Ironies of Automation', Lisanne Bainbridge noted that we tend to automate those elements of a process that are easy to automate. This can lead to the phenomenon of 'leftover automation', where there is a piecemeal set of tasks, and associated impacts on situation awareness, job satisfaction and performance.

> "Very often, digitalisation does not completely replace a person. Instead, it changes their task, job or role"

This leads to questions about what we can do together, as professional experts involved in aviation and other sectors, to ensure that we maximise the potential brilliance of people and technologies, and minimise the impact of fallibility. In human factors practice, we have always embraced the philosophy of 'fitting the job to the person'. Perhaps this is now better described as 'fitting the work to the people', or even, 'fitting the system to people and technologies'. Whatever approach we take, retaining our curiosity is key.

Living laboratories

In my current role, embedding scientific thinking in transport settings, we see some great examples of 'living laboratories' where technologies are tested in real-world settings. The real world, and the multiple ways that different users interact with technologies is very hard, if not impossible, to mimic in a laboratory or simulated setting. This is especially clear when we see interactions between different data sets or people with different purposes. Deploying technologies in particular environments can help us to iterate technology and design solutions to meet people's needs, whether it is an app to deliver an active travel solution, or data to support transport management and decision making.

The key is to ensure that we learn from these settings, capturing both quantitative and qualitative data to understand what is working, and what needs to be changed. This can be done with the help of structured conversations with users, and expert observations to learn from the tacit expertise of users in their workplace settings, understanding the complex interactions of different activities and work contexts. To supplement such data, we can use data derived from the technology itself, and measure physiological responses, such as heart rate variability, face temperature, blood flow in the brain, or eye movements.

In learning from real-world technology deployments, developing theories of human-technology partnership is also important. Theoretical concepts and frameworks – such as workload, situation awareness, joint cognitive systems, and affordances – provide descriptions and explain patterns which we see in multiple settings. These theoretical frameworks help us to conceptualise complex systems, and enable us to transfer learnings between different work settings and industries.

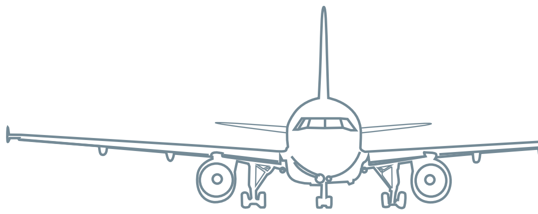
"We need to get the right balance between understanding the 'here and now' and thinking differently about the future"

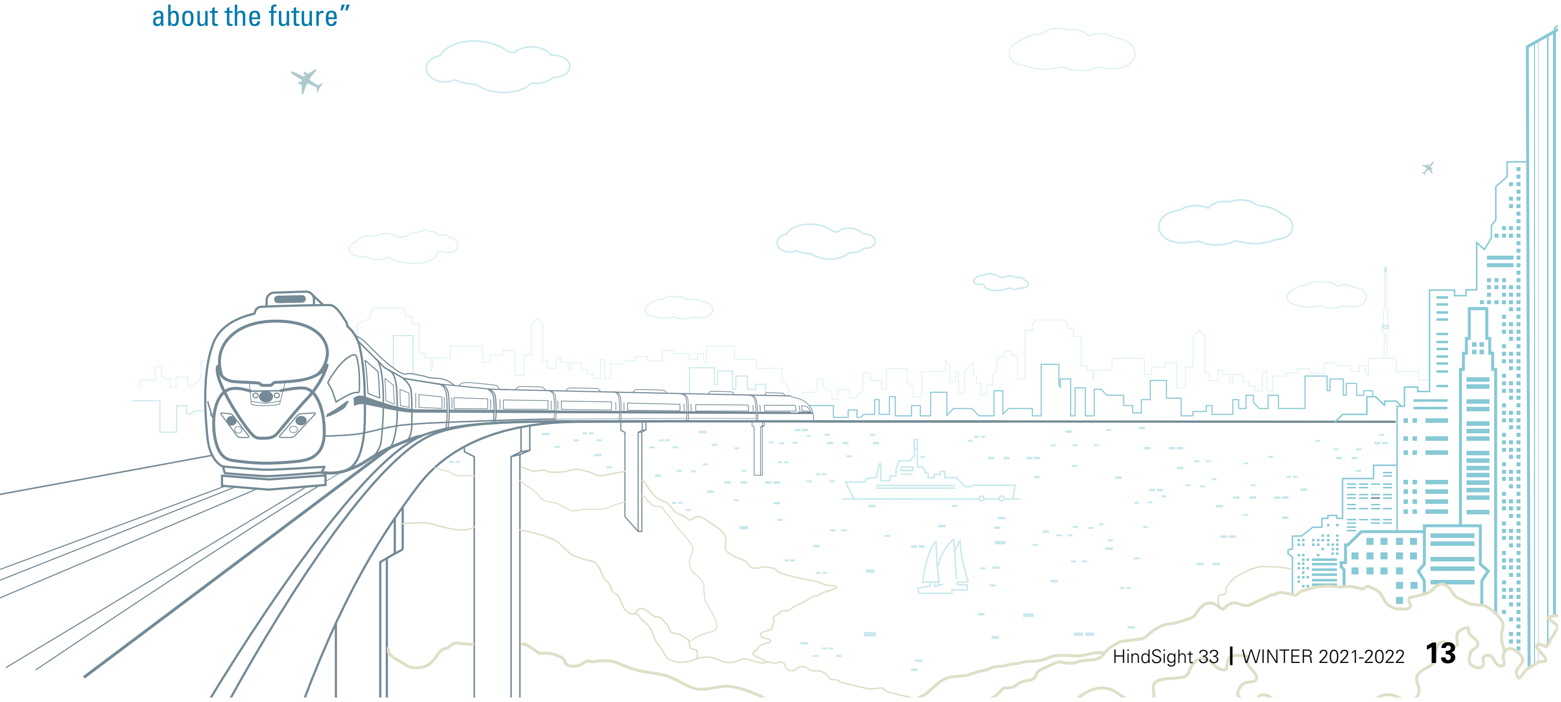
Systems thinking and innovation

Most complex work settings involve multiple people, multiple settings, multiple roles, and multiple technologies. With digitalisation, we have different actors responsible for different parts of the system, from design through control and maintenance. It is not enough to learn from each system element. We also need to understand how they interact. It is therefore critical to take a systems perspective. It is challenging to study work and represent it in a way that captures that complexity, whilst enabling understanding by others who may be responsible for designing and implementing technologies. But it is only through understanding and embracing complexity that we can deliver the best value from digitalisation.

In doing this, we need to get the right balance between understanding the 'here and now' and thinking differently about the future. 'Design blindness' can limit our ability to think beyond the familiar. This is best typified by the mythical Henry Ford quote that if he had asked people what they want, they would have said "faster horses". This probably applies beyond just design. We all need to look at the world differently and think differently to understand how people and technology work together as a joint system, minimising the impact of fallibility and maximising the opportunity for brilliance. Whatever our role we all have a crucial part to play. S

Sarah Sharples is a Professor of Human Factors in the Faculty of Engineering at the University of Nottingham. She has led research in transport, manufacturing and healthcare, and currently leads the Engineering and Physical Sciences Research Council (EPSRC) 'Connected Everything Network Plus'. She was President of the Chartered Institute of Ergonomics and Human Factors from 2015 to 2016. Sarah was recently appointed Chief Scientific Adviser for the UK Department for Transport. **https://www.gov.uk/government/people/sarah-sharples**





THE MANY MEANINGS OF AI

Artificial intelligence is often seen as the pinnacle of the drive for digitalisation, but there are pitfalls along the way. **Erik Hollnagel** takes us on a potted tour of AI, its many meanings, and its proper use.

KEY POINTS:

- **We have developed technology throughout history to amplify our abilities, but amplification has worked less well for cognitive abilities than for physical abilities.**
- **Technology is often used to replace or substitute human functions rather than to amplify or support them.**
- **Automation to replace human functions with technology has often failed to support people to remain in control of what happens.**
- **Digitalisation could usefully amplify what we do well, to amplify intelligence, while we stay in control.**
- **Piecemeal development of advanced technical solutions makes it impossible to comprehend the consequences of digitalisation.**

In the 1980s, the first large-scale commercial applications of artificial intelligence (AI) began – although AI in those days was called 'expert systems'. Among those who worked in the business it was often joked that the acronym AI had different possible interpretations. For academics AI meant Artificial Intelligence; for hackers it meant Anything Impossible; for defence it meant Anything Invincible; and for marketing it meant Anything Interesting (and still does?). But there is a fifth and perhaps more appropriate interpretation: Amplified Intelligence.

The digital dawn

We are today, for better or worse, forced to cope with digitalisation. Despite the frequency by which the term is used at present, digitalisation actually began in the 1960s with the first message sent over the ARPANET in 1969. The first expert systems saw the light of day in the early 1970s, well before the advent of the personal computer (Apple II in 1977 and the IBM PC in 1981). Digitalisation, meaning the conversion of text, pictures, or sound into a digital form and not least the processing thereof by computing machinery, had during the 1970s gradually been introduced in safety-critical process control (Netland & Hol, 1977) and in many service applications.

In the following decades digitalisation became ubiquitous and completely transformed daily life, first in industries and then in our private and public existences. It would therefore seem reasonable to assume that the problems of digitalisation by now have been completely solved. The reason why this is not the case, hence the motivation for this special issue of HindSight, is that the short-term benefits of digitalisation for human performance often have been outdone by the longer-term problems that digitalisation creates.

Technological amplification of human abilities

Humans have always striven to make their lives easier by overcoming the limitations of their 'natural abilities'. The body and the brain, the human physiology and psychology, unmistakably limits what we are able to do. Finding ways to overcome these limits has been a human endeavour from the beginning of civilisations. Our natural intelligence has allowed us to develop technological 'amplifiers' and clever ways of using them. Physical abilities have been amplified with regard to power, speed, reach, precision, and endurance. Sensory abilities have been amplified with regard to size, distance, duration, scale, and thresholds. And mental or cognitive abilities have been amplified with regard to speed, quantity, and permanence. Early examples include the wheel, the lever, bow and arrow, the abacus, cuneiform writing, later followed by the telescope and microscope, various forms of engines, calculating machines, and computers.

Amplification has worked well for physical abilities but less so for cognitive abilities. This became obvious in the mid-1940s when the technologies were used to build partly self-controlling systems that were too fast and complicated for what the unaided human could manage. But the faster things happen, the more important it is to remain in control. This created a need to engineer for 'the human factor', often ironically by using even more technology as a substitute for what people could not do well enough. The dilemma was clearly stated by Paul Fitts:

"We begin with a brief analysis of the essential functions ... We then consider the basic question: Which of these functions should be performed by human operators and which by machine elements?" (Fitts, 1951).

In 2019, more than 70 years later, the FABEC (Functional Airspace Block Europe Central) expressed their

AI Augmented Intelligence

ARTIFICIAL INTELLIGENCE

ALGORITHMIC INDEPENDENCE

Augmented Ignorance

ANYTHING INVINCIBLE

Anything Interesting

Anything Impossible

automation strategy in almost the same way: "Let ATCOs focus on the real, challenging work, to do what they are the best at, and leave the routine work to the machine".

System innovation is often driven by what humans cannot do rather than by what they can do. Technology is often used to replace or substitute human functions rather than to amplify or support them.

Staying in control

Paul Fitts introduced the use of automation to replace human functions with technology. But this use failed to acknowledge the essential condition that it is necessary at all times to remain in control of what happens. Humans are aware of what they are doing and can imagine what the outcomes may be. Machines and technology can do neither. Digitalisation relies on highly effective but poorly understood algorithms, and AI is even worse in this respect. By replacing human functions with technology that is not fully comprehensible, control is gradually and irretrievably lost. Forty years ago, Earl Wiener noted that "It is highly questionable whether total system safety is always enhanced by allocating functions to automatic devices rather than human operators, and there is some reason to believe that flight-deck automation may have already passed its optimum point" (Wiener & Curry, 1980).

> "Amplification has worked well for physical abilities but less so for cognitive abilities"

The problem with the substitution philosophy is that "the designer who tries to eliminate the operator still leaves the operator to do the tasks which the designer cannot think how to automate" (Bainbridge, 1983). The need to leave some parts of the work to humans is seen as a deplorable shortcoming of technological prowess, but also as something that soon will be remedied.

The unwavering technological optimism is one of the reasons why AI is the ultimate dream of automation and seen as the final (?) technological fix. Some even hope that we soon will reach 'the singularity' where machines will become truly intelligent and predict that Artificial General Intelligence will have arrived by 2040-50. Others see this as a hypothetical point in time at which technological growth irreversibly becomes uncontrollable.

But rather than using digitalisation as a substitution for what humans cannot do, it can also be used to amplify what they do well, to amplify intelligence. (This idea has a long history and was introduced as intelligence amplification by Ashby in 1961.) Instead of using digitalisation to replace what humans do badly, it should be used to support what humans do well, and stay in control.

The pitfalls of technological solutioneering

Humans have always been attracted to promises of nice and easy solutions. There has been no shortage of these either in the context of work or in other areas of human endeavour. Human factors – or human factors engineering – may itself be seen as a 'nice and easy' solution, in the sense that it can overcome the problems arising from "the production of mechanical monstrosities which tax the capabilities of human operators" (Fitts, 1951, p. iv), or in today's terms be used to reduce human error, increase productivity, and enhance safety and comfort. Even if it usually is more difficult in practice than the theory. It is a sobering thought that Norbert Wiener – the creator of cybernetics – at the very beginning of digitalisation wrote about "gadget worshipers, who regard with impatience the limitations of mankind, and in particular the limitation consisting in man's undependability and unpredictability" (Wiener, 1964). Fifty years later the view was forcefully repeated when Morozov (2013) wrote about 'solutionism', defined as "an intellectual pathology that recognizes problems as problems based on just one criterion: whether they are 'solvable' with a nice and clean technological solution at our disposal".

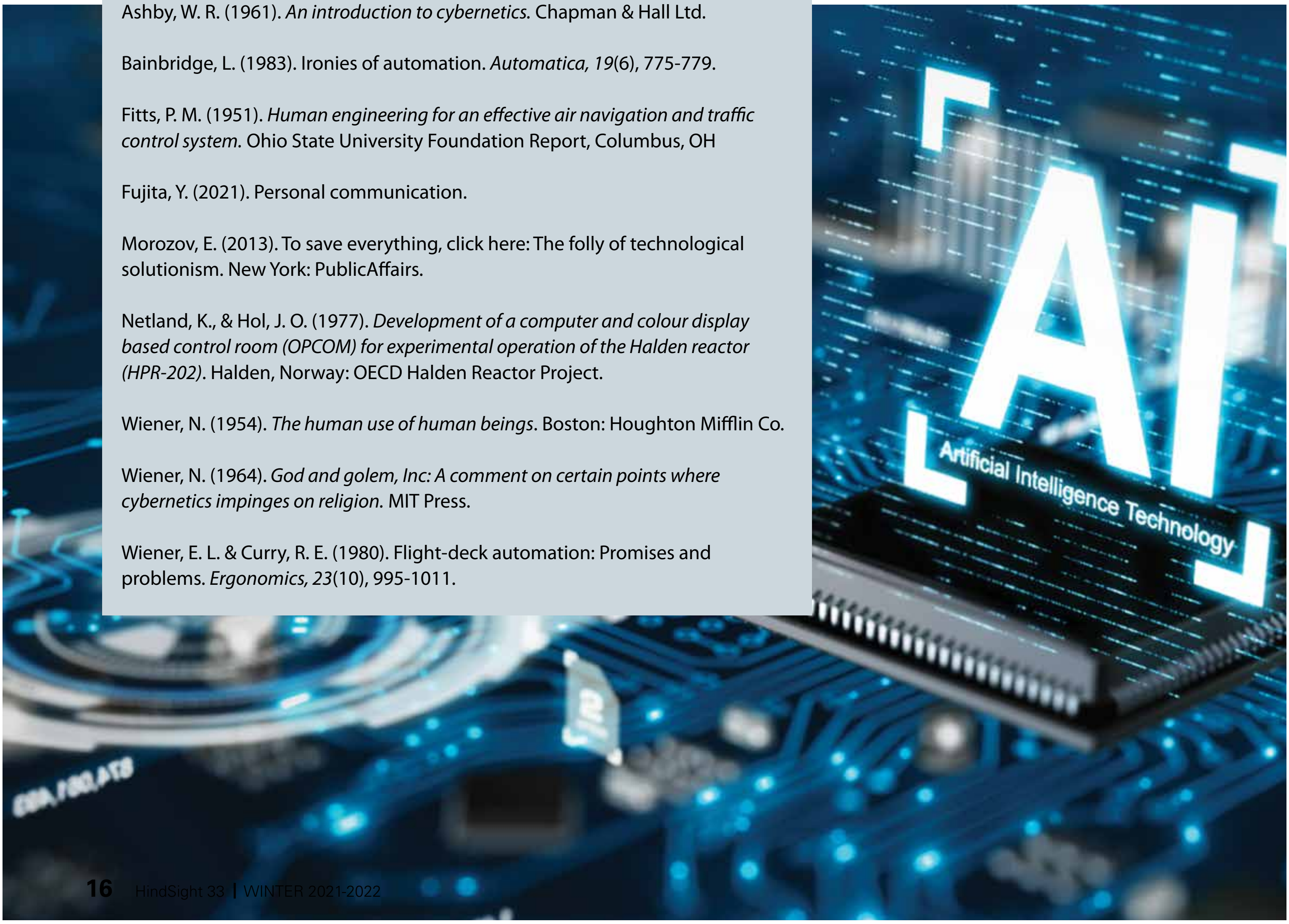
The uncritical and overoptimistic belief in digitalisation is a form of solutionism, with the inevitable consequence that we will lose control of what we do. Problems are traditionally solved by breaking them into manageable parts which then are attacked and solved one by one, as if they could be dealt with in isolation. By doing so it becomes impossible to comprehend the consequences of what we are doing (Augmented Ignorance; Fujita, 2021), which in a vicious circle increases the need for 'nice and clean' solutions. Norbert Wiener characterised this situation as far back as 1954 by noting, "[W]e have modified our environment so radically that we must now modify ourselves in order to exist in this new environment".

Algorithmic independence?

But the problem is not with digitalisation as such, since digitalisation is not even remotely intelligent. The problem is with how it is being used. Digitalisation basically relies on sophisticated algorithms that can solve well-defined problems with amazing ease. Because of the convenience they provide, we accept them one by one, enticed by the many advantages and oblivious of the drawbacks. (This is currently most obvious in the case of the social networks, but it is just as serious a concern in less conspicuous applications). So perhaps amplification of intelligence should be supplemented by a sixth interpretation of AI: Algorithmic Independence. Digitalisation all too easily creates algorithmic monstrosities that we then have to find yet another 'nice and easy' solution for. S

"Rather than using digitalisation as a substitution for what humans cannot do, it can also be used to amplify what they do well, to amplify intelligence"

Erik Hollnagel is professor emeritus from LiU (S), ENSMP (F), and SDU (DK). His work focuses on unified system change and management. He is the author of more than 500 publications including articles from recognized journals, conference papers, and reports as well as twenty-eight books, and is still struggling to make sense of the blooming, buzzing confusion.



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A conversation with FAA's Kathy Abbott
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Steven Shorrock
FALLIBILITY AND BRILLIANCE
Sarah Sharples
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FLIGHT DECK HUMAN FACTORS AND DIGITALISATION: POSSIBILITIES AND DILEMMAS

A CONVERSATION WITH FAA'S KATHY ABBOTT

While there have been several decades of research on automated systems and human performance on the flight deck, developments in technology are accelerating the potential for change. **Steven Shorrock** talked to **Kathy Abbott**, one of the FAA's Chief Scientific and Technical Advisors, about the possibilities for digitalisation, some of the dilemmas we still have to address.

KEY POINTS

- **Digitalisation is enabled by availability of big data, and improvements in sensors and data storage. There are many possibilities to improve NOTAMS, CPDLC, safety data, and many other applications.**
- **'Reduced crew' long-haul operations are attracting industry attention, but issues of information, control, and responsibility remain critical. Introduction of automated systems may change the kind of staff needed, without necessarily reducing staffing.**
- **The safety continuum helps the FAA's Aviation Safety organisation to determine the appropriate level of rigour in standards, policies, and processes.**
- **As well as technical expertise, there is a need for more expertise in operations and the operational environment, human factors, complexity, and systems thinking. Lessons learned from experience, including unintended consequences of the introduction of automated systems, must not be forgotten.**
- **Pilots, controllers, and other frontline staff can have more of a say in the drive for digitalisation through participation, working through the staff associations and labour unions.**

In the world of flight deck human factors, few names are better known than that of Dr. Kathy Abbott. Dr. Abbott is the Chief Scientific and Technical Advisor for Flight Deck Human Factors in the Federal Aviation Administration. Along with the FAA's other Scientific and Technical Advisors, she applies her expertise to the promotion of safety-enhancing innovation, policies, and practices in the FAA's regulatory, certification, and oversight programmes. In short, Dr. Abbott is the most senior technical person in the FAA when it comes to flight deck human factors.

Dr. Abbott 's expertise spans aircraft certification, equipment design, and flight standards, through operations, pilot training, safety investigation, and data analysis. In other words, *"anything that touches the pilot"*. Starting her education in mathematics and information science, she went on to study computer science up to doctoral level, before spending 16 years at NASA as a research engineer. With over 26 years at FAA since then, there are probably few in the world more qualified to talk about digitalisation and human performance in the flight deck.

Enhanced capabilities

Digitalisation is nothing new, either in the flight deck or on aviation more generally. There are thousands of research articles and reports in human factors, and many applications already. So I was curious about why it is a trending topic now. Why are we hearing more about automated systems, autonomy, and artificial intelligence? Dr. Abbott reflected that several enablers that may be fostering this. *"One key enabler is the availability of big data, with improvements in sensors and data storage."* Developments in these technologies bring a realisation that we can get more value from these enhanced capabilities, that we can do more than we could do before, via technological applications.

One example is what Dr. Abbott described as *"a perennial problem"*: NOTAMs, or notices to airmen. *"Hopefully, digitalisation will help us do a better job of putting NOTAMs in a usable form for pilots and for other people that need to use those data."*

A second example application is controller pilot data link communication (CPDLC). *"This is changing the way that pilots and controllers communicate. And there are consequences because we're not eliminating voice – it's a mix of digitalisation and the way that we've done it by voice."*

Then there are applications for safety data, and the ability to process big data to take advantage of the data that we have. *"We have more data than we can really process right now from different data sources. And of course, the interest in the safety side of things is to use that. Can we find the risks and mitigate them before they become an accident?"* Dr. Abbott noted the potential to use data also to analyse what people do well, though in some ways this can be more difficult in practice.

Single pilot operations and the pilot role

Such applications are significant, but with burgeoning digitalisation come new concepts of operation that are even more fundamental, and controversial. There has been some interest from airlines, as well as airframe manufacturers, in 'reduced crew' long-haul operations, where a sole pilot is in the flight deck for much of the time. A primary motivation is cost saving, along with airline flexibility, partly achieved via reduced staffing. The topic has been subject to intense commentary and increasing research over recent years. I was curious about the key issues for human performance, but also for safety more generally.

We began with the most fundamental consideration: that the pilot in command is responsible for the safety of flight, and as long as you hold that person responsible, you have to enable them to do the job. With increasing automation and autonomy, issues of information, control, and responsibility become inseparable. *"At what point can the pilot no longer be held responsible?"*

Issues of liability are also likely to become much more complicated. *"You can't hold a piece of equipment responsible from a legal point or regulatory point of view. I think we need to have fundamental considerations of how responsibility and liability get distributed in some of these new concepts."* This could be complicated further by differences between legal jurisdictions that pilots may enter.

Another issue concerns the safety contribution of the second crew member. Without that crew member, *"how do we know that we have fully mitigated the risks that may be involved?"*, asked Dr. Abbott, *"and what assumptions were made and how would those have to be changed?"* An 'obvious' topic concerns pilot incapacitation. *"If you only have one pilot, are you essentially requiring a pilotless aircraft capability?"* Then there are licensing implications, such as the potential effects on medical requirements because of the risks of incapacitation. There are many other fundamental questions and concerns, also depending on whether one is considering the modification of existing aircraft or the design of new aircraft.

"You can't hold a piece of equipment responsible from a legal point or regulatory point of view. I think we need to have fundamental considerations of how responsibility and liability get distributed in some of these new concepts."

These are some of the considerations that affect whether it is possible to achieve the level of safety required with a single pilot for public acceptability. The FAA 'safety continuum' can help to focus its safety resources in line with the public's expectations. *"We refer to the safety continuum as a way of characterising that acceptable levels of safety and certitude differ for different groups or categories of aviation, and different levels of risk. Public transportation has to have a higher level of safety than private transportation."*

The safety continuum is integral to the FAA's standards and oversight. It helps the FAA's Aviation Safety organisation to determine the appropriate level of rigour in standards, policies, and processes. For newer concepts such as advanced air mobility, this raises questions such as 'What is the risk that's acceptable for that operation?' and 'How does it interact with others in the aviation system?'

Returning to reduced staffing, in many cases, even this is not so straightforward. Referring to work by the United States Air Force, Dr. Abbott revealed a counter-intuitive finding: with unmanned aircraft systems, staffing needs increased. Experience in other parts of the military has found that the introduction of automated systems changes the kind of staff that you need, without necessarily reducing staffing. *"If you're not reducing staffing, are you really reducing costs or are you just shifting cost around? And how do you assure that you've achieved the same level of safety or better?"*

Dr. Abbott sees opportunities, but also risks if we don't manage those opportunities properly. *"We want to leverage the benefits of new technology, but just because it's new technology doesn't necessarily mean it's an improvement, or that the cost benefit from a safety point of view is as imagined. It's important to be realistic."* There can be crucial differences between claims and operational reality.

Digitalisation and the varieties of human expertise

With the drive for more digitalisation, there is an obvious need for technical expertise. This finding mirrors experience in air traffic management, where the need for technical expertise is outpacing other forms of expertise. Often, the expertise is highly specialised, concerning specific technologies. There is much human factors research and practice in the design and engineering of aviation systems, especially in terms of aircraft certification. But the lion's share of attention is on operational actors such as air traffic controllers, with very few studies on engineers responsible for software development (and engineers in air traffic management generally).

Dr. Abbott noted that engineers who are designing systems often don't have extensive knowledge of operational work and the operational environment, and how technology is (or will be used) in reality. *"I personally have heard design engineers say that they don't understand why it's a problem, that it works exactly as designed. So that's one of the challenges. It does work exactly as designed."* Technology may work from the point of view of doing what the designers intended it to do. But from operational perspectives, there are often considerations that the designers either didn't or couldn't know about, concerning the variability and complexity of operations.

While this is familiar territory in human factors engineering, it is often not 'part of the curriculum' for those many engineering roles, such as software engineering, who do not always require specific formal qualifications, even in aviation. *"It doesn't mean that every single person has to have all that knowledge, but they certainly need to be working as part of a multidisciplinary team so that it gets addressed."* Now and over the coming years, there is a pressing need for more expertise in operations, human factors, complexity, and systems thinking, when it comes to technical development.

"If you're not reducing staffing, are you really reducing costs or are you just shifting cost around? And how do you assure that you've achieved the same level of safety or better?"

Unintended consequences

One of the concerns about digitalisation, automation and autonomy concerns the understanding of engineers – especially those who are relatively new to aviation – who may be unaware of the findings of human factors research, and the lessons learned from experience. *"It's important for the human factors community to make sure that those lessons get communicated so that we don't have some of the same mistakes because we have systems now that are going to be even more capable."*

One of the lessons learned is that new technology often introduces unintended consequences. *"All of that needs to be looked at from a broad and integrated perspective, not just in isolation for the one specific kind of system. We've seen so many cases where there are side effects that were not expected."*

The problem, said Dr. Abbott, is not a lack of willingness to consider unintended consequences, but that people in technical roles lack of the knowledge of how to do it, or haven't brought in the people who can help do it. Predicting so-called 'emergent properties' of new technology is notoriously difficult, and even more so when expertise in individual technical systems, or even technical system architecture, is not matched by expertise in systems thinking (including systems engineering), complexity science, and human factors.

> "We've seen so many cases where there are side effects that were not expected."

Integrating human factors expertise

The need for human factors research and practice in the context of digitalisation and automated systems has been known for decades. But the issue has more recently come into sharp focus via the recommendations of reports on the B737 Max accidents by the National Transportation Safety Board (NTSB), the FAA's Joint Authorities Technical Review (JATR), the US Department of Transportation Special Committee, and Indonesia's Komite Nasional Keselamatan Transportasi (KNKT). These recommendations refer to many aspects of the integration of human factors in design and certification, including system safety analysis. Some of the legislation since has also highlighted these points. One of the critical points is ensuring that assumptions about pilot responses are reasonable, so that there's not a mismatch between design and line operations.

Assisting human work

I wondered what developments in digitalisation with significant positive potential are of most interest to Dr. Abbott at the moment. Looking back at the history of some of the big improvements in aviation safety since digitalisation, Terrain Awareness and Warning Systems (TAWS) and the Airborne Collision Avoidance System (ACAS), she noted that we can take it to the next step to enhance the way that people in operational roles contribute, *"not just stopping them from doing things wrong"*.

But once again, we must be mindful of complexity. *"One of the things that digitalisation enables is flexibility, but one of the potential side effects, is that complexity can increase with flexibility. Sometimes flexibility for one player in the system makes it more complex for the pilot and vice versa."* Managing in the face of complexity requires systems thinking.

What can front line staff do?

Throughout the conversation, operational staff were at the front of our minds, but pilots, controllers, and other front line actors may well feel that decisions are being taken by people – whether manufacturers or regulators – who may be far from the operational environment. So what can pilots, controllers, and other frontline staff do to have more of a say in the drive for digitalisation? One answer is through participation. *"Working through the staff associations and labour unions, front-line staff can have a voice in a number of groups that are making some of these kinds of decisions, such as standards groups, regulatory groups, and research projects. Front-line actors can have a stronger voice than any individual would have."* S

Dr. Kathy Abbott is the FAA's Chief Scientific and Technical Advisor (CSTA) for Flight Deck Human Factors, with over 40 years of work on human performance and human error. Dr. Abbott has led the integration of human engineering into FAA/international regulatory material and policies for flight guidance systems, avionics, all-weather operations, Required Navigation Performance, crew qualification, data communication, instrument procedure design criteria, electronic flight bags, electronic displays, organisational culture, design-related pilot error, flight crew alerting, manual flight operations, and other areas. She has been involved extensively in accident, incident, and other safety data analysis.

Dr. Abbott came to the FAA from the National Aeronautics and Space Administration (NASA), where she was responsible for leading analytical, simulation, and flight studies with the specific objective of improving aviation safety and operational efficiency. She is a Fellow of the Royal Aeronautical Society, an Associate Fellow of the American Institute of Aeronautics and Astronautics, and a Member of the Livery of the Honourable Company of Air Pilots. She is a certificated private pilot, with familiarisation training in several large transport aircraft. Dr. Abbott earned her B.S. in Mathematics and Information Science from Christopher Newport College, an M.S. in Computer Science from George Washington University, and a Ph.D. in Computer Science from Rutgers University.

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https://www.faa.gov/aircraft/air_cert/design_approvals/human_factors/

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BUILDING ADAPTIVE CAPACITY:

AMPLIFYING THE COMBINED STRENGTHS OF HUMANS AND MACHINES

Is the future of digitalisation autonomous machines, or will humans retain a critical role? If we want to maintain the ability of the system to adapt before, during and after events, we need to take advantage of the strengths of people and technology as a human-machine system, say **Rogier Woltjer** and **Tom Laursen**.

KEY POINTS

- **Recognising the interaction and interdependence between humans and technology is key for successful digitalisation.**
- **The aim is to combine the strengths of humans and technology so that they amplify each other.**
- **Continuing to acknowledge humans' and technology's contribution to the adaptive capacity of the ATM system is an essential success factor for digitalisation.**
- **Four aspects that can help to understand adaptive capacity are trade-offs, strategies, systems thinking, and margins and performance boundaries.**
- **Asking questions based on resilience engineering principles may help to maintain and increase adaptive capacity.**

Introducing adaptive capacity

Digitalisation will transform ATM in the coming years. New technology will provide benefits as well as introduce new challenges. The ATM industry is already designing systems that respect the interaction and interdependencies between humans and technology. But as technological development is accelerating, the current ability to design effective human-machine systems needs to be amplified.

One of the main contributors to the high performance that aviation has reached is the aviation system's

'adaptive capacity'. Adaptive capacity refers to the ability of a system to adjust its functioning prior to, during, or following varying conditions. Conditions range from rare and high-impact events such as volcanic ash, to the everyday, such as adjusting to weather conditions or traffic demand. But more technology often leads to increased complexity as well as more possibilities that small variations propagate across system components into serious consequences (known as 'tight coupling'). This development can challenge adaptive capacity and make it harder to adjust to varying conditions.

Instead of technologically optimising for efficiency or capacity and addressing human performance and safety cases separately, we suggest an explicit focus on building adaptive capacity as a central design feature into ATM concepts.

We suggest taking advantage of the respective strengths of people and technology, raise some questions based on research papers (e.g., Rankin et al., 2014; Woltjer et al., 2015), and connect these to some of the current thinking on human-machine work systems. We highlight some of the concepts that may be used to understand the adaptive capacity of the air traffic management system. These are trade-offs, strategies, systems thinking, and margins and performance boundaries.

Trade-offs require adaptive capacity

Any human-machine system has limited resources available. Time available is limited, so is airspace, personnel, as well as cognitive resources (human and machine). It is therefore not possible to optimise all goals (even when extra resources are sometimes deployed).

ATM therefore continuously adapts and balances important goals such as safety, environment, cost effectiveness, and capacity, as optimising for one goal may have an effect on adaptive capacity for balancing other goals, short-term or long-term (Hoffman & Woods, 2011).

For example, in the initial design phase of an ATC situation display and technological support system, trade-offs need to be made in the design phase between different goals. In one such system there was a decision to let a calculated flight profile for each aircraft type decide the sectors where the flight is presented to the operators. This leads to situations where aircraft are not presented to sectors that can be impacted if the flight performs differently than the calculated profile. In turn, this leads to situations where it can be cumbersome to offer the most efficient flight path to aircraft. Design decisions influence trade-offs between costs, safety, capacity, and environmental aspects of everyday work years later.

Some related questions are:

- What trade-offs lie behind the daily actions and decisions that ATCOs make?
- How are these trade-offs addressed in ATM concept design?
- Do new features of technology affect what trade-offs ATCOs will need to make, to cope with variability?

"As technological development is accelerating, the current ability to design effective human-machine systems needs to be amplified"

Strategies that get everyday work done

The ATM system needs to be able to handle situations with variability every day. To handle variability the ATM system has developed many different strategies over time. These strategies are different ways of working that are a combination of taught, instructed, written, and undocumented procedures, tacit knowledge, experience, and creative solutions. Operators and decision makers use many effective ways of working that emerge in practice, to handle the variety in traffic, airspace, weather, demand, system maintenance, actions of other stakeholders, and many other factors that arise every day.

One example of how operators use and change between strategies to handle everyday challenges, is in situations where the operational demand changes from a need for a high tempo to a stretch of capacity. In the former situation, one sector is feeding the approach control with the objective to optimise the distance between aircraft, done by fine-tuning the sequence. In the latter situation, where there are too many aircraft in the approach sector, the ATCO changes strategy from optimising the distance between aircraft to reducing the tempo of the entire system. This is done by instructing pilots to reduce to minimum clean, using the holding pattern, extending flight routes, etc.

Applying a framework for analysing these strategies (Rankin et al., 2014) we may ask:

- What strategies do controllers use to cope with different situations?
- Which conditions make these strategies necessary, and to which (possibly conflicting) needs and objectives do these strategies respond?
- Which resources do these strategies rely on to work?

The technological systems that controllers have available to them may be used in unexpected ways to solve a particular problem. Questions arise here such as:

- How are current technological tools used as part of these strategies?
- How can we expect the new technology to affect these strategies?

In the spacing to an airport, for example: How will new technology support the controller in achieving his or her goals and objectives? How will the strategies of fine-tuning in high tempo and stretching capacity change, when we move from today's concept to a 4D-trajectory concept based on novel navigation systems? The strategies used to respond to variability need to be addressed by design of future technology to support adaptive capacity.

Systems thinking and complexity

'Systems thinking' involves thinking about how different parts of a system interrelate and interact (sometimes in unseen and unexpected ways) and how particular behaviours and outcomes emerge. The adaptive capacity of the ATM system needs to be addressed for combinations of activities and systems at different scales that interact. Activities can be described for different systems depending on which one you zoom into. For example, the executive and planner controller in a particular sector using a variety of tools form a system, performing functions such as conflict detection inherently together.

Zooming out, the team of controllers, supervisors, technicians and technical systems at an ATS unit form a system, solving issues such as short-term adjustments in allocating personnel across sectors or handling a technical issue. Zooming out even further, adjacent tower(s), approach control, ACC, and network manager perform functions inherently together as a whole, such as redirecting flows of traffic around extensive cumulonimbus activity that delays departures and has arrivals put in holding patterns or rerouted. From a longer-term planning perspective, actors such as CAAs, regulators, EASA, ICAO, affect operational activities in various ways.

Strategies can be observed at each of these scales, and technological systems need to be designed with these system effects in mind. Questions that could be asked relating to new technology include:

- How does the new technology affect activities at these different scales?
- How does the new technology affect the system's ability to handle variations that propagate across scales and different time horizons?

"Design decisions influence trade-offs between costs, safety, capacity, and environmental aspects of everyday work years later"

Margins and performance boundaries

Margins and buffers are important to understand adaptive capacity. Examples for aircraft operations are fuel margins and margins to remain well within the aircraft performance envelope. Examples for ATC are airspace margins such as not vectoring too close to sector boundaries, handing over traffic at a certain distance or time from sector boundaries, time margins in sequencing and spacing activities, and, of course, separation margins that are adjusted to situational demands.

New technology often brings the system closer to one performance boundary or another. For example, technology may help to optimise traffic flow, but this may decrease margins in everyday work.

Digitalisation can, however, help in presenting information that controllers use to assess how far a situation is from a performance boundary. For example, conflict detection tools and improved prediction algorithms behind aircraft trajectory prediction vectors have enabled more precise management of separation margins.

Questions to ask when introducing new technology include:

- Do we know where performance boundaries are?
- How does the technology affect performance boundaries and margins?
- How does the technology help ATCOs to anticipate, monitor and manage how close to the limit a situation is?

Improving the joint use of strengths of humans and machines

Behind the label of digitalisation lies an assumption of increased use of technology. To gain the most benefit from this increase, it would be helpful to consider questions from the research field of resilience engineering to guide us to answers to real-world challenges.

While striving for more powerful, adaptive and functional technology, we should refrain from making it more independent. With questions like those above, we can develop more capable technology through interdependency and teaming with humans. This is the strategy that the ATM industry has used for decades, but not communicated explicitly, and it has led to successful implementation of technologies.

Questions like these are crucial to answer in a thorough, humble, and cautious way to be able to benefit from the functionality that new technology introduces, and at the same time achieve the necessary adaptive capacity. As outlined by Bradshaw et al. (2013), let's not be tempted by the idea that machines work autonomously and that they are capable of creating adaptive capacity on their own.

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A REGULATOR'S PERSPECTIVE ON DIGITALISATION AND HUMAN PERFORMANCE

When it comes to digitalisation, it can be hard to know what regulators expect. In this article, **Kathryn Jones** and **Anna Vereker** give a regulatory perspective on digitalisation to support human operators.

It is tempting to think that regulators should have an advanced understanding of the impact of the various technological advances in aviation. The reality is that we share this knowledge journey *with* the industry. As ICAO's *Human Performance Manual for Regulators* (Doc.10151) states, our role is *"to make it easy for people in the aviation system to do the right thing and avoid negative consequences"*. We need to develop our regulatory approach with support for the person in mind. This is at all levels of regulatory influence, from State Safety Programmes and options for regulatory intervention, to the changes in oversight driven by the demands of technological advancement.

This rapid change in the use of technology is not restricted to aviation; we are all impacted at a societal level by digital transformation. For many of us, digital assistants on smartphones have much reduced the need to make difficult mental calculations, remember phone numbers, or even use a map. It – in theory at least – frees up brain functionality for other more interesting or more useful things. This process of handing off less interesting tasks to a digital assistant is a common theme in aviation too. Most commercial aircraft now have a digital suite which augments the capabilities of the human pilots, as well as air traffic control systems, flight operations scheduling, and many other functions.

"Just because something can be designed, doesn't mean it can be applied usefully on the day"

How technology changes the nature of work

One of the five core human performance principles recently published in ICAO's Doc.10151 is that "*people's performance is influenced by working with other people, technology and the environment"* (see *HindSight* 32). There is recognition that the way we work *with* technology has changed the way our work looks and feels, and the tasks we undertake. As an aviation regulator, we want to understand how organisations have understood this change, and how they are supporting their people to do their best in their operational context. We want to know that technological tools help people to make the best decisions on the day, and support them with the tasks that we know people are not as good at achieving – for instance remembering to do things in advance (prospective memory) and monitoring tasks.

For digital assistance to be successful, it must be able to provide options within the boundaries of its functionality *and* be easy to understand and use by the people involved. It must cater for changes to peripheral tasks in addition to the 'main' users. It must be able to support people on the day and within the context it will be used. This is an often-forgotten element; just because something can be *designed*, doesn't mean it can be applied *usefully* on the day.

Understanding complexity

We want to ensure that organisations understand how digitalisation affects a complex system. Digitalising one task can have a big impact elsewhere in the system. It may change how an operator understands the system is working, or make the job harder for someone else in another part of the system. Traditional safety analysis methodologies such as barrier and bow-tie models may not be well suited to understanding these sorts of changes in a complex system.

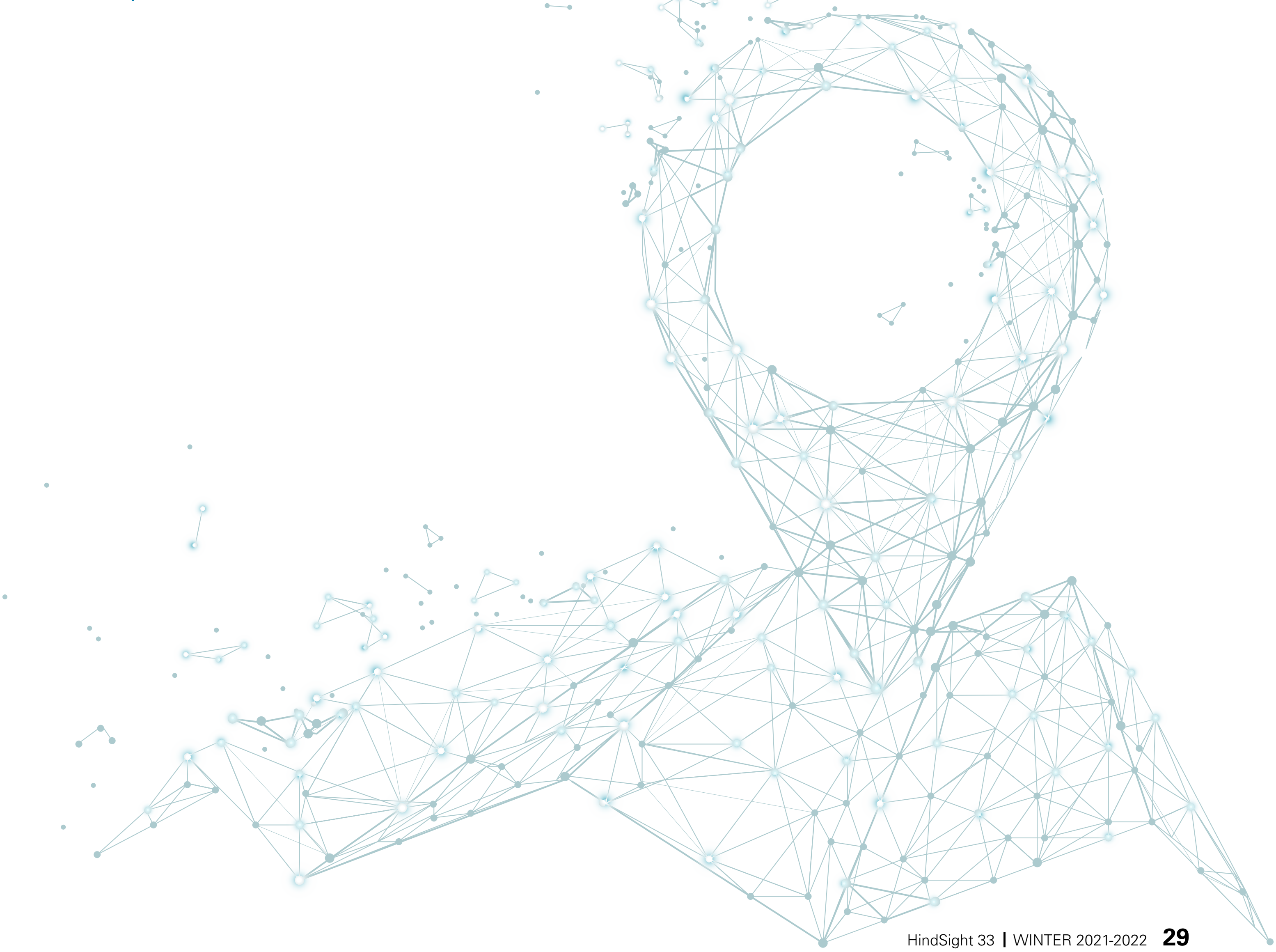
As a regulator, we want to see new methodologies emerge that are better able to deal with systems and complexity. Take the map navigation function on your smartphone: it is not simply a digital version of a paper map. Instead, there is recognition that a person driving a car will have difficulty trying to read a map at the same time as driving – so the map application provides audible directions to help the driver, and is often mounted on the dashboard of a car so that the driver can easily see the map without having to hold the smartphone. However, by not looking at the map before we start our journey, we often lose sight of the bigger picture and can end up driving down unsuitable roads or not knowing how to avoid a closed road. We now have regulations preventing car drivers from holding and using smartphones while driving, recognising that this is unsafe, but we do not require them to have a 'big picture' view so that they manage the different conditions on the day. As aviation regulators we are looking for digitalisation to support human operators to do their best both in using the equipment and understanding the context.

"Digitalising one task can have a big impact elsewhere in the system"

Beyond prescription

As regulators we need to avoid 'solutionising' digital applications. There may be new applications that would be helpful but might be precluded by prescriptive regulations. Instead, we want operators to understand their own systems better, and understand how digitalisation may help their people do their best. As a society, our appetite for increased digitalisation (and automation, including autonomous operations) will change over time, and with increased technological development. We do not want to hamper this development, but we do want to ensure that safety is at the forefront of progress.

In air traffic control, a new type of 'digital' tower is being introduced; this might be an augmented physical tower located at the airport or might be a remote application from another location. Careful consideration has been given to how best to support the human controllers involved in this work, and what sorts of technology will assist them to do their best. It is possible for some cameras to provide more information than a controller would gain from using their eyes in a physical tower, but at the same time there could be several limitations (for example, poor weather occluding a camera). Some of these differences are more obvious than others, and there is an agreement for ongoing monitoring of the effects of digital towers on the human controllers so that any long-term impacts are captured and understood.



For now, the system still relies on a human controller, but in the future, there may be a different interaction of digitalisation and automation that changes this role. We need to ensure that we are mindful of safety impacts, and make best use of human operators, and all their positive capabilities in this situation.

Collecting safety data

Collecting safety data is a core activity in supporting our understanding of the system and in aviation. It has been subject to both digitalisation and in some cases automation. We have air and ground systems that collect data, and help the human operators translate this into meaningful trends. Digitalising mandatory occurrence reporting (MOR) forms has also improved the user experience of submitting these reports and may improve reporting as people find it easier to log them. However, data itself always has limitations in the insights it can provide, and we need to be wary that in making the collection process easier, we must listen out for 'noise' between data points that can provide vital contextual information about safety. Once again, we need the technology to support the people, valuing qualitative information as much as we easily accept quantitative data.

The road ahead

This is a shared road that we are all travelling on, and it will call on all of us to use our experience and knowledge in different ways. Through collaboration and curiosity, we can work together to ensure that we make the best use of the resources available to us and continue to explore ways to prioritise system safety with human factors at the fore.

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Anna Vereker is a Chartered Occupational Psychologist and EAAP Aviation Psychologist. She has a broad range of experience with aviation human factors, including with the military and air traffic control. She is passionate about encouraging robust consideration of human factors issues in complex systems, and continues to be curious about new methods, research, and ways to influence the industry.

DIGITALISATION VS HUMAN FLEXIBILITY

Digitalisation places a heavy burden on designers to understand the context of use of designed technology. But the world of work often requires space for flexibility to adapt to different situations. **Anders Ellerstrand** reflects on the risks of rigidity.

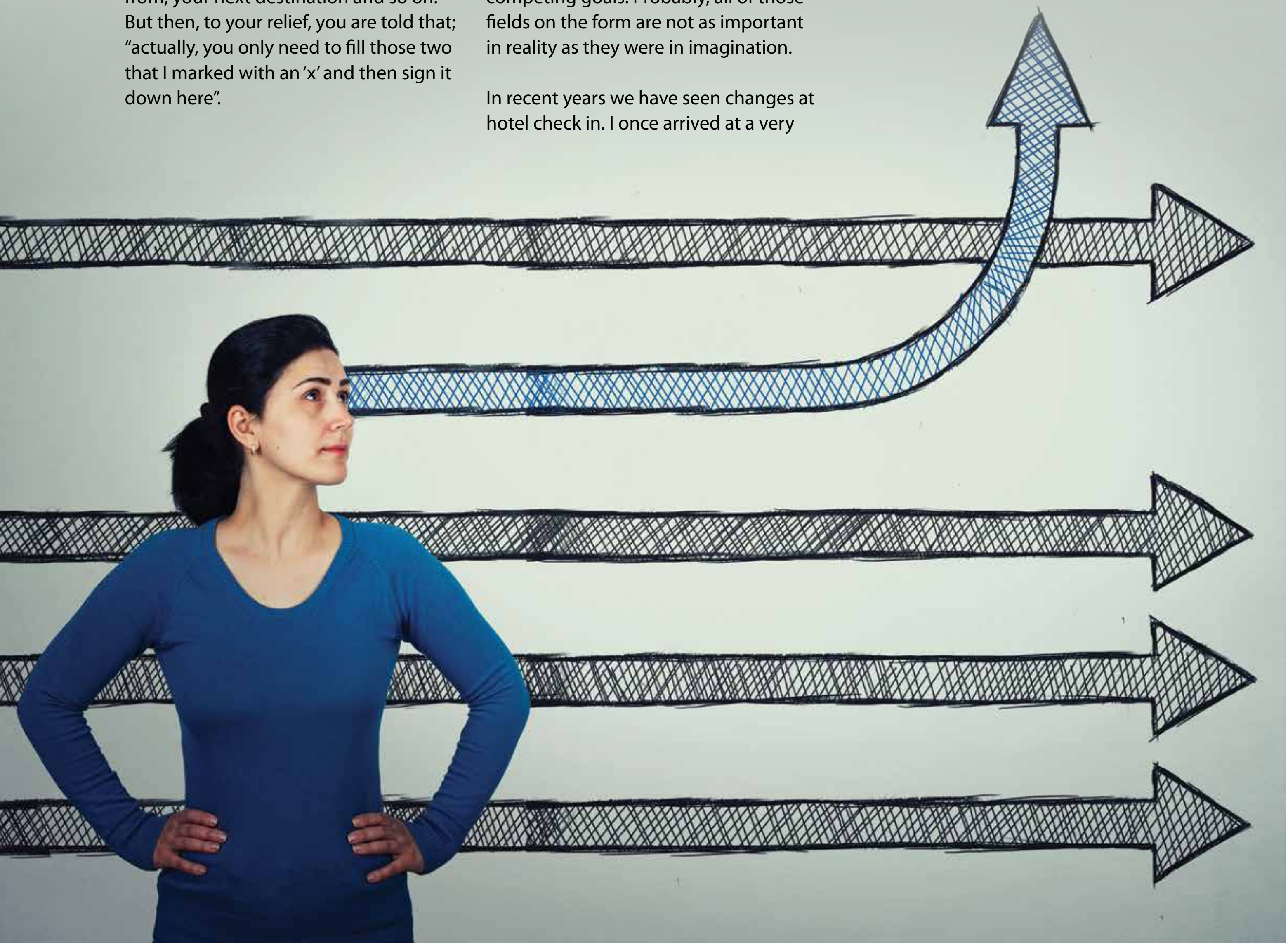
Have you ever checked in to a hotel late in the evening, tired and longing to get up to your room, and go to bed? Then, as part of the check-in procedures, you are given a check-in form to complete. You see all those empty spaces that you should fill with information; personal information, where you are travelling from, your next destination and so on. But then, to your relief, you are told that; "actually, you only need to fill those two that I marked with an 'x' and then sign it down here".

Work-as-imagined, digitalisation, and work-as-done

For me, this is an example of designed 'work-as-imagined' (see *HindSight* 25) in a form that clashes with the needs of hotel guests. The hotel staff has found a 'work-as-done' that manages these competing goals. Probably, all of those fields on the form are not as important in reality as they were in imagination.

In recent years we have seen changes at hotel check in. I once arrived at a very

"The burden of getting it right may shift more towards designers"



modern, low-price hotel close to an airport. To reduce cost, the staff was at a minimum and everything was designed for self-check-in. I went to a screen, telling me to "Start your check-in by clicking here". Here comes digitalisation! No way I could just "fill in here and there and sign". Every page that came up on the screen had to be filled correctly before the next page came up, and only by filling it all according to requirements was the card key printed at the end, allowing me access to my room. In design terms, this is called a 'forcing function' – the user is forced to do certain things to achieve a certain result.

The whole procedure was not only arduous, but also quite difficult. So, there was one of the staff who had to stay behind the guests assisting the whole process, trying to expedite it as much as possible. So much for saving on staff costs…

Finishing the design…in the ops room

So, what has this got to do with digitalisation in ATM and other safety-critical sectors? There is today, in most workplaces, a physical separation between written procedures and actual operations. The procedures in binders or on computers are not always reflected in actual operations. You are supposed to follow procedures, but you are able not to. This means that any poorly designed or insufficient procedures can be fixed by humans adapting and 'finishing the design' in order to get the work done.

For some people this is a big problem, with the often-cited argument that "human error [or non-compliance with procedures] is the cause of 80 % of all incidents and accidents". It is commonly thought that "If only people would follow the procedures, all would be well". If you believe this, digitalisation may seem to offer the perfect solution. When procedures and operations are no longer separated, but integrated in a common system, the possibility to bend rules or take shortcuts can be removed. The design can no longer be 'finished' in operations.

"With digitalisation, certain operational adaptions can be made impossible"

Bending the rules

With digitalisation, certain operational adaptions can be made impossible, which is of course one intention. An everyday example is the car that is not able to start until you have fastened the seatbelt. Sounds like a good idea? The problem is that digitalised systems that are not possible to override also take away the human ability to adapt to many unforeseen situations. I saw a video clip of a woman approaching her car when two armed robbers approached her. In the clip, the woman is extremely fast into the car, gets the engine running, puts it in reverse and quickly gets herself out of the threat. Imagine a car that requires her to fasten the safety belt first, for safety reasons. Different goals can come into conflict and we can't always be sure which is the most important in a given, perhaps unimagined, situation.

I used to work as a Watch Supervisor in an ATC centre. One issue we tried to deal with for a long time was the activation of military restricted airspace. That involved a lot of different tasks, to be performed in a certain sequence, where no task should be omitted. Sometimes we failed and an incident report was written. The cause was always that the procedures were not followed.

This is a case where digitalisation could make it impossible not to follow the procedures. The digitalised version with its forcing functions would require all steps to be performed in the correct sequence – otherwise the restricted area could not be activated.

The digital double-bind

The real problem here is far too easy to miss. The main reason for the problem we were having was that this was usually happening in the early morning when we were very busy and constantly interrupted. Restricted areas were to be activated, but there were also military training areas to be prepared, following a very different procedure. And it was also a time when many controllers came to work, passing the Watch Supervisor to get or provide information. It was often necessary to leave the procedure, to start another one in the same system, to later go back and continue. Would a digitalised system allow that? By introducing a fail-proof digitalised procedure you could probably eliminate the problems with activating restricted airspace. But, in doing so, you could also eliminate all that clever flexibility that got us through those busy mornings, full of competing goals, time constraints, and limited resources.

So, if you did appreciate the person in the hotel who told you to fill only the two boxes with an 'x' and sign 'there', you may find the future not so satisfying. If you believe that a key reason that aviation is efficient and safe is human flexibility and ability to adapt, then you may have reason to be concerned. The burden of getting it right may shift more towards designers, who have to predict and understand all of the possible use cases of software functions.

Assisting human work

I believe, digitalisation and automation could bring many advantages. I even believe the problems I met when activating restricted airspace in the morning could be mitigated through the help of automation and digitalisation, but I prefer to see those improvements as a result of them assisting the human in doing a better job. It is not a given that we will get to a better place by having technology restricting or even eliminating human flexibility.

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DE-RISKING FOQA:

FLIGHT DATA MANAGEMENT AND PILOT PROTECTION IN AN ADS-B WORLD

Rapid digitalisation of flight data technology may place human operators at potential professional and legal risk without changes to flight operational quality assurance (FOQA) arrangements, according to **James Norman**.

KEY POINTS

- **Airlines and unions need to reconsider and reimagine what flight operational quality assurance (FOQA) data is, its use and protection.**
- **Open-source flight data, such as ADS-B, needs to be protected as strongly as traditional FOQA data.**
- **Airlines and unions should adopt contractual language that expands FOQA protections to all recording and transmitting devices, future proofing against emerging and novel technologies.**

This issue of *HindSight* and its focus on digitalisation and human performance comes at an opportune time for a discussion about the consequences of these factors with regard to FOQA (Flight Operational Quality Assurance) in the US (FDM, Flight Data Monitoring, in the EU). FOQA is considered an essential component of flight safety management, along with its qualitative counterpart, aviation safety action program (ASAP). According to the FAA (Federal Aviation Administration, 2004), FOQA is *"a voluntary safety program that is designed to make commercial aviation safer by allowing commercial airlines and pilots to share de-identified aggregate information with the FAA so that the FAA can monitor national trends in aircraft operations and target its resources to address operational risk issues (e.g., flight operations, air traffic control (ATC), airports)."*

"FOQA is considered an essential component of flight safety management"

FOQA Insight

For FOQA programs, digitalisation is the process in converting analogue data (flight sensors, control inputs, etc.) into digital data (ones and zeros). For aviation safety, that has meant the evolution from solid state recorders to digital flight data recorders (DFDR), including present-day cellular uplinks capable of transmitting flight data in real time or after termination at the gate. This evolution has been a case study for how technological progress has profoundly affected flight safety. Digitalisation has now gone beyond aggregate analysis conducted by an airline and is being leveraged for pilots, able to see their individual flight data on a tablet or personal device, allowing comparison of their performance against an aggregate set.

Taken together, FOQA and ASAP bring most of the horsepower that an airline uses to understand line operations by identifying and mitigating hazards. But the two schemes have not developed in tandem. ASAP is currently on its third iteration of FAA guidance (FAA, 2020), but FOQA's guidance remains in its original language as codified nearly two decades ago. The time has come for a reassessment of the tenets of FOQA: its purpose, protections, and uses going forward.

Until very recently, a discussion about flight data in FOQA programs would have been relatively straightforward: data gets downloaded after a flight, ingested onto encrypted servers, scrubbed for exceedances and aggregate trends, and used to further the safety goals of both the airline and the industry. This process was neat and tidy, protected by local letters of agreement between unions and companies as well as by federal law. All participants – from line pilots up to senior management – understood the boundaries of the program. Importantly, programs rarely encountered misuse of flight data, likely because the industry has matured to the point where nearly all FOQA programs are quite similar across airlines. The actors knew their roles. The script was routine…until now.

ADS-B and the open-source era

Thanks to ADS-B (automatic dependent surveillance broadcast), many aspects of the visibility and use of flight data have shifted into open-source public domain. ADS-B was mandated for most US airspace and its operators in January of 2020. While it is true that the mandate was more burdensome for general aviation than the airlines, the combination of the ubiquity of ADS-B and the open-source nature of its access makes it a game changer. Flight trajectory, ground track and groundspeed are its main components, however *actual* airspeed and elements like bank angle can also be derived. Did your airline have a rejected take-off or an unstabilised approach? The event can now be captured entirely *outside* of traditional FOQA methods. And there's no need to stop there; sites like LiveATC.net can allow the general public to tether this pseudo-flight data with the ATC 'tapes' as well.

While faster, better and cheaper access to flight data has been brought about by ADS-B, it comes with a host of issues that need to be urgently addressed if FOQA intends to maintain the buy-in with labour organisations it has earned up until this point. The first issue is the bedrock of any safety program: protection.

The non-disclosure deal

US federal regulations provide an appealing incentive to airlines: voluntarily share safety information with the FAA, and that information will be protected from disclosure to outside parties. Up to now, this applied to both ASAP and FOQA. Further, a second regulation specifically protects pilots from enforcement action *"when such FOQA data or aggregate FOQA data is obtained from a FOQA program"* (14 CFR § 13.401). Data obtained *outside* the FOQA program is fair game for enforcement action, and no proposed rules exist to address this chasm. In a worst-case scenario, it is conceivable that if an airline's FOQA program were to be shut down, much of the data could still be obtained via ADS-B – completely devoid of pilot and company protection, with significant implications for safety culture.

All data is FOQA data

Given this scenario, it is important to utilise a best-practice phrase in agreements between labour unions and airlines that *"all data is FOQA data"*. Carving out specific uses for FOQA data as solely a flight safety device or maintenance function may have been sufficient in the past, but it is now important that airlines future-proof their contractual labour agreements to protect the company and pilots to the greatest extent. ACARS (aircraft communications addressing and reporting system) data, engine condition monitoring, inflight entertainment systems – anything capable of transmission or recording should be designated as FOQA data. ADS-B's ability to obtain data and operate outside of long-standing federal FOQA protections should sound an alarm bell. It is in the best interest of airlines to make sure non-punitive language at least exists in their systems.

As a disrupter, ADS-B has also forced the industry to call into question other aspects for the purpose of FOQA. The rapidity of data acquisition may influence the human element beyond flight safety *per se*. For example, what if acceleration forces weren't used just to generate turbulence reports, but also used as a customer satisfaction tool? *"Dear Mr. Smith, we regret that you experienced a bumpy ride over Colorado on your last flight; please accept these frequent flyer miles in return."* Or with increased attention on sustainability, post-flight customer satisfaction surveys could be enhanced by including emissions savings garnered from single engine taxi or optimised flight planning. There are many scenarios that could see flight data leveraged beyond flight safety, and these uses should be included under the FOQA umbrella to benefit from the protections described previously.

"Rapid digitalisation, by way of new flight data technology, could place human operators at potential professional and legal risk if existing FOQA arrangements are left unchallenged"

Cameras in the flight deck

Discussion of different data streams would not be complete without addressing a topic loathed by pilot unions and lauded by the NTSB: cameras in the cockpit. The issue lies at the confluence of digitalisation and human performance undoubtedly. The NTSB reintroduced the recommendation for cockpit image recorders in their most recent 'Most Wanted List'. The NTSB cited recent crashes where such data many have helped to understand the manipulation of flight controls. Cameras may be useful in general aviation where the accident rate has reached a stubborn plateau, and recorders of any type are not required for most operations. However, in airline cockpits, flight data recorders have evolved from forensic devices once rarely used, to essential components of a FOQA program in the present day. Video recognition and machine learning software would need to be designed specifically for an airline cockpit if human performance data were to be digitalised and used in a proactive, meaningful manner. Could FOQA one day create parameters based on kinaesthetic movement? Certainly. But as of now, this technology does not exist.

Whose data is it anyway?

Finally, we need to ask: whose data is it anyway? Of course, airlines own the data, but it is the pilots who generate the data. A pilot could spend a career generating flight data, revealing interesting or useful insights on how he or she operates the aircraft, yet never be able to access data on their own performance. This is changing with the proliferation of personal monitoring devices and apps. The next generation of pilots may come to expect their personal flight data to be easily accessible to them. Companies are already beginning to cater to this need, and some airlines are implementing it. What is likely to allure pilots to want to access their flight data concerns individual flights or specific events: Was it a hard landing? Was I stabilised? This could gradually see a move away from the aggregate nature that FOQA was originally built upon. Unions and airlines should understand that individual data is most valuable when benchmarked, no matter how interesting or high profile an individual event.

De-risking FOQA

The US aviation safety industry has an opportunity to address and protect against potential stress points for FOQA programs. Rapid digitalisation, by way of new flight data technology, could place human operators at potential professional and legal risk if existing FOQA arrangements are left unchallenged. It is hoped that industry can muster the same collaborative efforts that have been successful before, and FOQA programs can emerge stronger and more valuable than ever.

James Norman lives is a B757/767 pilot and FOQA gatekeeper for a US airline. He is a Ph.D. Candidate at the University of North Dakota, and his dissertation research focuses on voluntary reporting culture. He resides in Minnesota with his wife and twin daughters.

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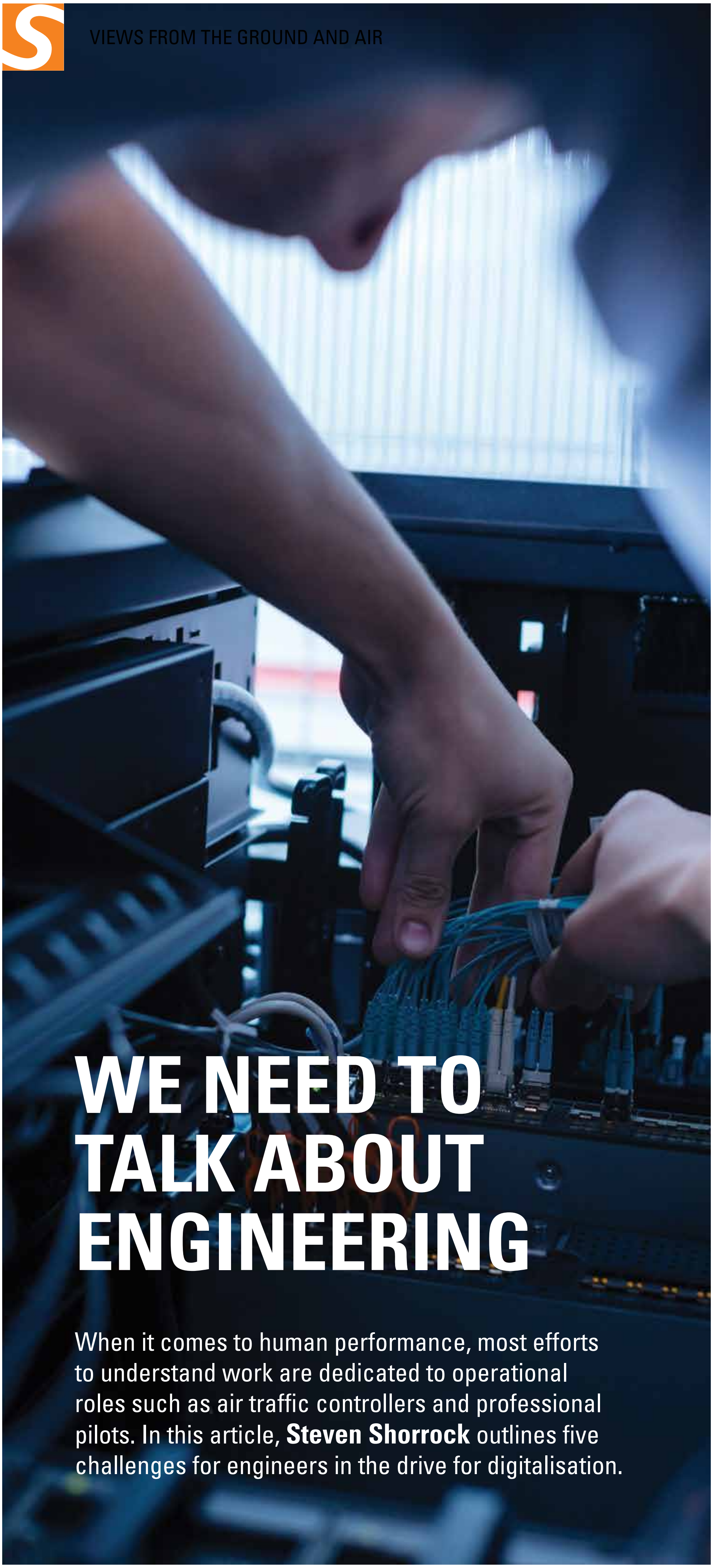

WE NEED TO TALK ABOUT ENGINEERING

When it comes to human performance, most efforts to understand work are dedicated to operational roles such as air traffic controllers and professional pilots. In this article, **Steven Shorrock** outlines five challenges for engineers in the drive for digitalisation.

After many years working in and with air navigation service providers (ANSPs) and air traffic management organisations around Europe, talking about work with almost every kind of role from front line staff to CEOs, I notice a curious thing. Little attention is paid to the nature of the work of those that we rely on to keep all the critical technical systems running effectively: the engineers. There are many studies of the work of air traffic controllers, and, of course, professional pilots. But there are very few studies, either published or unpublished, on the work of engineers in ATM.

Few people – other than engineers and engineering managers – seem to talk to engineers about the nature of their work. What is working well in their day-to-day work? What problem situations do they face? What challenges and dilemmas do these present? How do they respond to these? What do they need to make work more effective? Discussions with engineers are rather more along the lines of whether and when things can or will be done. Like their operational counterparts, engineers tend to be associated with 'getting stuff done'. But how they do it is given little attention.

These sorts of questions are becoming more urgent and critical, especially with the digitalisation drive. Reflecting on the period when I first dipped my toe into the world of engineering in the late 1990s, until now, I get a sense of how much things have shifted. Engineers' work is changing in a way and at a pace that they have never experienced before. Few outside of their world really understand it.

In this article, I outline five universal challenges that summarise what many engineers from around Europe have relayed to me. These challenges have implications not just for engineers, but for the managers and other staff who interact with engineers, whether in operational, recruitment, training, safety, quality, or other roles.

"There can be a delicate and difficult trade-off between innovation and maintenance requirements, both planned and unplanned"

Challenge 1. Dealing with change and production pressure

When we talk about 'workload' in aviation, we usually think about 'sharp end' operational roles such as controllers and pilots. But increasingly in ATM engineers are balancing on sharp edge of workload peaks, partly associated with continuous changes in technologies and ways of working with them. Engineers can struggle with the number, scale, and speed of changes, sometimes occurring simultaneously in major software releases. Many people overestimate what can reasonably be achieved by human engineers in the acceleration of digitalisation. Few people, except engineers and their immediate managers, understand the pressure. Unfortunately, the increase in work – both planned and unplanned – is often not matched by increases in people with appropriate expertise.

And engineers have worries, but they rarely seem to talk about them without coaxing. These worries concern many things. Some relate to the nature of the equipment itself, such as lack of redundancy, system readiness for implementation, and use of technical systems beyond design intent. Some relate to the work, such as backlogs, thoroughness of maintenance, and the capacity to deal with unpleasant surprises requiring intervention. Who worries about the worries of engineers?

There can be a delicate and difficult trade-off between innovation (to provide additional functionality) and maintenance requirements, both planned and unplanned. Shortcuts and workarounds – traditionally often loathed by engineers – can become normalised, as efficiency rules over thoroughness (e.g., time for testing during the night). It should be no surprise, then, that surprises happen, sometimes requiring rollbacks to previous software releases, while engineers hunt for latent bugs that may have been introduced several releases earlier. Engineers juggle demands and deadlines, pressures and priorities, and can end up feeling overloaded, sometimes overwhelmed, and often without the kind of peer support that is available to operational staff.

"With more complexity, it is impossible to document everything as one would imagine."

Challenge 2. Coping with complexity

Engineering in ATM has always been 'complicated', reflecting the nature of the technical systems. But engineering has changed significantly in the last decade or so; it is now much more complex. There are now more goals, relating to safety, quality, security, reliability, availability, etc., which can shift in emphasis over time. Technical system structure now comprises a more diverse mix of new and legacy system elements. Crucially, interconnectivity between these (e.g., routings, data streams) is more complex, along with interdependency between hardware and software elements (e.g., tools and applications). The boundary of the system is less well defined, with multiple system environments (e.g., primary, backup, test), and collaborating systems such as data centres, sometimes outside of the ANSP itself. With older, complicated systems, things tended to work much more 'as documented'. But with more complexity, it is impossible to document everything as one would imagine.

For all these reasons, technical systems are harder to manage. What will be the unintended consequence of a software update on collaborating technical systems? How can we detect problems with code in a software release when there are no obvious consequences until specific operational conditions occur? How can one know in which release a bug was introduced? Should we roll back to a previous software release (which may itself contain bug fixes), or try to find and fix the bug we are presented with now? Just as air traffic controllers can find it difficult to keep a mental picture of traffic in some situations, engineers increasingly struggle to maintain a mental model even of their own technical systems, let alone how they may interact with other systems. All of this requires staff, expertise, and time; all of which are in short supply.

Challenge 3. Planning and coordination

In operational roles, planning and coordination tends to be over the timeframe of minutes or hours. In technical roles, coordination can be over minutes and hours (for maintenance and testing) through to months and years (for projects). With growing complexity, planning and coordination has become much more difficult, with many stakeholders, both internal and external, who have different demands, knowledge, understanding, tools, terminology, and languages. Because of the interdependencies between systems, where systems depend on other systems to be able to function, systems are more affected by failures of other systems. Without effective planning, engineers can end up overloaded, diverting from one activity to another, and losing track of what they were originally working on. Without effective communication, there can be assumptions and misunderstandings about who is doing what, when, why, where, how, with whom and for whom. This can result in unpleasant surprises.

Challenge 4. Maintaining expertise

Engineers involved in projects and maintenance face a heavy burden in terms of the knowledge and skills required. The knowledge requirements are not fully known, however. And in ATM, much of the needed expertise is developed 'in-house' via experience. Engineers obviously need to understand the hardware and software directly relevant to their work now, and the tools, procedures and processes that (should) assist their work. But they also need to have some understanding of emerging technologies that may be relevant to their future work, interdependent aspects of collaborating internal and external systems, and new tools (e.g., for ticketing, communication, reporting). And with increased complexity and interdependency, engineers need to understand at a 'good enough' level the system architecture as a whole. Each engineer has a mental model of the structure and behaviour of interconnected subsystems, which may be more or less complete and accurate.

Increasingly, there is also a need know and use new and fundamentally different development approaches and processes that were rare even a few years ago in ATM (e.g., agile software development, compared to the more established waterfall model of system development). This creates a need for different philosophies and practices for different systems. But engineers often lack dedicated time to attend training courses, or even group discussion and reflection.

There is another pattern at work in engineering that does not affect operational staff in the same way: with a need for deep expertise, there is a tendency for some engineers to become 'single points of expertise', who are not easily replaceable. This, in turn, affects the resilience of organisations to function in case engineers change jobs, need to attend a course, are off sick, or retire.

Finally, there is an additional trade-off when it comes to expertise. With the need to hire engineers quickly, without the commitment of a long-term contract, contractor engineers help to fill important gaps. But, of course, once contractors leave, they take their existing and acquired expertise with them.

Challenge 5. Learning from experience

Learning from experience is as critical to engineers as it is to operational staff. But, in some ways, it can be more difficult. Technical systems for ATM tend to be very reliable, thanks to expertise in design, implementation, testing, and maintenance. When things do go wrong, engineers need to be deeply involved in learning from incidents. This is unplanned work that takes time away from planned work, which may already take engineers to full capacity. Additionally, while a low failure rate is, of course, very welcome, an implication is that learning from failures alone gives a narrow base of experience for learning. This presents a corresponding need to learn from everyday work.

Without such learning, many questions go unanswered. What has worked well, that we should continue or extend? How is work-as-done drifting from work-as-prescribed and work-as-imagined? What has surprised us recently? Again, complexity and production pressure create difficulties for learning from experience, because of difficulties in understanding the technical system, and lack of time and opportunity to invest in learning.

We need to talk about engineering

As managers, air traffic controllers, recruitment specialists, training specialists, legal specialists, or safety, quality and security specialists, how much attention do we really pay to the work of engineers? How much time is spent understanding their work, and our impact on their work? How much effort is spent making it easy for them to do a good job? Whatever your role, it is worth spending some time reflecting on how your decisions impact them, and how you can help them, while they try to help us.

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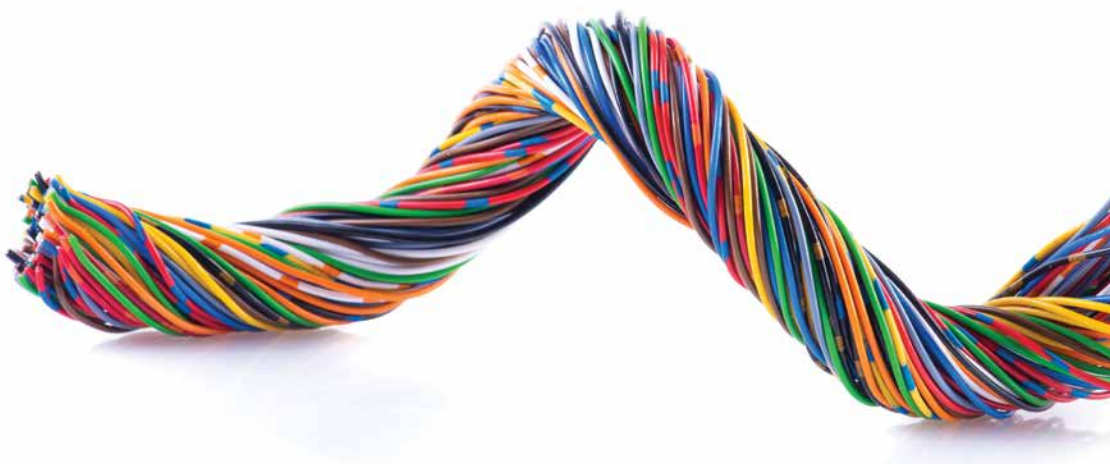

GENDER DIVERSITY IN TECH:

THINGS CHANGE WITH TIME, BUT YOU HAVE TO CHANGE THEM YOURSELF

Despite significant effort to change attitudes, gender stereotypes persist in society, with damaging consequences. **An Exsteen** describes what effect those stereotypes have on a woman working in a male-dominated field, and how she chose to contribute to the creation of a more inclusive world.

KEY POINTS

- **Stereotypes prescribe what a person should look like in a certain job and how a person should behave in that job.**
- **We can overcome stereotypes by creating awareness and paying it forward to support other women to reach their goals.**
- **Two roles are important for improving diversity and inclusion: activists and coaches. Activists accelerate systemic change. Coaches accelerate personal development.**

Where it all began

When I was a little girl in the 1980s, there was a television show set in Australia called *The Flying Doctors*. A team of doctors flew to all corners of the outback to help people in need. I adored that show, not so much because of the doctors, but because of the pilot that flew the little aeroplane to take the doctors to their patients. I too wanted to become a pilot and fly an aircraft, and since then, I have always had atypical interests and passions.

When I was 11 years old, my ambition slowly started to change. This was around the time that my father bought a home computer. In 1986, those were still very rare in households, so having one was very special. From the very beginning, I was fascinated by it. I was using it all the time. My father had bought a book about programming, so I taught myself to program. As I grew up, it came as no surprise that I went on to study computer science, and I developed my career in IT. However, the fascination for aircraft and aviation never left me.

When I joined EUROCONTROL in 2018, I got to combine both my childhood passions: aviation and IT. It is like a dream come true. But it hasn't always been easy. Being a woman in a male-dominated field involves many challenges. In this article, I outline some of these and some strategies for change.

How you look

A first challenge is the stereotypes that exist in our society about what a person in a specific role should look like. If you ask six-year-old children to draw a surgeon, a firefighter, or a pilot, they will tend to draw men. This may be partly because of their exposure to the media, such as films, cartoons, and books. A woman does not fit the stereotypical image of such roles. Then there is language (like 'fireman'), education (comments of teachers and other children), comments by family members, observation, etc.

I experienced on many occasions during my career that I do not fit the stereotype image of an IT professional. At one point, I was promoted to project leader while I was working in a big bank. I started leading smaller internal projects with small project teams of only a handful people. These were quite successful. Then I got two big projects at the same time, one in the Netherlands and one in Ireland. In Ireland everything went well, the collaboration was easy and the results manifested early on. In the Netherlands, however, it was more complicated.

I remember having to go for a first meeting in the Netherlands. My boss also had business there in the afternoon, so he decided to join me. When we entered the meeting room, the participants immediately assumed that he was the project leader. He looked older, with greying hair and a nice suit. I was a woman, looked very young and was wearing a pink fluffy sweater. The people in Rotterdam had difficulties accepting that I, as a young woman, was the project leader. At first, they only talked to my boss. They sent the required information only to him, and didn't show up in meetings that I organised.

I worked very hard, and very late, to prove my competence, and I had to remain persistent to get there. Gradually they came around and the situation improved. But I can imagine that some other people would have given up by then, given the same situation.

The key point is that because I didn't fit the stereotype image of a project leader, I had to prove my competence. My boss, who did fit the stereotype, was accepted, and was assumed to be competent from day one.

I stopped wearing pink after that, and now I only wear dark colours, like black and blue. I change what I look like to fit in better.

How you behave

> "I experienced on many occasions during my career that I do not fit the stereotype image of an IT professional"

Throughout my career I found out that I don't only have to be careful about what I look like, but also how I behave. This also seems to be associated with stereotypes. Here are some examples from my experience:

- A woman who is being assertive is often perceived as "aggressive".
- A woman who is leading is often perceived as "bossy".
- A woman who tells the truth is often seen as "difficult".
- A woman who asks hard questions is often seen as "complicated".
- A woman who takes up space is often described as "too much".

I found that I have to be careful with emotions, especially strong emotions like anger. In the beginning of my career, I sometimes got angry when I saw there was a delay in delivery, or when there was a lack of commitment from other teams. Very soon I learned that this had a very negative effect on the way people perceived me.

There is much research to show that the same behaviours by men and women are interpreted and treated – even rewarded or punished – differently. For instance, in one study (Brescoll and Uhlmann, 2008), both males and females evaluated angry female professionals and angry male professionals differently, assuming lower status for angry female professionals. The same study found that while women's emotional reactions were attributed to internal characteristics (e.g., "she is an angry person"), men's emotional reactions were attributed to external circumstances.

In short, when a man gets angry, it is more likely that he is perceived to be firm and a strong leader (and so more respected), or that external circumstances were responsible. But when a woman gets angry, she is perceived as emotional and unstable and she is less respected. As noted above, a stereotype is at work: strong emotions, like anger, do not fit the picture-perfect image of a woman.

I learned over the years that if I wanted to survive in this male-dominated world, I had to adapt my behaviour. I had to comply more to the ideal image of a woman, and at the same time not sit in a corner and shut up, but actively participate in the discussions. That is not easy, because it involves suppressing one's real self. It is also not fair.

Getting support

Thankfully, I met great people who helped me in my career. These people supported, encouraged and championed me. One example is the support of a female colleague I once had. She taught me about the importance of getting the 'glamour jobs'.

It seems to come naturally to many men to work themselves in the spotlight and get high-visibility jobs. According to EU data (European Commission, 2021), women are still heavily outnumbered by men in leadership positions in the corporate sector in the EU. On average, the European Commission reported that 29.5% of board members of the largest publicly listed companies in the EU were women, as of October 2020, with a range between Member States of 8.8% to 45.1%.

Getting in the spotlight is something that does not come naturally to me, and perhaps to many other women. I just did what was needed to get the job done as part of a team, even if it was doing a menial job in the dark corner of the room. But I learned that if I wanted a high-visibility job, I had to get myself noticed.

Paying it forward to create a more inclusive world

Looking back, I often made big steps in my career thanks to the help and support of another person. Once I realised how much of an impact such people made on my career, I decided that I wanted to do this too. I made it my personal goal to continue to 'pay it forward', by supporting other women to reach their goals. And I am convinced that I can use my own experiences, in my 'atypical' career, to support, coach and help other people reaching their career goals.

I also wondered how I could reach a broader group of people besides the ones I know personally and meet at work every day. I found the answer in a diversity and inclusion professional Michelle Mees. She says that in order to create a more inclusive world, we need both systemic change and personal development. We need to change the system, but also the people and the way we think.

Mees identifies two types of diversity and inclusion professionals that make that happen: activists and coaches. Activists accelerate systemic change. Coaches accelerate personal development. Activists are the ones who stand on the barricades and call out for change.

Personally, I have never been much of an activist. I don't feel comfortable standing on the barricades. I am much more comfortable with a non-judging approach where I share insights and make people think about themselves and the bigger picture. After all, that is what has best worked for me too. It was a key insight to learn that you can have as much impact as a coach as you have as an activist, but the roles work in different ways, and both are needed to create change.

I now do presentations on my experiences as a woman in tech. In these talks, I share my insights on what I have learned about causes and possible solutions of diversity and inclusion issues. I help people reflect on stereotypes and bias and how to consciously overcome unconscious bias. I also act as a diversity and inclusion focal point where I help individual people. We can all help by trying to be a better ally (see Melaku et al., 2020).

I believe that everybody deserves to live up to their potential, regardless of what they look like or where they come from. S

"The same behaviours by men and women are interpreted and treated – even rewarded or punished – differently"

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DISASTER RECOVERY AND BUSINESS CONTINUITY: A SHORT INTRODUCTION

Few things concern operational and technical staff more than major outages and technical failures. These, and disasters affecting the ability to remain in control, are the subjects of disaster recovery and business continuity planning. In this article, **Stefan Maes** gives a short introduction, relevant to all of us who depend on IT for business operations.

KEY POINTS

- **Disaster recovery and business continuity are closely related, but differ in scope.**
- **Disaster recovery is the process of making all important IT infrastructure and operations available again following an outage, whereas the business continuity process focuses on the business applications (IT centric vs application centric).**
- **Different solutions will have to be put in place depending on business needs and budget and technology availability.**
- **Building a disaster recovery and business continuity plan is not sufficient: it needs to be continuously rehearsed, reviewed, refined, and retested.**

"What to do if they discover World War II ordnance and we have to evacuate our site, in part or as a whole, for its safe disposal?" This was one of the questions we in EUROCONTROL asked ourselves before the start of the excavation works for the construction of the new NM Operations Centre. The answer was quickly found as it was already documented in EUROCONTROL's disaster recovery plan. Following a risk assessment, some disaster recovery procedures have been activated as a precautionary measure.

Disaster recovery and business continuity

Today, IT is essential to almost all business operations, and for that reason, it is at the centre of business continuity and disaster recovery planning. While closely related, disaster recovery and business continuity are not the same thing. The key difference between the two is in their scope. Disaster recovery is the process of getting all important IT infrastructure (data, servers, software, applications, operating systems, etc.) and operations up and running following an outage or disaster.

The following types of outages are typically considered for a disaster recovery scenario:

- computer systems and services failures,
- power outages and power failure, and
- natural disasters (earthquake, fire, floods, etc.).

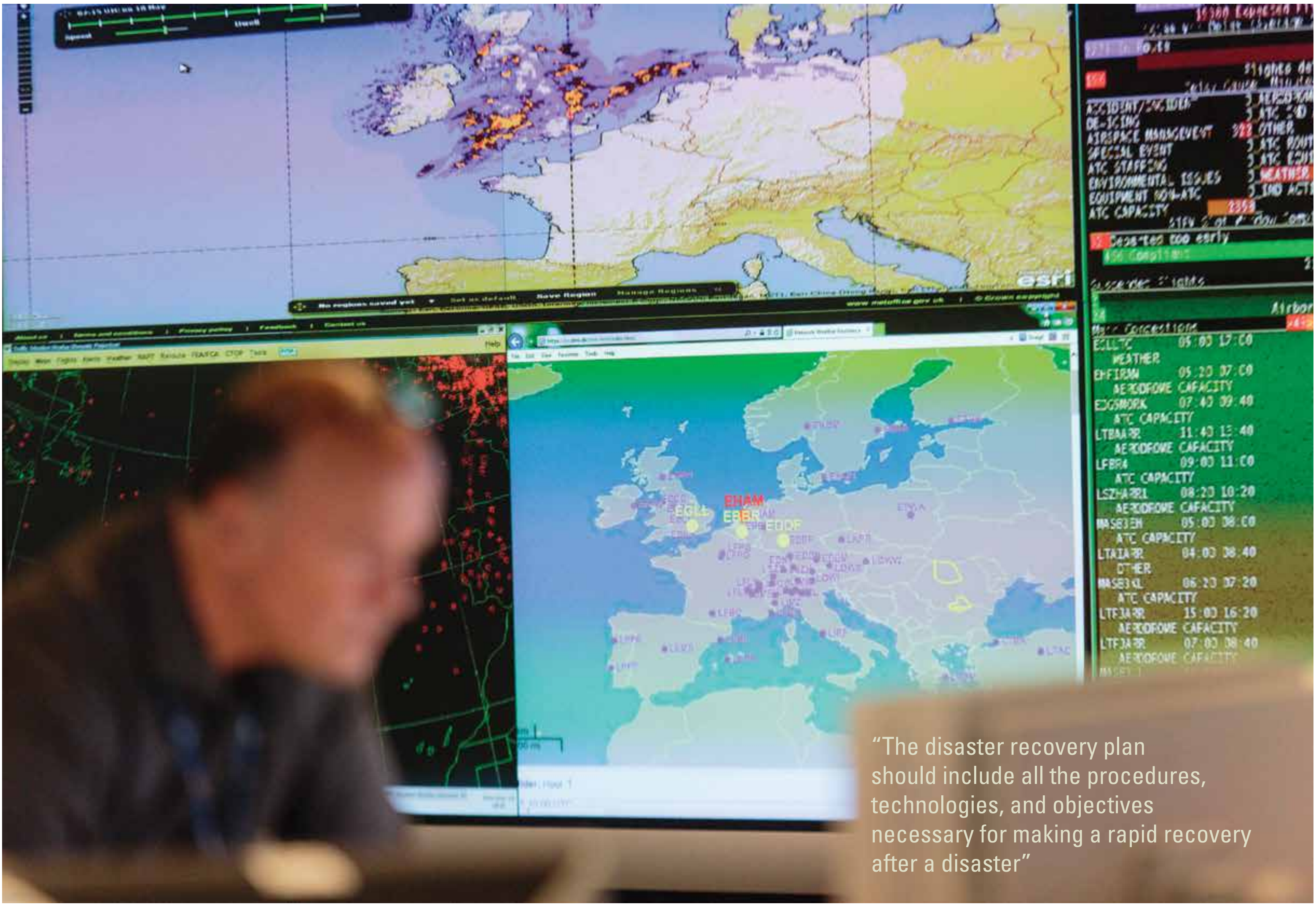
Business continuity differs in that it is the process of getting the business applications and business services back to full functionality after a disaster.

Both are obviously relevant not only to technical staff, but also operational staff, safety staff, management, and almost everyone else. Many ANSPs, airlines, airports and other such organisations have experienced an outage or disaster, and operational and technical staff tend to remember them well. When they affect flight operations, resulting in long delays and cancellations making the headlines, the public remember them too.

"Many ANSPs, airlines, airports and other such organisations have experienced an outage or disaster, and operational and technical staff tend to remember them well"

The disaster recovery plan

The disaster recovery plan dictates how the business should respond to a disaster. Before creating a disaster recovery plan, an organisation should first review its business continuity strategy and cautiously consider the potential impacts of disasters: Which areas are vulnerable? What are the potential losses if the business applications processes go down for a day, a few days, or a week?



"The disaster recovery plan should include all the procedures, technologies, and objectives necessary for making a rapid recovery after a disaster"

The disaster recovery plan is then developed according to business needs. Most likely, different solutions for different business applications will be required.

The disaster recovery plan should include all the procedures, technologies, and objectives necessary for making a rapid recovery after a disaster. As a minimum, a plan should account for the following:

- *Recovery point objective:* This refers to the desired state after recovery. To define the recovery point objective value, the following questions are relevant: *"What data should be restored?" "What data can I afford to lose?"*
- *Recovery time objective:* This refers to your desired timeframe for completing recovery before the situation becomes critical. In other words, it answers the following question: *"When should data be restored and business applications running again?"*
- *Recovery technologies:* This refers to all systems currently implemented, or those that should be, in support of recovery. The following question is relevant here: *"What technologies are required to recover from disaster?"*

Again, these are not merely technical issues. The involvement of operational staff is necessary to deal with each and to answer the questions above.

Depending on the values of the recovery point objective and recovery time objective, different recovery technologies may be needed for different business applications, each with their own price tag. When the business criticality dictates very small recovery objectives (minutes), one has to think of so-called 'active-active' solutions where applications and infrastructure are running in parallel in multiple locations.

As recovery objectives become larger, one can think of:

- *active-standby solutions*, where recovery infrastructure is available and ready in a disaster recovery site and only application data needs to be restored,
- *restore solutions*, where infrastructure capacity is reserved, but operating systems and applications need to be installed from scratch and application data needs to be restored, and
- *rebuild solutions*, where infrastructure first needs to be acquired, after which a restore as described above can start.

Other important information in the disaster recovery plan includes:

- *Recovery protocols:* These protocols should identify who does what in the event of a disaster, including clearly defined roles and how you expect recovery personnel to communicate with each other.
- *Vendors, suppliers, and other third parties:* This is a list of all parties who may be needed to support recovery, as well as their emergency contact details.

What about…?

…the workplace?

The major focus of disaster recovery and business continuity is on the business applications hosted in a data centre. One should, however, not forget about providing business users access to their applications in a disaster recovery situation. Application access from home is increasing, but is not always feasible. Hence it may be necessary to foresee off-site office space to be used in case of disaster.

…the cloud?

While hosting applications on the cloud (public or private) typically removes the burden to build a data centre recovery scenario, this does not remove the need for a disaster recovery or business continuity plan. It is still necessary to have a plan on how to deal with (extended) outage of the cloud services.

The business continuity plan

The disaster recovery plan should be complemented by a business continuity plan, which acts as a single, multifaceted document for managing every aspect of disaster preparedness.

A business continuity plan will usually include a risk assessment (a thorough assessment of disaster scenarios, their likelihood, and their impact) and impact analysis (an outline of how each possible disaster scenario could impact your business, e.g., costs of repair, disruption to services).

Linked to these will be steps and systems to help prevent each of the disasters listed, such as implementing anti-malware to prevent cyberattacks, and detail on how the business will respond to each disaster to minimise the impact.

There will also be areas for improvement identified during the creation of the plan, as well as recommended solutions, and contingencies such as a backup office location to be used in the event of a disaster. And there will be protocols for maintaining communication with recovery personnel, such as a text alert system.

The importance of testing

Testing the plan is the only way to know it will work. Obviously, a real incident is the true test of whether everything is correctly covered in the plan. However, a controlled testing strategy is much more comfortable and provides an opportunity to identify gaps and improve.

Many organisations test a business continuity plan two to four times a year. The schedule depends on the type of organisation, the amount of turnover of key personnel, and the number of business processes and IT changes that have occurred since the last round of testing.

Common tests include table-top exercises, structured walk-throughs, and simulations. Test teams are usually composed of the recovery coordinator and members from each functional unit.

- A *table-top exercise* usually occurs in a conference room with the team going over the plan, looking for gaps and ensuring that all business units are represented.
- In a *structured walk-through*, each team member walks through his or her components of the plan in detail to identify weaknesses. Often, the team works through the test with a specific disaster in mind. Some organisations incorporate drills and disaster role-playing into the structured walk-through. Any weaknesses should be corrected and an updated plan distributed to all pertinent staff.
- Lastly, *disaster simulation testing* can be challenging and should be performed annually. The test requires an environment that simulates an actual disaster, with all the equipment, supplies and personnel (including business partners and vendors) that would be needed. The purpose of a simulation is to determine if you can carry out critical business functions during the event.

During each phase of plan testing, some new employees should be included on the test team. 'Fresh eyes' might detect gaps or lapses of information that experienced team members could overlook.

Review and improve

Much effort goes into creating and initially testing disaster recovery and business continuity plans. Once that job is complete, some organisations let the plan sit while seemingly more critical tasks get attention. When this happens, plans go stale and may not support staff as well as they should, when needed.

Technology evolves, and people come and go, so the plan needs to be updated too. Key personnel should be brought together at least annually to review the plan and discuss any areas that must be modified.

Prior to the review, feedback should be sought from staff to incorporate into the plan. All departments or business units should review the plan, including branch locations or other remote units. If you have had the misfortune

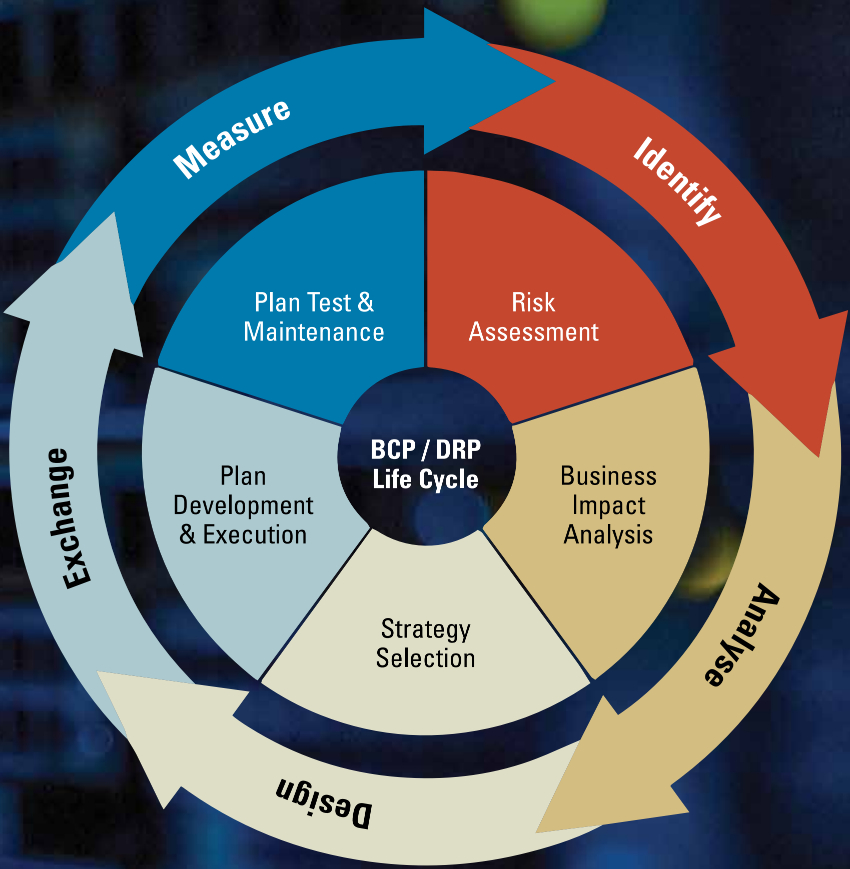


Figure 1: Life cycle of the business continuity and disaster recovery plans

of facing a disaster and had to put the plan into action, lessons learned should be incorporated. Many organisations conduct a review in tandem with a table-top exercise or structured walk-through.

> "It is important is that key staff, including operational, technical or safety staff, are involved in the lifecycle of business continuity and disaster recovery planning"

In Closing

This article provides only a brief introduction of what is involved in disaster recovery and business continuity, the related plans and what is required to keep these up-to-date and relevant to your company. Your IT experts and business analysts can provide you with more information and guidance, as can several companies specialised in these matters. It is important that key staff, including operational, technical or safety staff, are involved in the lifecycle of business continuity and disaster recovery planning (see Figure 1). If you are not, then it is time to ask questions to ensure that your operation can recover from disaster.

And in case you were wondering, no World War II explosives have been discovered during construction of the new NM operations centre. So far…

Stefan Maes works as an IT infrastructure architect at EUROCONTROL. He graduated from the University of Antwerp with a PhD in Chemistry. For his professional career, he took a very different direction, pursuing his interest in information and communications technology.
He is currently actively involved in various tracks of EUROCONTROL's iNM programme.

MUAC CONOPS 2030

With customer preferences and the impact on the environment moving up the agenda, MUAC is redefining its ambitions. This is reflected in MUACs new concept of operations, as **Robert Parys** and **Peter Hendrickx** report.

In the last year, in the midst of the COVID-19 pandemic, MUAC has spent time defining its ambition with regard to the concept of operations planned for development over next decade: CONOPS 2030. This initiative expands and replaces MUAC's previous flagship programme called ATC2ATM.

The CONOPS 2030 major objective is to have built-in flexibility to plan staff and the airspace more efficiently while optimising performance. Alongside traditional metrics like safety, cost, capacity, productivity, and delays, we will consider our customers' preferences and the impact of our operations on the environment.

Data-driven decision-making

The CONOPS 2030 ambition is based on a high degree of automated support assisting users in data-driven decision-making. The systems will utilise predictive and machine-learned models to provide solution advisories, based on historical data augmented by real-time events. All relevant data from a variety of MUAC systems, as well as external sources (i.e., ANSPs, airports, Network Manager, military units, and airframes), will be better integrated to improve Ops room situational awareness.

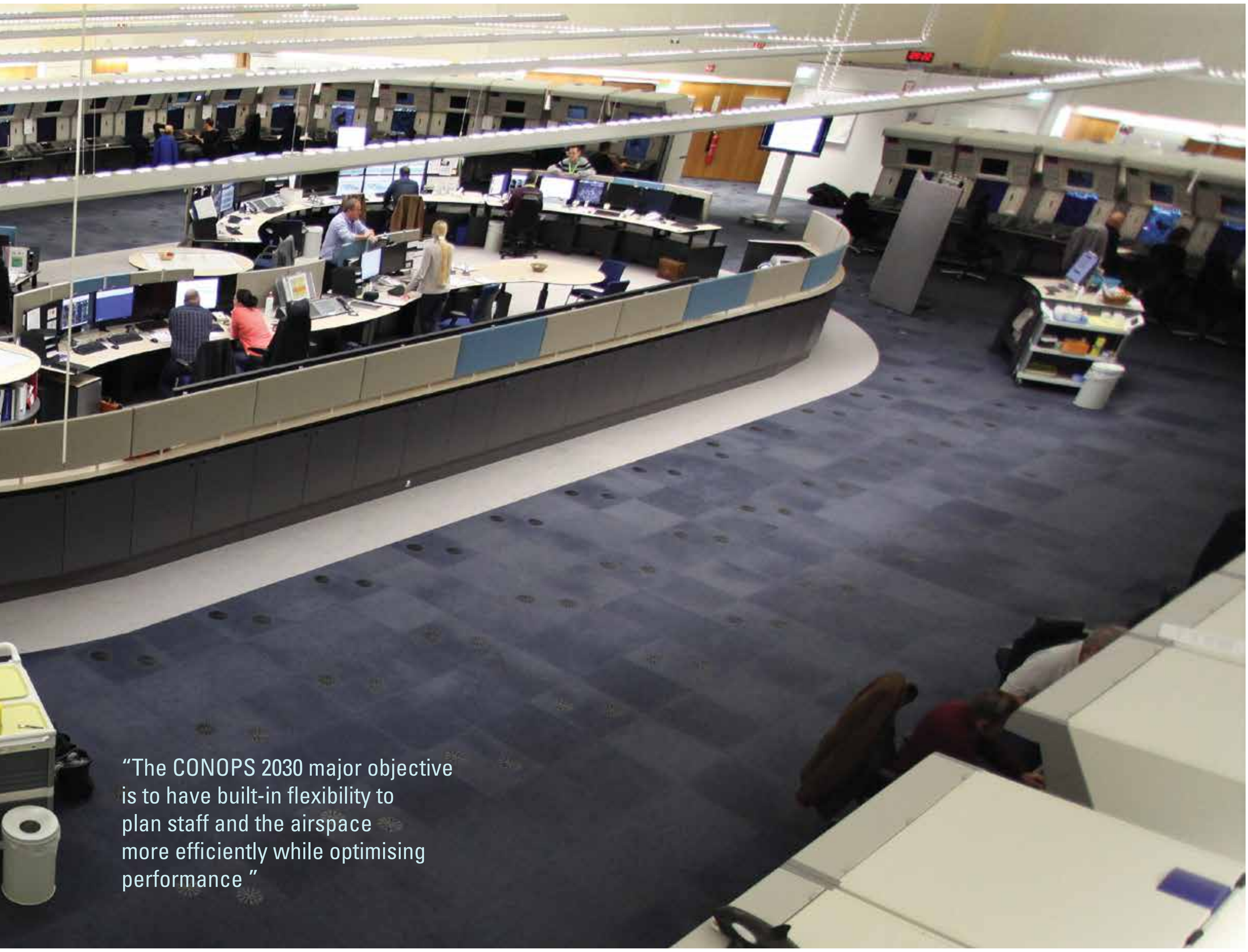
MUAC's revamped Central Supervisory Suite will drive sectorisation plans, which will include more flexible sector staffing concepts than today. They will do that in coordination with other actors based on workload metrics, derived from mixing traffic demand with its complexity.

Supporting the controller in the hot seat

In MUAC, we believe that the Executive Controller (EC) role, as known today, will handle the traffic in 'the hot seat' for years to come, but they will receive support, as and when needed, by:

- A Coordinating Controller (CC) whose role will evolve to better share the workload in the sector.
- A third controller for short overload situations, to avoid opening a fully staffed sector for sometimes a few extra flights.
- Automated control systems assisting upon request, able to control autonomously non-complex CPDLC flights, working under full control and supervision of controllers.
- Traffic complexity reduction collaborative processes involving the Network Manager, neighbouring ANSPs, airline operators, and taking into account the impact on the environment.

With CONOPS 2030, the Executive Controller will be executing and supervising the execution of plans prepared by the complexity reduction processes, and fine-tuned by the Coordinating Controller, with CPDLC being the norm for communication



"The CONOPS 2030 major objective is to have built-in flexibility to plan staff and the airspace more efficiently while optimising performance."

with the aircraft. Using ADS-C data will close the loop ensuring air-ground consistency. The Executive Controller will be expected to intervene when the plans made earlier need a tactical adjustment, or upon an unforeseen tactical event. The system will help them in spotting anomalies.

A new level of operational performance

In the future, our customers' and partners' preferences will drive MUAC operations, communicated digitally and in real time, along with environmental goals and internal performance targets (minimising complexity and maximising throughput). We hope that our network value-adding services will be appreciated and in return will bring us flexibility from our customers and partners.

By 2030, we also plan to implement modern training methods, including competency-based training supported by self-training simulator capabilities. This should shorten the time needed for controllers to cross-train from one sector group to the other.

CONOPS 2030 will bring MUAC into a new level of operational performance required to cope with challenges of the future. This journey starts today.

Robert Parys joined MUAC in 2011 and works in the Change Management team. He is a certified project, programme and change manager with broad experience in large-scale project and programmes in the ATC and ATFCM domains. He is currently innovation co-champion, CONOPS 2030 programme and Optimised Sector Manning project manager.

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Peter Hendrickx joined MUAC in 2000, and after different positions in the Operational and Technical domains, he is now Head of the ATM Development Unit responsible for the Future Operational Concept. He is innovation co-champion at MUAC, and Project Manager of the ARGOS Project, concerning automation of routine ATCO tasks and automated ATC for basic flights.

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NOTAMATION: ARTIFICIAL INTELLIGENCE AT WORK

The huge number of NOTAMs is a well-known problem in aviation, for pilots at least. What many don't realise is that NOTAMs also present a challenge to EUROCONTROL's Network Management Operations Centre staff. **Camille Uylenbroeck** explains how artificial intelligence will help to reduce the burden.

KEY POINTS

- **Artificial intelligence (AI) is able to help operational staff to manage and prioritise their time and decision-making.**
- **Based on statistical analysis, AI can mimic past decisions.**
- **AI comes with new ways of working that need to be defined with the help of operational staff.**
- **AI does not manage novelty well, so systems must cater for it, by introducing safeguards and by keeping humans in the loop.**
- **AI can be misleading for humans, who must develop new skills.**

This is a story about automation, how we can benefit from it and why we should still be careful about it. It begins with a little notice, called NOTAM (Notice to Airmen), sent to alert aircraft pilots of potential hazards. This notice is very flexible: Many different actors can send it at any time, about anything, and each one of them has its own way of working, which can be very positive.

Unfortunately, it can be very difficult to deal with NOTAMs when you are at the receiving end of so many of them. All NOTAMs are different and are presented in capitals, with obscure coding and abbreviations. We are not talking here about the aircraft pilots, but about the people working in EUROCONTROL's Network Management Operations Centre (NMOC). They receive between 500 and 900 NOTAMs per weekday and must read them all to find the needles in the haystack – the 1.5% of them that lead to 'data modification requests' (DMRs). These are requests to register NOTAM changes in the EUROCONTROL data. Today, this must be performed continuously, while doing other tasks, never knowing when an important NOTAM is going to show up.

Innovation comes in the picture

A year ago, EUROCONTROL operational staff submitted this problem to an idea collection meeting and my team (the Network Manager Lab) proposed a solution: What if we built a machine learning model able to provide a relevance score to the operational people? What if we built a magnet, to organise this giant haystack and to put the potential needles first?

> "What if we built a machine learning model able to provide a relevance score to the operational people?"

After all, we had an enormous amount of data, collected over years, concerning NOTAMs and the subsequent DMRs. This seemed ideal for machine learning. We could teach a classifier to recognise the same features of relevance to NMOC staff to decide whether a NOTAM is of interest. The software would then be able to give a score to each NOTAM accordingly, sorting them to help NMOC to make a decision. And that is what we did.

We talked to NMOC staff, a lot. We tried to understand, as much as possible, what they were watching out for, why they would make one choice or another. We also analysed the data, trying to capture patterns and influences concerning DMRs. We ended up with a mixed approach, using classic algorithms, machine learning and natural language processing techniques, to understand the human-written NOTAM texts.

Learning from the past

We first allowed the operators to enter keywords to get an artificially high score for the NOTAMs containing the keywords. Artificial intelligence does not manage novelty very well. Events like an eruption of a volcano, flights dedicated to COVID19 vaccines, or closure of an entire country's airspace are very rare. However, we wanted the tool to be as flexible as possible, to be able to gather NOTAMs describing an exceptional situation NMOC wanted to keep visible – one that the machine learning classifier never saw before.

Then, we coded some simple filters to refine the stack before training the machine learning classifier on it. After some data cleaning, we also learned the most frequent sequences of words that *never* produced DMRs, such as 'ACT MUST BE COORDINATED', indicating an airspace activation (usually also notified in other tools, so never needing DMRs). These two steps attribute the lowest possible scores to the NOTAMs, indicating that a DMR is unlikely.

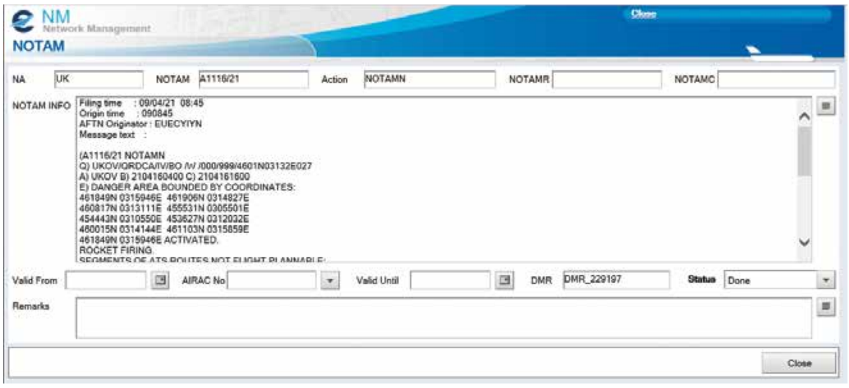
Building the artificial brain

Finally, we used a small 'neural network' as a classifier. A neural network is a set of connected nodes called artificial neurons, which roughly model brain neurons. The network comprised three hidden layers of 10 neurons, to predict a DMR probability for each NOTAM. A little balancing was necessary here, to give more weight to the DMR class, otherwise the algorithm thinks itself very smart: it just predicts that no NOTAM ever produces a DMR, being right 98.5% of the time. We then transformed this DMR probability into a simple scoring system, from A (the most susceptible to producing a DMR) to F (the lowest possible score).

The most important and the most difficult job was to give to the algorithm the best features to make a choice: the ones playing a role in the DMR probability of each NOTAM. Some features were simple, such as indicating if the NOTAM was a 'new', a 'replace' or a 'cancel'. Some features were obvious but more difficult to engineer, such representing the human-written texts via natural language processing computer programs (designed to process and analyse large amounts of written text).

We ended up choosing the presence or absence of the most discriminating sequences of words. Finally, some features were added thanks only to NMOC staff willingness to work with us and explain – and reexplain – their work. For example, two types of NOTAMs (the 'replaces' and the 'cancels') are applied on previous NOTAMs. It appeared that the presence or absence of DMRs for these NOTAMs were among the most important decision criteria for NMOC. Therefore, this became one of the most important features of the classifier.

> "The most important and the most difficult job was to give to the algorithm the best features to make a choice"



The machine sorts while human focuses on the essentials

Finally, after lots of refinements, changes, trials, errors, and corrections… it worked. Just in the 'A' score, we managed to catch 83% of the NOTAMs producing a DMR among the 7 to 14 daily 'A' NOTAMs. If we add the 'B' score, we catch 92% of our needles among the 17 to 31 'A' and 'B' NOTAMs. With the 'C' score, we catch 96% of them among the 45 to 82 A, B and C NOTAMs arriving every day.

To summarise, instead of browsing randomly arrived NOTAMs, an operational staff member will first look for A score or A and B score. With a review of a maximum of 31 NOTAMs, 92% of those requiring a change in NM systems are caught.

We also hope to reduce use errors by allowing operators to take more time for the more relevant NOTAMs. However, the introduction of AI could also produce another source of errors via the so-called automation bias. It happens when users put so much trust into the technical system that they ignore valid contradictory information. For example, a NOTAM labelled E or F will be difficult for the operational staff to link with a DMR, because it will be such a rare event. However, automation bias can be reduced here by decreasing the complexity of the information displayed, like transforming a probability to a letter score, or providing support information instead of directives or commands.

As good as it gets?

This tool will not prevent NMOC from going through the entire daily batch of NOTAMs, because they cannot afford to miss even one NOTAM. Indeed, the software will be wrong sometimes – it is inevitable. However, the tool will help the operational people to have flexibility to prioritise their actions according to the score given to the overdue NOTAMs. Therefore, they will be a lot quicker to treat the NOTAMs with DMRs, since these NOTAMs will be at the top of the list. Staff can then to choose a quiet time of the day to review the rest. This is what we were aiming for. For now, the tool is as good as it gets.

"The tool will help the operational people to have flexibility to prioritise their actions according to the score"

Camille Uylenbroeck has been working in EUROCONTROL as a Sopra Steria data scientist for three years, after graduating in computer science engineering. She has worked among the NM Lab team on several innovative projects involving machine learning. She has also won the Digital Sky Challenge of 2019, a 48h Hackathon, with her team in the environment category.

An operational perspective

"At the Network Manager Operations Centre (NMOC) we optimise traffic flows by constantly balancing capacity and demand, while helping to ensure the safe and efficient operation of flights going to and over Europe. To support this ATFM function, NMOC is monitoring manually between 600 & 800 NOTAMs daily, from which only a small percentage requires an update in our system in real time. This new AI, by assigning priority index on each NOTAM in an interactive dashboard, will reduce significantly the workload in NMOC. It is an important step towards the modernisation of our systems.

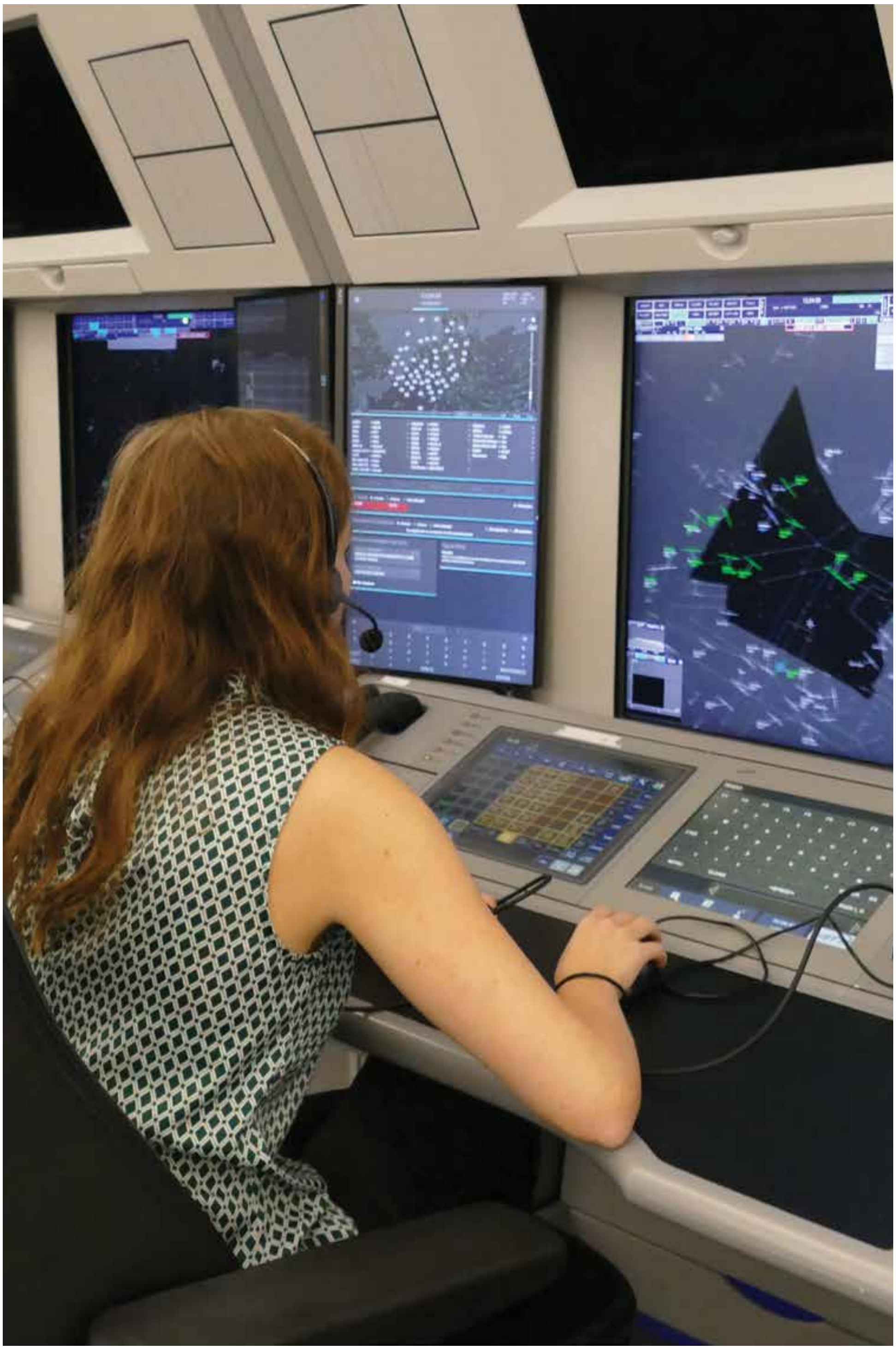
"One of the important missions of NM is to ensure the European Crisis Management function. Recent crises (volcanic, pandemic, geo-political) have highlighted how vulnerable our Network can be during these situations. In such cases, NM needs to bring a rapid, well-informed and coordinated response to minimise any negative impact and maintain safe and efficient operations at local and network levels. To support this task and to be a leader of this function in Europe, detailed monitoring of NOTAMs by NMOC is crucial. Integrated in a new HMI NOTAM dashboard, the AI will also allow us to receive in real time, and with high level of priority, any alert about a potential disruption or crisis in the Network."

Daniel Degehet, Operations Manager at EUROCONTROL NMOC

Daniel Degehet was a Belgian Military ATCO for several years before joining EUROCONTROL in 1993 to participate to the creation of CFMU. In 2015, after 20 years' experience in NM Operations, he was promoted to Operations Manager in NMOC.

FOCUS ON…MUAC TECHNICAL SYSTEMS

Operating in one of the busiest airspaces in Europe, EUROCONTROL MUAC is handling demanding and complex technical developments. Members of the **MUAC Technical Systems Uni**t and **MUAC Ops Units** outline some of their work concerning digitalisation in ATM.



"MUAC has always had a pioneering spirit, and we are currently undergoing more change that at any time in history"

I lead the Technical System Unit (TSU) composed of more than 150 engineers responsible for the development, maintenance and operations of MUAC's IT infrastructure and applications. We serve internal and external operational users, ensuring the continuous evolution and round-the-clock safe and efficient operations of our advanced technical systems. We work in close collaboration with change management and operational staff to support current operations, ATM development, and technical system development.

There is growing demand and complexity, both in traffic and in terms of technology. From a technical perspective, there are two key areas of focus: automation and interconnectivity. In terms of automation, in the Ops area there are plans to make flow management more autonomous, for example. This will involve ensuring optimal sector opening times and ATCO rostering. There will also be more automation in the ATC area with regard to delegation from human to machine in certain low complexity scenarios and more automation support in high complexity scenarios. Behind the scenes, test automation and automation of software integration and deployment is being introduced. This is to help cope with the scale and complexity of engineering work. Every year, we have four to five major system updates and up to 100 system baselines. System resilience is critical to ensure we can anticipate, monitor, respond and learn.

In terms of interconnectivity, a big change is that systems are now more interlinked. We have moved from traditional separate systems toward more interconnectivity, especially in terms of Air Traffic Flow and Capacity Management (ATFCM), where there is more interconnection with the Network Manager, as well as with airlines and airports. Security and resilience must be embedded in system design, including the system architecture.

My focus is on the evolution of technology, including the strategy and vision. One key ambition of MUAC is to become a certified ATM data service provider serving several Ops rooms at different locations. This is the 'ATM Data as a Service' (AdaaS) concept, which was already demonstrated in partnership with Slovenia Control. The concept is centred on a common ATM system replicated in two geo-redundant data centres to cope with maintenance requirements and the risk of catastrophic failures. The service will initially apply to the Belgian ANSP skyes and the Belgian Air Force, as well as Slovenia Control. We also foresee an agreement with DFS for their Karlsruhe Centre, to cooperate further on common system developments and virtualisation.

MUAC has always had a pioneering spirit, and we are currently undergoing more change that at any time in history. This is not only a technological change, but also a cultural shift and change in the whole organisation. I am fortunate and proud to be leading a great team of engineers, working with our partners to deliver a world-class system.

Răzvan Mărgăuan
Head of Technical Systems

"Digitalisation has led us to change the way we think"

My role is day-to-day management of the MUAC Ops room for systems, airspace and procedures. I help to make sure that the conversation between the Technical Systems Unit and Ops is fluent. I help to ensure that the severity of issues reflects the reality, that workarounds are developed and known to 24/7 staff, and that correct priority is given for implementing solutions.

We manage our high complexity interdependent systems by creating points in our processes to meet weekly for coordination and monthly for trend analysis. The conversations focus first on safety then balancing sometimes conflicting interests. In some cases, Ops accepts delays in non-critical implementation if the technical sequence of baseline implementation is complex. In other cases, the Technical Systems Unit works on issues we identify as critical and with highest priority by delaying other non-critical work. Often, we have to coordinate with many external military, civil, technical and operational partners.

Digitalisation has led us to change the way we think of not only systems but also accompanying procedures, competencies and the management of critical events. For example, we understood that we have to develop technical ability to monitor any system's health and monitor the data quality within the system. At the same time, there are intense conversations on how we deal with increased automation, detection of credible corruption and data streams. We are constantly learning as we go, and perhaps one of the most important things we have internalised is never to be complacent.

Milena Bowman
Executive Manager Airspace, Systems and Procedures, MUAC OPS

"The challenge is always to keep the right balance between correct functioning, operational acceptance, and pace of delivery without jeopardising safety"

The MOSYS team consists of a variety people with different operational and technical backgrounds. They work closely together with other actors across the organisation and external partners to develop an understanding of the different requirements, and continuously look for improvements and develop new innovative concepts. It is critical to deliver products to meet the customer's needs, while keeping the overall system design and integrity as a central consideration.

As we have most of our own technical systems development in-house, and work 'close' to the customer, we can develop at a rapid pace. This requires a challenging change management process to allow sufficient validation from end-user perspective. We all know that with innovative products not everything is right from the start. The challenge is always to keep the right balance between correct functioning, operational acceptance, and pace of delivery, while maintaining safety.

Kristof Schippers
Team Lead, MOSYS (MUAC Operational Systems)

"The new Shared ATM System will run from the MUAC data centre and will provide ATM-Data-As-A-Service"

MUAC, the Belgian ANSP skeyes, and the Belgian Air Force are jointly designing a Shared ATM System (provisionally called 'SAS3'). SAS3 will run from the MUAC data centre and will provide ATM-Data-As-A-Service (AdaaS) to the OPS room at skeyes, Tower systems at Belgian airports and to the different airbases of the Belgian military. An equivalent service will be used by our own MUAC Ops room. All AdaaS instantiations are set up as a managed service provided by MUAC in collaboration with its partners. Dedicated system clusters for each Ops Room ensure that failure modes in one cluster do not propagate to a neighbour. This allows horizontal scalability (serving more Ops Rooms in the future), while still supporting rich interoperability and re-use of software (we always maintain the same software version for all OPS Rooms with configurations specific to each).

A particular challenge is interfacing with auxiliary systems not managed by MUAC, like arrival managers, tower systems, electronic strip systems, or safety nets specific to lower airspace. This will be achieved by the 'OpenATM' interface, a standard system-wide information management (SWIM) interface based on modern technologies that will serve as a common integration layer.

Herbert Naessens
Team Lead Architecture & Systems Engineering (TS/ASE) and Project Manager Traffic Prediction Improvements (TPI)

"We have recently started to explore the potential benefits of artificial intelligence"

Our team is mainly working on increased automation of various areas of the ATM business. Current topics include manpower planning tools, where advanced mathematical optimisation techniques allow for a high degree of automation of ATCO work planning, down to the allocation of physical positions in the Ops room. These tools are highly adaptive and maximise staff comfort while minimising traffic delays. While these tools are already fully operational at MUAC and NM, the next generation is currently being developed with both functional enhancements and technological transformations. Another important topic is the development of novel assistance tools for the ATCO such as conflict detection and resolution tools, paving the way toward automated ATC monitoring and control. Years ago, we deployed the first operational implementation of machine learning in ATM worldwide (the Traffic Prediction Improvements project led by my colleague, Herbert Naessens). To take the concept further, we just started to explore the potential benefits of artificial intelligence in a potential fully automated flow management process based on machine learning (deep neural networks).

Micha Janssen
Team Lead Airspace, Capacity and Environment (TS/ACE)

"We support the virtualisation platforms on which almost all components of the ATM system are running"

My team is working on a variety of components of the MUAC ATM system. As a service to the other teams, we support the virtualisation platforms on which almost all components of the ATM system are running. Additionally, we provide tools for the Ops room and maintain the simulator used for ATCO training and system testing.

Concerning digitalisation, I would like to emphasise two great recent achievements: the new Operational Support Data Retrieval (OSDR) and the deployment of the remote test and training infrastructure. In 2017, my team started with the development of the new OSDR. We deployed the first version in October 2018 and made it possible for ATCOs and other Ops room staff to access all operational documentation electronically from their position. The information is displayed in a web browser on a dedicated screen next to the radar screen.

Now, three years later, many functions have been added, such as graphically displaying weather predictions (wind, CB nowcast, turbulence, and temperature), METARs, NOTAMs, aircraft performance, current and upcoming sectorisations with current and predicted load, planned activations of danger/restricted areas, etc. Many other features are in the pipeline.

In order to uphold essential controller training and software test and development activities during the lockdown period, we made the MUAC's Test and Training available outside the MUAC premises. Together with other teams, we rolled out this development in record time after the start of the lockdown in March 2020. From early April 2020 onwards, MUAC employees have been able to use within a web browser on their private PC at home, controller working positions in the Test and Training Room.

This solution allowed MUAC to uphold its development, test and training capacity, whilst keeping staff numbers at the premises to the minimum. Meanwhile ATCOs use this set-up also for self-training and in meetings to demonstrate the functionalities of our ATM system by sharing the controller working positions via MS Teams. This has allowed us to keep the competency of our ATCO staff up to date and is a key enabler to the swift and flameless traffic recovery with zero impact for the airlines and the passengers. The benefits of this remote test and training solution will extend beyond the pandemic and will be enlarged and automated further.

Dominique Mathijs
Team Lead, Simulation – Replay – Support (TS/SRS)

"We maintain one of the most complex and one of largest sub-systems of the Maastricht Data Processing and Display System"

In the Flight Data Processing (FDP) team, we maintain one of the largest and most complex systems of the Maastricht Data Processing and Display environment (MADAP). The FDP is truly the 'brain' of our technical system, responsible for generating and maintaining the flight trajectories and the distribution of flight relevant information to the controller working positions and to many other sub-systems.

For a safety-critical system with a large code base (over 1 million lines of code), such as FDPS, the risk of 'regression' grows statistically with new developments. A regression is when a code change in the software impacts the existing functionality, perhaps where a feature stops working (a type of software bug).

Until recently, 'non-regression assurance', which aims to verify whether new or modified functionality operates correctly, has been achieved through long sessions of manual testing by the FDP team. This year, we modernised our testing capabilities by automating our regression tests. For that purpose, we are using a test engine that allows us to write test scenarios that can be executed automatically and on-request. We have currently completed the foundation of the test framework and started developing automatic tests, replacing our manual tests. The next step will be to put in place a test-driven development methodology where each new software change will bring additional tests, which will continuously improve system robustness and stability. The new test framework will be introduced in January 2022.

With the latest SAS3 cooperation agreement signed by MUAC and the civil and military Belgian ANSPs, the technical roadmap will include major changes. Automatic tests are the only test strategy that can efficiently mitigate that risk. Thanks to the automatic tests, non-regression assurance can be done earlier on, and we will save on testing effort. This will allow our team to focus on functional features, dedicate more time to innovation, and better support the OPS room.

For MUAC, this is a major milestone on the path of building a fast and efficient continuous integration and deployment pipeline to ensure a resilient and futureproof MADAP system.

Khaled Badri
Team Lead, Flight Data Processing (TS/FDP)

Learn more

About our Maastricht Upper Area Control Centre https://www.eurocontrol.int/info/about-our-maastricht-upper-area-control-centre

Traffic prediction improvements https://www.eurocontrol.int/project/traffic-prediction-improvements

Civil and military air traffic control in Belgium now managed using a single air traffic management system https://www.eurocontrol.int/press-release/civil-military-atc-belgium-managed-using-single-atm-system

ATM Data as a Service (AdaaS) - Towards the concept of data centres https://www.eurocontrol.int/publication/atm-data-service-adaas-towards-concept-data-centres

EUROCONTROL and Slovenia Control sign cooperation agreement to deploy the ATM Data as a Service concept https://www.eurocontrol.int/news/eurocontrol-muac-slovenia-control-sign-agreement-deploy-adaas

All civil and military air traffic controllers to use the same system to manage Belgian airspace https://www.eurocontrol.int/press-release/civil-military-atc-use-same-system-manage-belgian-airspace

HUMAN AND ORGANISATIONAL FACTORS

Q&A

PERFORMANCE BASED NAVIGATION (PBN) ROUTES

Nuno Cebola is Director Human Factors at NATS

nuno.cebola@nats.co.uk

1. What is a significant change planned within your organisation that has relevance to human and organisational performance?

We are planning to implement Performance Based Navigation (PBN) routes across a significant amount of our lower airspace. PBN is *"Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace"* (ICAO PBN Manual, Doc 9613). New satellite technology offers the potential to design more direct and more efficient routes. In the en-route phase, this navigation technology allows aircraft to follow a flight path with increased accuracy without the need to navigate using ground-based beacons. In the departure and arrival phases, PBN allows for the design of routes that are deconflicted, with reduced need for tactical ATC interventions.

In the air, enhanced technological systems reduce manual inputs by flight crews. On the ground, the change will reduce radiotelephony (RT) load and transfer certain tasks such as radar vectoring from controllers to airborne systems. But controllers are expected to monitor these aircraft.

We have done smaller scale changes in the past, but we are now looking to do so for a much larger proportion of lower airspace in conjunction with airports across the UK.

2. Why is this change necessary? What is the opportunity or need?

Apart from the last years due to the COVID-19 pandemic and other events, air traffic has continuously increased over the last several decades. In the UK, we have very complex airspace due to the limited physical airspace available to us to work with, and significant levels of air traffic (2.6m in 2019). So, for us, traffic increase also means more complexity and so we are always on the lookout for new ways to increase our capacity.

As noted by CANSO (2015) for ANSPs and controllers, *"PBN reduces controller workload due to: Decreased dependency on tactical radar control; Potential introduction of flight path monitoring/ alerting tools for controllers; Reduction in complexity and variability of procedural approach control; Lower dependency on radiotelephony (RTF) with decline in incidents caused by read-back/hear-back issues."*

PBN has been identified as one of the ways to improve not only capacity, but also safety and efficiency.

3. What are the main obstacles facing this change?

Changing the nature of tasks performed by people in a system to include more monitoring activities is not new, and neither are the challenges this brings. One of the main issues is how to ensure the human who is responsible for monitoring remains in the loop when things go wrong, and the human is then required to take control. This can also be seen with automated systems when, in some circumstances, control is transferred back to the human. The issue with this is when the person does not understand what the machine was doing and what action is required before being required to take full control. Similar examples are found within the aviation industry, where the pilots have struggled to understand what the technology was doing and why, and subsequently diagnose and address the issues.

With PBN routes, ATC will do much less tactical radar control. Adequate measures are necessary, however, to ensure that the ATC system can identify and address conflicts for situations where controllers need to intervene. Controllers need to understand what is happening, the tasks they'll continue to perform themselves, and what action is required of them should they need to intervene.

4. What is the role of front-line practitioners? How is their expertise incorporated into change management?

In the aviation industry, we pay a lot of attention to our safety performance, how to continually improve it and learn lessons associated with changes to our operation. This is no different and the same processes apply. Frontline staff are involved in safety and human error assessments, and all changes are validated by our controllers, who need to feel comfortable and confident in their use and application.

5. What do they think about the change?

Operational staff appreciate the expected workload reduction in the relevant sectors. However, there are potential implications for complexity in areas where controllers have to intervene with radar vectors or other actions.

Read more

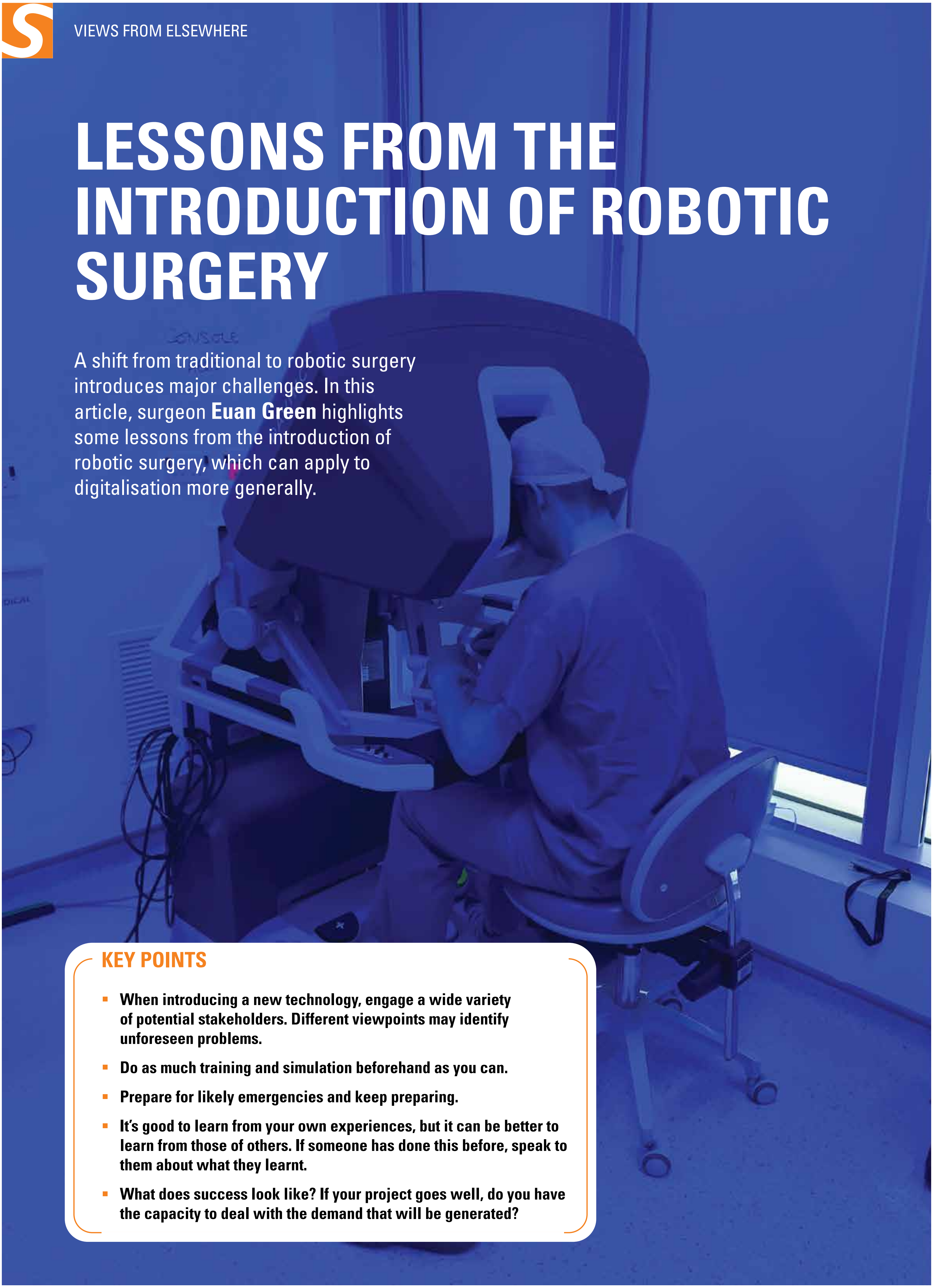
CANSO (2015, March). *Performance-based navigation: Best practice guide for ANSPs.* https://canso.org/publication/performance-based-navigation-best-practice-guide-for-ansps/

NATS (2021). *The future of airspace.* https://www.nats.aero/airspace/future/

SKYbrary (2021). *Performance based navigation.* https://skybrary.aero/articles/performance-based-navigation-pbn

LESSONS FROM THE INTRODUCTION OF ROBOTIC SURGERY

A shift from traditional to robotic surgery introduces major challenges. In this article, surgeon **Euan Green** highlights some lessons from the introduction of robotic surgery, which can apply to digitalisation more generally.



KEY POINTS

- **When introducing a new technology, engage a wide variety of potential stakeholders. Different viewpoints may identify unforeseen problems.**
- **Do as much training and simulation beforehand as you can.**
- **Prepare for likely emergencies and keep preparing.**
- **It's good to learn from your own experiences, but it can be better to learn from those of others. If someone has done this before, speak to them about what they learnt.**
- **What does success look like? If your project goes well, do you have the capacity to deal with the demand that will be generated?**

Introducing a new technology is challenging in any field, but when the consequences of getting it wrong can have life-altering complications, it is especially important to get it right first time round. In surgery, changes in technology are often incremental – a slightly better instrument or cheaper version of an existing product – but sometimes the change is radical. My hospital's introduction of a robotic surgery programme over the last year or so is of the latter variety. With some experience behind us, I will reflect here on how we went about this, the challenges we anticipated and planned for, and the unanticipated challenges that we encountered.

Why robotic surgery?

The first question to be addressed is "why make a change towards robotic surgery?" We've been managing very well without a robot. Within the challenging financial environment in the UK's National Health Service, there has to be a clear justification for such large expenditure (exceeding one million pounds).

Keyhole surgery (laparoscopy) has, for the last 30 years, enabled operations to be undertaken with smaller incisions. This means less pain and quicker recovery for patients. From a technical point of view, robotic surgery offers better optics by providing 3D high-definition video with better magnification and the ability to visualise near infrared fluorescence. This makes it easier to see more of the fine detail of blood vessels we haven't been able to see before. Robotic technologies also offer instruments with a greater range of movement than that of the human hand and the limited movements of traditional laparoscopy, while enabling tasks like knot tying and dissection of patient tissues to be done almost as easily as with human hands.

But ease of use and keeping up with the new standard of care in many surgical procedures is not convincing enough for financial directors, at a time of tight budgets and other pressures on the NHS (e.g., COVID). The deciding factor was that there are potentially significant benefits to patients. Better technology allows us to undertake more complex and challenging operations in a minimally invasive fashion. Compared to traditional open surgery, robotic surgery can bring faster recovery to our patients. It can also allow us to operate on older, less healthy patients who might not be able to tolerate an open operation without serious risk of problems.

With a collaborative effort from a range of surgical specialities and the support of a charitable group, we were able to justify the expenditure to the executive board.

> "Better technology allows us to undertake more complex and challenging operations in a minimally invasive fashion"

Engaging stakeholders

The introduction of a significantly different method of operating poses potential challenges not just to surgeons, but to many people throughout the organisation. We set up a working group that engaged as many different stakeholders as we could identify. This was critical to our success. Rather than simply looking at the surgeons who will be operating with robots, it was important to think much more widely, involving:

- the company that makes and sells the robot (as they have experience of setting up similar programmes elsewhere),
- the nurses who will help set up and assist in the operating theatre,
- the support staff who order and check the stock of consumable items used during operations,
- the technical staff responsible for ensuring electrical and technical safety, and
- the staff groups who will be looking after patients before, during and after their operation (anaesthetics, recovery and ward staff). We used this group to identify the potential barriers to adoption and to look at how we might counter them.

By using expertise from a range of disciplines and those who had experience of setting up services elsewhere, we hoped to minimise the number of 'unknown unknowns'.

Major issues that were identified were as follows:

- staff training on the use of equipment and how to make sure the first operation on a patient went well,
- ensuring that there was a clear supply chain for obtaining disposable items and sterilising reusable items, and
- training staff in how to manage emergency situations during surgery.

Training and procedures

Adequate training was achieved by using the experience of others. This first involved visiting other units with established robotic surgery programmes and experience of how to carry out operations smoothly and safely. We trained using virtual simulation and software that could train basic techniques. We then used these as building blocks to lead into more complex virtual simulation. This led on to lab training using a real robot in a supervised environment on simulated tissue requiring certification, before progressing to operating on patients.

When it came to starting to operate on patients, this was done with the hands-on support of a 'proctor'. A proctor is another surgeon from another hospital, with extensive experience of robotic surgery, who has been trained in how to provide support to surgeons at the start of their robotic career. This was done while simultaneously choosing initial operations that were likely to be straightforward to start with, then slowly building in more complexity whilst support was still present. Nursing staff went along a similar journey of education.

A key element for me was to have a colleague training at the same time so that we support and advise each other once the support of the proctor was no longer there.

Issues around supply chains and sterilisation were resolved by making full use of the wider working group within the hospital who had experience of creating and implementing standard operating procedures. This ensured that new equipment was regularly checked, maintained, and cleaned in the way required and that responsibility for managing stock levels of items was clear.

Managing emergencies

For management of rare but serious emergencies, we set up a series of emergency drills simulating how we would manage a problem and undock the robot from a patient to allow rapid open surgical access. This identified problems that might occur. For example, the bulky robotic equipment got in the way of the trollies carrying emergency equipment into the operating theatre, which seems minor but is important. Given the rarity of true surgical emergencies like these, it is important to continue to run these drills at intervals; while surgeons stay in their roles for many years, nursing and support teams can change regularly. It is important that safety measures are kept high on the agenda and fresh in everyone's minds.

Success…with some unexpected issues

The robotic surgery programme has been a success. It has been of clear benefit to our patients, shortening in-hospital recovery for operations. Cancer operations to remove a kidney previously had a three-day stay for keyhole operations. This has been reduced to one day. The reduction has brought benefits to the hospital as we've tried to cope with higher numbers of emergency admissions during the pandemic. Patients have had noticeably less pain after their operation, and we have been able to take on more complex work as time has gone on. We have gone from two to six surgeons using the robot, with more being trained to broaden the scope of what can be done, bringing the benefits to more patients.

There were unexpected issues that have since been dealt with. For instance, the robot and associated items are larger than any traditional surgical equipment. The operating theatres – with a lot of thought and modelling – were required to fit and store the robot. The only operating theatres thought to be large enough to house the robot are suspended over a parking bay. Prior to its arrival, no-one had considered whether this structure would cope with the additional 1500 kg of weight, which required some structural engineering input.

As we have progressed and used the robot more frequently, we are getting to the point where there aren't enough days in the week for everyone to use it for everything we want it to be used for. After a long and complex setup process, we hadn't anticipated that we would need to be looking at a second machine within a year of getting the first.

The success of the introduction of this revolutionary technology has been through careful planning and engagement not just of those directly using the robot, but a broad array of people indirectly involved and in the identification of potential problems well in advance. Consultation with those who have seen programmes implemented before allowed us to learn from the experience of others rather than just our own.

Euan Green works as a consultant urological surgeon at Salford Royal Hospital in Greater Manchester, England, and has a specialist interest in robotic-assisted surgical treatment of kidney cancer. He is the trust cancer lead for urology and sits on the Greater Manchester Cancer Pathway Board. He is the training programme director for urology in Greater Manchester and Lancashire and a senior clinical lecturer for the University of Manchester.

WE NEED TO FIX IT

While 'human error' is often blamed when things go wrong, the 'technical' part of 'sociotechnical systems' often escapes the spotlight. In this article, **Harold Thimbleby** outlines how hidden risks with digitalisation have far-reaching consequences – and how we can start to fix them.

KEY POINTS

- **Digital technology supports everything we do in safety-critical industries.**
- **There are also hidden digital problems that affect everything we do, and things will go wrong.**
- **IT-related problems can have significant consequences for justice, as well as safety and security.**
- **The formal qualifications and relevant experience required for system designers in safety-critical sectors are often not specified in the way that they are for front-line staff.**
- **We have to manage digital risks more effectively to prevent associated incidents and even miscarriages of justice.**

Digital problems are ubiquitous and can affect any of us at any time, even without us being aware of it. When things go wrong, especially when there are disastrous consequences, there will often be an investigation. This might be anything from an internal review, a disciplinary process, or even police investigations and criminal proceedings. In my experience in healthcare, too often investigations do not appreciate the central role that digital plays. Computer systems have sometimes been badly designed, failing to support what users need to do. Poor design encourages workarounds and errors, and computers can be buggy, causing further problems. There may be a cyberattack or unauthorised manipulation of data. Or data may just get 'lost'. These are all common scenarios.

"IT-related problems can have significant consequences for justice, as well as safety and security"

Computers and the courts

In some cases, IT-related problems can have significant consequences for justice, as well as safety and security. In 2015, one criminal case concerned alleged fabrication of patient data by two nurses at the Princess of Wales Hospital, in Wales. The Court determined that the evidence concerning IT systems was unreliable and was therefore excluded. As a result, the nurses were freed. This was only after *"enormous expense … incurred in trial preparation – hundreds of hours of time spent by experts, by the investigators, by lawyers"*, and after much court time, and much distress for the nurses and families of the patients concerned (England and Wales Court Ruling, 2017).

I got involved as an expert witness, and provided the evidence that established that the nurse's alleged "fabrications" could in fact be traced to the company that built the computer system (see the Court Ruling, also Thimbleby, 2018). An engineer had deleted patient records, creating the impression that the nurses had been fraudulent.

The key point of this story is that nurses, managers, internal investigators, police, lawyers and more, all failed to realise that the computer system the hospital was using was unreliable. Moreover, patient records had been modified by an outsider who had no authority to do so. From the first investigations in 2012 to reaching court in 2015, the hospital and the police had had years to think about it, but they still didn't realise.

This story is like the 'Post Office Horizon' case, where the UK Post Office prosecuted nearly 750 sub-postmasters and sub-postmistresses, averaging one prosecution a week, just on digital evidence based on logs from the 'Horizon' computer system (see Wallis, 2021). Many defendants were fined, lost their jobs, their homes, and ended up in prison; some, tragically, committed suicide. The Horizon case has been called the largest miscarriage of justice in UK legal history. The Court of Appeal held that the failures by the Post Office were an abuse of the process of the Court, and that the prosecutions were an affront to the conscience of the Court. It was established that some of the evidence concerning Horizon was misleading and other evidence was withheld.

The Horizon case is still going through appeals and has an inquiry under Sir Wyn Williams (2021), for which I am also helping provide evidence. We have asked the inquiry why it has not asked whether the developers of Horizon were competent to build such a system. It seems a silly question, but if accountants are giving evidence in court, you would automatically check whether they were qualified. So, wouldn't you also expect the programmers who are building complex accounting software that does accounting for thousands of Post Office staff to be competent in accountancy, overseen by accountants, or at least working in teams with accountants? I am aware of no evidence that such basic precautions happened with Horizon.

Both the Princess of Wales Hospital and Horizon cases ended up in court. One commonality between the cases is the Common Law presumption (of England and Wales) that a computer producing evidence is working properly at the material time, and that computer records are therefore admissible as evidence without question (Ladkin et al, 2020). In both the cases here, nobody questioned the quality of the computer systems, and the Court in the Horizon case forbade defendants access to it since it was presumed correct.

"In both the Princess of Wales and Horizon cases, the many defendants were not aware of any computer problems when the prosecutions were brought"

This Common Law rule is nonsense when it is spelled out. Of course computers have bugs, and, just like human evidence, their evidence is no better than hearsay unless it can be audited back to independent evidence. Unfortunately, the Common Law presumption is applied blindly, though relying on it certainly avoids courts getting out of their depth discussing computer technicalities.

The lesson for us, therefore, is to try to avoid getting to court over a problem that was, or was partly, caused by computers. We must make sure incident investigators know the limitations of the police and the courts to sort out blame or culpability in digitally related or digitally induced incidents. More pointedly, we must try to make sure investigators realise that digital technology may have a central role in incidents until professionally proven otherwise.

Note that in both the Princess of Wales and Horizon cases, the many defendants were not aware of any computer problems when the prosecutions were brought. In hindsight, it might have been helpful to ask, "Is anyone else being prosecuted for the same alleged offence?"

Computers and competency

For the last four years, I've been writing a book on digital systems, and how we can see, understand, and solve associated problems. The book – *Fix IT: See and solve the problems of digital healthcare* (Thimbleby, 2021) – is about digital healthcare, but the same issues spread far beyond healthcare. All safety-critical industries have similar problems. (The book has a chapter on aviation.)

At the top of the left-hand page in the book (Figure 1), you can see a list of some of the many topics an anaesthetist must be qualified in before they can practise as anaesthetists. Including their general medical training, it takes about 14 years to train as an anaesthetist. They have to learn many medical topics, as well as topics in physics, human factors, and what to do in an incident. Once they've passed their exams and qualified, they are permitted to anaesthetise and treat patients with modern anaesthetic equipment, like ventilators, infusion pumps, anaesthetic machines, and more.

Almost all modern equipment has embedded computers, so when an anaesthetist uses anything, what it does to the patient depends on the quality of its programming. So the anaesthetist might decide the patient needs 5 mg of a drug, but it is the programmer who determines how much the patient actually receives, and how fast.

On the facing, right-hand, page of the book, you can see all the topics medical programmers are required to know before they can program medical equipment like ventilators. The publishers asked me if I'd missed out the details, as the figure in the book is completely blank. The fact is, there are no details to show, and that was the point of the figure. You can start programming medical apps, infusion pumps, or whatever you like with no qualifications or experience.

Some professions do have stricter rules. For instance, Air Traffic Safety Electronic Personnel (ATSEPs) require competence in providing and supporting air traffic systems, covering their specification, procurement, installation, maintenance, testing and certification. It's an

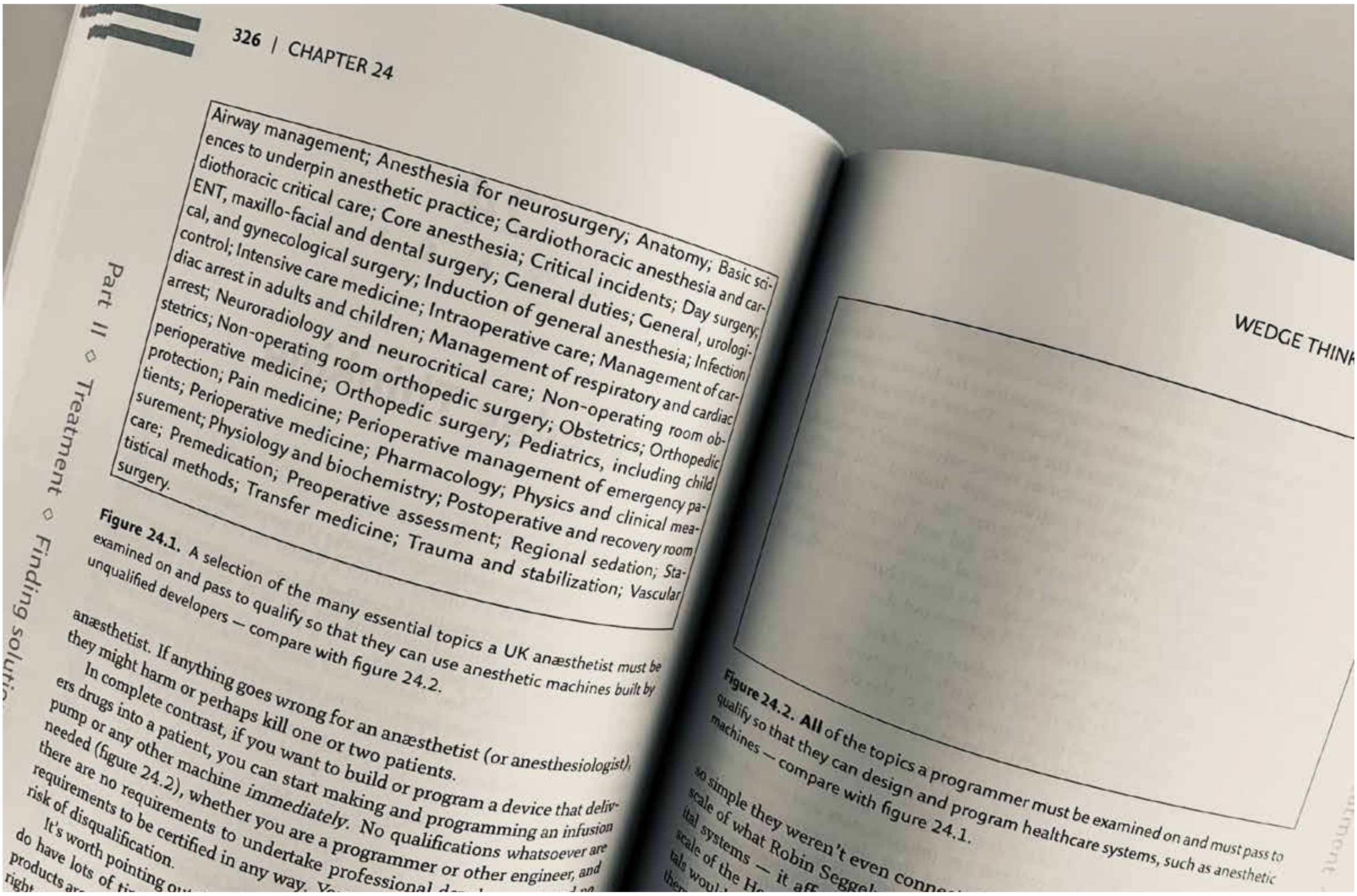


Figure 1: Formal knowledge requirements for UK anaesthetists and anaesthetic machine programmers.

improvement over anaesthetic safety, but it, too, places no requirements on the software developers.

In many areas of life, we must have qualifications, continuous professional development, relevant experience, and so on, before we are even allowed to work. There are generally rules about probation, supervision, etc. Yet increasingly, everything we do and what effect it has on the world is ultimately decided by digital systems. There are few rules to ensure these are designed professionally to assure safety. When things go wrong, then, the users are the only people who have apparently broken any rules, so they are easy to scapegoat.

Computers and cost

The digital systems you are using may have been brought in because they were cheaper than competitors and promised desirable solutions. Unfortunately, their programmers often have little idea about the skills and work of users. Users are often forced into workarounds to overcome the limitations of the technology. Things typically work after workarounds, so managers imagine things are working, and if anything goes wrong it must be a staff problem, not a technical problem.

We can learn a lot looking back to earlier periods of technical innovation. When Röntgen discovered X-rays in the late nineteenth century, they seemed like magic, helping to see broken bones, diagnose TB, and help during surgery. But ignorance, combined with enthusiastic overuse, resulted in many people getting cancer.

X-rays were very exciting when they were first discovered, just like digital is amazing now. Yet X-rays had risks that were not recognised, understood, or regulated – just like digital today.

"Digital has hidden intrinsic risks, and until we recognise them, errors and miscarriages of justice will continue"

So what to do?

If you thought the problem with any troublesome computers was that they're getting old, slow and obsolete, so you just need to get them updated with the latest innovations, you'd be wrong. Digital has hidden intrinsic risks, and until we recognise them, errors and miscarriages of justice will continue. So here are some recommendations:

1. If you are a front-line practitioner, record and communicate to safety professionals in your organisation how digital quirks cause unexpected, hidden problems for you or your colleagues.
2. Make sure that incident investigation teams include competency in software engineering and digital risk management.
3. Check that digital developers are suitably qualified and experienced, for the same reasons we require anaesthetists, radiographers, pilots, air traffic controllers, and other professionals to be properly trained: people rely on their competence to

keep people – customers, patients, passengers – safe.

4. Procurement must ensure new digital systems are dependable, and that developers properly engage with skilled front-line staff, before and after developing them. What standards were they developed and tested under?
5. Digital systems should be designed to anticipate failures using risk management expertise. Systems must keep auditable logs and double-checks of everything they do, so when incidents occur, reliable information is available to investigators.
6. If you are a manager, regulator, or policy-maker (or can influence one), try to turn any of these points into company policy or professional requirements.

It seems like a tough list, but digital technology is not well understood, and is changing every day. We must expect bugs when we are pushing boundaries. Cloud, blockchain, machine learning, artificial intelligence, digital signatures…no digital technology promoted today as an exciting, innovative solution has been around long enough to sort out its problems. Therefore, we must.

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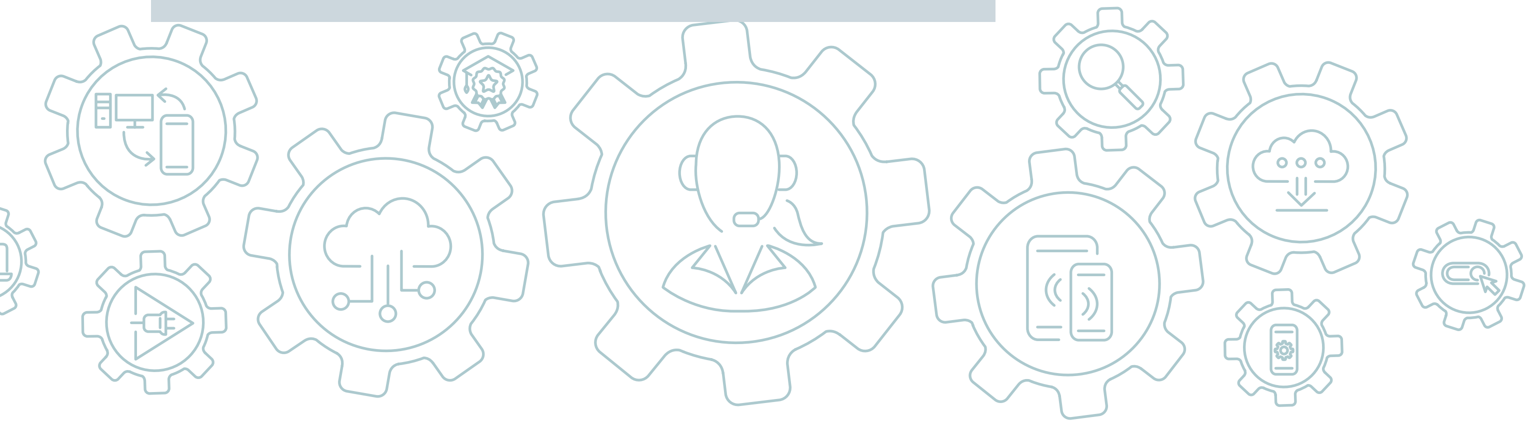

MAKING AUTOMATION A TEAM PLAYER IN BIOPHARMA MANUFACTURING

Making automation a better partner is critical for the human-machine system as a whole. **Jim Ball** and **Kristen Pham** outline strategies to achieve this in biopharmaceutical manufacturing, with relevance for all sectors.

I nervously set the adaptive cruise control at 65 mph and hovered my foot over the brake pedal, prepared to slam on the brakes as soon as I got too close. As the car in front of me slowed down, I felt that pull of my body moving forward. My car was slowing down to match the lower speed. *"Hey, it worked, that's great!"* I thought, *"but what about side streets? At what point would this automation fail?"* I repeated this series of micro-experiments over the next few weeks until I was comfortable and familiar with the workings, capabilities, and limitations of this new adaptive cruise control. It took me quite some time to learn to trust this new technology.

This same sort of apprehension shows up in our work when new technology is introduced, and it often forces us to shift our thinking in how we go about our job. Our organisation recently upgraded our biopharmaceutical manufacturing control software to a software with more automation capabilities, allowing operators to do fewer manual tasks. In

a manufacturing context, these tasks include opening valves, and recording information such as activity start times, product information, flow rate calculations, and people involved in the tasks.

It took time to realise the benefits of a more automated system. This was partly because of end users' hesitation to trust the automation to complete tasks they have always manually done themselves. How could we improve our automation so that it would function more like a team partner to our operators in an integrated system (Christoffersen and Woods, 2002)? Here are three strategies we deployed to overcome this challenge:

1. We needed a way to test and learn in a safe environment.

The production environment was not an appropriate environment to test, so we had workshops where operators walked through the procedures with automation engineers in a simulation environment. This gave operators and automation engineers an opportunity to ask questions about various situations about what is done in the automation. For example, we could assess confusion in interpreting prompts, determine where logic loops were needed, or identify places where tightly coupled operations led to loss of positive control. Other ways we have tested in a safe environment include mock runs to test the interaction with both the automation and the equipment to test operation and interface functionality, and process validation.

"We needed to design the automation in a way that operators are aware of what the automation is currently doing, the reason why it's in that current state, and what it will do next"

2. We needed to automate with humans in mind.

Our purpose for implementing automation is to perform difficult tasks and reduce cognitive and physical workload on the operators.

a. We needed to design the automation in a way that operators are aware of what the automation is currently doing, the reason why it's in that current state, and what it will do next (Billings, 1996). This typically leads to more information on the interface which could lead to more clutter, increasing the risk of confusion between different modes. Our goal is to find a way to display all necessary information on the interface without it being too cluttered.

b. Confirmation prompts in the automation can help the operators maintain positive control and give them the authority to make decisions in the process. However, the prompts must be easy to understand but also detailed enough to give the operator the ability to make an informed decision.

c. As new automation is introduced, changes in the sequence of tasks will require new explanations of how things work in the real world to understand this new sequence. Without the proper training or shift in these 'mental models', operators may not be equipped to make decisions during off-normal events (Lee et al., 2017). This can cause stress for the operator and lead to distrust in the automation. By helping our end users see the effects or actions that the new automation introduces and how it is different from the past, we can mitigate these risks.

d. Alarms should be meaningful and give sufficient detail about the problem that caused the alarm to activate. Having too many nuisance alarms that are not meaningful and are usually ignored can make it difficult to know if it is a 'true' alarm that needs to be attended to immediately before an issue arises (Norman, 2013).

3. We needed to have designers collaborate with end users.

Designers may have one vision in mind while end users (operators) may have another. The system must be designed to support the user's needs instead of forcing the user to adapt (Christoffersen and Woods, 2002). To understand user needs, we observed operators interacting with the automation interface to perform their tasks in the manufacturing suites. This diversity of perspectives from a cross-functional team led to improved design and better end user performance. The designers learned what problems the operators were having, and what they would like to have on their interface to make their jobs easier. As a result of this collaboration, we saw an increase of commitment to the change and higher level of ownership by the end users.

Automation can enhance the end user experience and improve process control, and the interaction between the operators and the automation cannot be separated. The experience of introducing this new technology was not an effort to replace our people with automation, but rather an effort at making the automation a better team player in the complex and interdependent work that we do.

Much like a new member of the team, our operators needed to discover new ways of working, and adapt to the quirks, intricacies, and even surprises, of the new automated partner. And much like a new partner on the team, this improved automation partnership allows us to provide high quality products for patients.

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HUMAN PERFORMANCE IN THE SPOTLIGHT:

DISTRIBUTED SITUATION AWARENESS

In this series, human performance issues are addressed by leading researchers and practitioners in the field. **Paul Salmon** gives some insights into distributed situation awareness and implications for digitalisation.

What is situation awareness?

At a simple level, situation awareness (SA) is the term used in Human Factors to describe the awareness that people have of 'what is going on' around them while performing dynamic tasks. The concept first emerged in aviation during the First World War and has gone on to become one of the most studied and debated topics in Human Factors. Though the initial focus was on the awareness held by individuals, this has now expanded to consider the SA of teams, organisations, and even entire sociotechnical systems. The relationship between SA and performance is complex, however, and it is widely acknowledged that SA is a critical consideration when designing work and work systems. It is especially pertinent to consider SA when designing and introducing advanced automation.

What is distributed situation awareness?

The idea behind distributed situation awareness (DSA) is that, in sociotechnical systems, no one person or 'agent' has all of the awareness required for the system to function effectively.

"In sociotechnical systems, no one person or 'agent' has all of the awareness required for the system to function effectively"

Can different agents have the same awareness of a situation?

Our research has demonstrated that different agents have different views on a situation, even when they have access to the same information. Each agents' SA is influenced by their goals, the tasks they are performing, and their experience of similar situations. The fact that different agents have different SA has implications for system design. Rather than attempt to achieve 'shared SA' where all agents have the same awareness of a situation, we have found that 'compatible SA' is more appropriate. This is achieved when different agents' SA connects to give the overall system the big picture. Achieving compatible SA involves acknowledging that individuals have different views on a situation and identifying who needs what information, when, and in what format. Incompatibilities can lead to suboptimal DSA where there are gaps in the SA required for effective performance.

What is the role of technology in optimising distributed situation awareness?

An interesting feature of DSA is that it explicitly considers the SA held by technological agents as well as that held by human agents. The idea that non-human agents could be situationally aware was controversial at first but has since become highly relevant given advances such as artificial intelligence. As such agents gather, interpret, and share information, they play a critical role in ensuring that a system can generate the DSA required for safe and efficient performance. Unfortunately, what we are seeing many areas is a failure to consider the important role that technological agents play in DSA.

"'Distributed situation awareness' explicitly considers the SA held by technological agents as well as that held by human agents"

What is important to consider when designing and introducing advanced technologies?

With advanced technologies such as automation, we need to consider not only human agents' SA but also the SA held by automation and how it shares SA-related information with humans and other technologies and vice versa. We have seen many recent incidents in aviation and road transport for example whereby advanced automation has either not been aware of something it needed to be, or where automation has not communicated critical information to human agents. This is not because the automation failed, rather it is because designers have not fully considered what the automation needs to know or what SA-related information the automation needs to pass to human operators. As a result, we are seeing breakdowns in DSA which in turn can lead to catastrophe.

It is important then when designing advanced technologies to consider the SA requirements of both human and non-human agents. What does the advanced technology need to be aware of for the system to function effectively? Then designers need to ensure that the automation can gather and understand the information required to fulfil these SA requirements.

The sharing of information between human and non-human agents is also important to consider. We label this sharing of awareness as 'SA transactions' and have found many instances where these transactions are inadequate, erroneous, or do not occur at all, resulting in suboptimal DSA. For example, in a recent automated vehicle collision, the automation did not inform the vehicle operator of an obstacle that it had detected in the road ahead. So it is critical to consider what information needs to be exchanged, when, and how non-human agents will exchange SA-related information with human agents.

A final consideration is how to ensure that human agents understand what non-human agents are aware of. Without this, it can be difficult for human agents to understand why automation is behaving in a certain manner, or why it has taken a particular course of action.

What happens when systems 'lose' DSA?

As DSA degrades the risk of system failure is heightened. Recent high-profile examples of incidents involving DSA failure include the Air France 447 collision and the Arizona Uber-Volvo test vehicle collision. When investigating and responding to such incidents it is important to maintain a systems perspective. It can be tempting to seek to identify the individual agent who 'lost SA'. However, as the SA required for effective performance is not something that can be held by one individual alone, it cannot be lost by one individual alone. Hence, the most appropriate view to take is that systems lose SA and not the individuals working within them. Accident investigators should examine the overall system to determine why DSA failed, not who lost it. In our experiences, DSA failures most often involve failures in the exchange of SA-related information between human and non-human agents.

"Distributed situation awareness failures most often involve failures in the exchange of SA-related information between human and non-human agents"

Paul M. Salmon is a professor in Human Factors and is the director of the Centre for Human Factors and Sociotechnical Systems at the University of the Sunshine Coast. Paul has over 20 years' experience of applied Human Factors and safety research in areas such as transport, defence, sport and outdoor recreation, healthcare, workplace safety, and cybersecurity.

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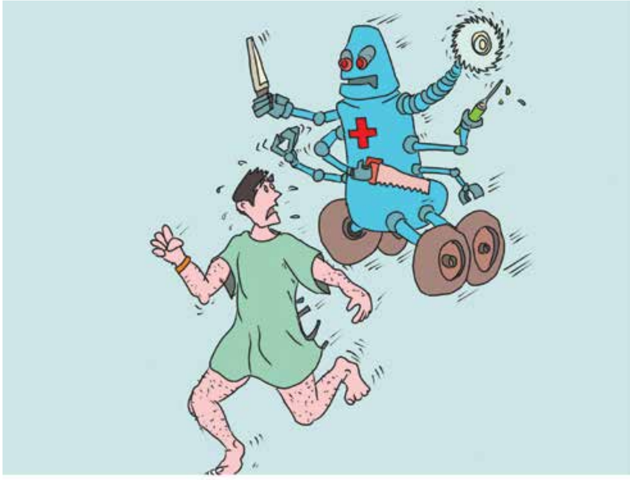
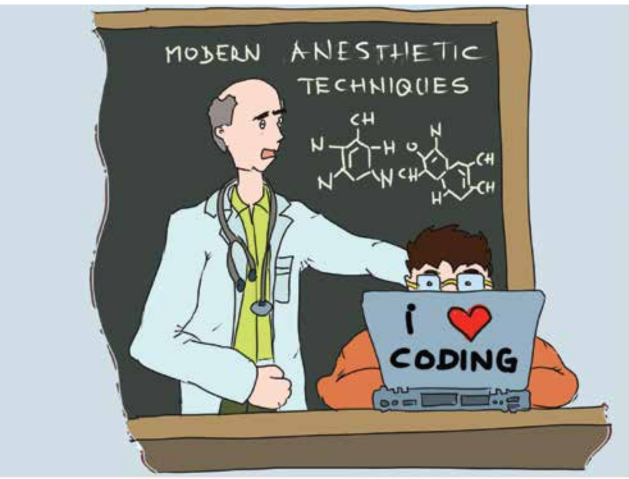
"We finished feeding the data. Now let's see if it can tell us what will be on the canteen menu next week..."

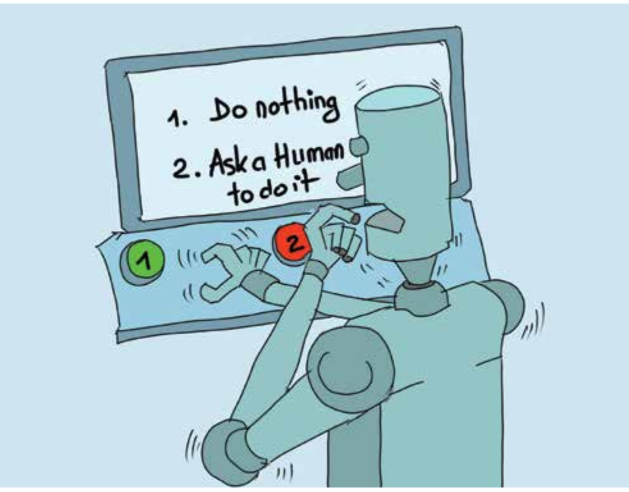


There is still work to be done on gaining trust in robot doctors



"And now I hand over to your lecturer in software development..."

"Shall we reduce the transfer rate?"



In the system of the future, most tasks will be delegated to the human.

CANSO-EUROCONTROL GLOBAL RESILIENCE SUMMIT ATTRACTS WORLDWIDE AUDIENCE

The COVID-19 pandemic has demonstrated that the resilience of the air traffic management (ATM) system, and the aviation system more generally, is fundamental to ensuring that it can plan for, manage, and recover quickly from difficult conditions. EUROCONTROL and CANSO hosted a Global Resilience Summit to explore resilience from multiple perspectives.

EUROCONTROL and CANSO organised a joint hybrid Global Resilience Summit on 8 and 9 December 2021. Together with participants on site at EUROCONTROL Brussels and around the world via live interactive video, we took a deeper look at how the interdependencies of human, technological and organisational resilience come together to position service providers for success.

Over the course of the two days, we:

- examined the resilience of our personnel;
- investigated how to improve organisational resilience;
- explored how to design and build resilience and agility into the ATM network;
- explored the technologies that can support resilience;
- examined what COVID-19 taught us about resilience.

The summit was piloted by EUROCONTROL's Tony Licu (Head of Safety Unit, Network Manager) and CANSO's Shayne Campbell (Safety Promotion Manager).

The Summit took off with welcome addresses by Eamonn Brennan (Director General, EUROCONTROL) and Simon Hocquard (Director General, CANSO).

Together, the welcome addresses painted the big picture for the aviation industry when it comes to resilience. Eamonn Brennan highlighted the success of the airports, airlines, and ATM industry in adapting to the evolving situation, but noted weaknesses in border security and uncertainty generated by government decision-making. Simon Hocquard summarised that *"If there's one thing the last 18 months has taught us, it's the incredible ability of individuals, organisations, industries, to move forward in the face of sometimes utter adversity. For me, that's the very essence of resilience."*

There was a keynote speech by Dr Catherine Bishop, former Olympic rower and diplomat, who reflected on resilience from a variety of perspectives, looking back on her experience in elite sports and diplomacy in conflict-affected parts of the world. EUROCONTROL's Dr Steven Shorrock then set the scene for the conference by looking back on eight interviews published in *HindSight* magazine.

Once at cruising altitude, the Summit traversed four sectors.

Organisational resilience

From an organisational point of view, resilience can be expressed as the capability of an organisation to respond to, or recover from, a crisis, a disruption, or any other unexpected event. Organisational leaders make decisions about resources and constraints that affect how their organisations adapt to unexpected challenges. This session brought together senior leaders from different parts of the industry to take a deeper look at how organisational resilience interplays with personal and technological resilience to better position service providers for success.

- Tim Arel, Deputy Chief Operating Officer, US Federal Aviation Administration
- Dr Hassan Shahidi, President and CEO, Flight Safety Foundation
- Ben Stanley, Associate Director, Egis Group

Technological resilience

As the industry continues to shift towards digital and more automated operations, technology is increasingly critical to resilient performance. Technological resilience, described as an organisation's ability to maintain acceptable service levels through, and beyond, disruptions to its critical processes and systems, is becoming an increasingly higher priority for ATM. Ensuring business continuity when unexpected events occur is significant for every ANSP. This session focused on the role that technology plays in resilient performance and discuss possible solutions that can enhance ATM delivery.

- Alex Bristol, CEO, skyguide
- Prof. Sarah Sharples, Chief Scientific Advisor, UK Department of Transport
- John Allspaw, Co-Founder and Principal, Adaptive Capacity Labs

Individual resilience

The people who ensure the overall resilience of an organisation, whether in operational, technical, support or management roles, can find themselves personally affected by chronic conditions and specific events. Personal resilience is the process of adapting well in the face of adversity, trauma, tragedy, threats, or significant sources of stress. This session took a deeper look at the importance of developing core skills to get through, recover and learn from difficult experiences.

- Dai Whittingham, Chair, UK Flight Safety Committee
- Carol Quinn, Counsellor, CISM interventionist and former ATCO
- Martin Bromiley OBE, Founder, Clinical Human Factors Group and professional pilot

Lessons learnt from the COVID crisis

The pandemic has had an unprecedented impact on the aviation community, exposing vulnerabilities and areas for improvement in the way ATM deals with unexpected events. The session brought together thought leaders from ATM to discuss some of the most important lessons learnt as a result of a prolonged downturn in traffic, as well as initiatives to support the industry's restart and recovery.

- Han Kok Juan, Director General, CAA Singapore
- Michelle Bishop, Director of Programmes, CANSO
- Razvan Bucuroiu, Head of Airspace and Capacity, EUROCONTROL

Resilience for the next crisis

The final approach concerned resilience for the next crisis. In this session, Steven Shorrock joined the flight deck to facilitate an engaging rapid-fire question and answer session with speakers from Day 1 and Day 2, covering resilience at all levels from regulators and senior leadership, through teams and individuals, in the technological and organisational contexts.

The event landed smoothly with a summary from the Summit pilots Tony Licu and Shayne Campbell. S

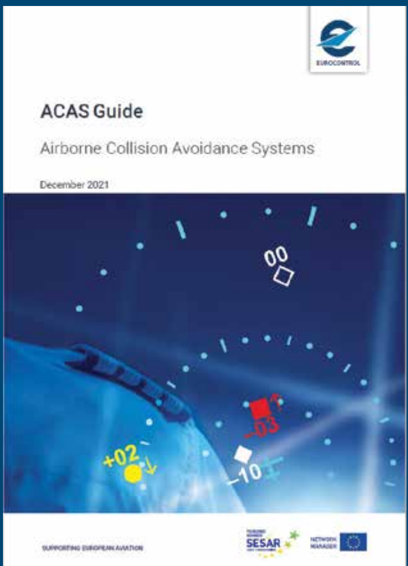
Watch the Global Resilience Summit on YouTube.

Day 1 – Welcome addresses | Keynote address | Setting the Scene | Organisational Resilience | Technological Resilience
https://youtu.be/jUwYv1KJoLE

Day 2: Individual resilience | Lessons learnt from the COVID crisis | How to be resilient in the next crisis | Summary
https://youtu.be/rE8Rl6dZalE

See also the EUROCONTROL webpage for the event:
https://www.eurocontrol.int/event/canso-eurocontrol-global-resilience-summit-2021

EUROCONTROL ACAS GUIDE UPDATED



An updated edition of EUROCONTROL Airborne Collision Avoidance Systems (ACAS) Guide has been published. The Guide is designed to support the understanding of the ACAS systems and the training of anyone involved in the operations of ACAS. The updated edition covers extensively the forthcoming ACAS Xa/Xo system as well as provides up-to-date information on TCAS II operations.

Download the guide on SKYbrary at https://skybrary.aero/bookshelf/acas-guide-airborne-collision-avoidance

A new ACAS SKYclip is now available on SKYbrary

This short, animated video recreates a real-life incident. After an ATC coordination error that put two aircraft on a collision course, TCAS RAs were issued. One of the crews responded in the opposite sense to the received RA, leading to a significant loss of separation.

See **https://skybrary.aero/video/tcas-ra-not-followed**

NEW EUROCONTROL WEBINARS

A variety of webinars and conferences have taken place since the last issue of HindSight. Those that are available to view online are highlighted here. Other EUROCONTROL webinars hosted in 2021 on human and organisational factors in operations, and safety more generally, can be found in HindSight 32.

EUROCONTROL hosts online 'ENAIRE Human Factor Days'

EUROCONTROL was delighted to host the online "ENAIRE Human Factor Days" between 27 September and 1 October 2021. This five-day event aimed to inspire and raise awareness about human factors and human performance in air traffic management (ATM), from academic and practical perspectives. Topics included:

- human work
- human capabilities and limitations
- fatigue and stress in ATM.

Sessions in English and Spanish were provided by representatives from EUROCONTROL, ENAIRE, Federal Aviation Administration (FAA), and Austro Control.

Recordings are available at https://www.eurocontrol.int/event/eurocontrol-enaire-human-factor-days.

Critical incident stress management webinar

A webinar on Critical Incident Stress Management was held on 5 October 2021. Sessions were provided by representatives from EUROCONTROL and the Irish Aviation Authority (IAA).

Recordings are available at https://youtu.be/GEKHBeNY7ml. See also 'Critical Incident Stress Management in ATM' on SKYbrary at https://skybrary.aero/articles/critical-incident-stress-management-atm.

Two webinars on 'Lessons learned on automation from the flying community'

Two webinars on 'Lessons learned on automation from the flying community' were hosted by EUROCONTROL. Part 1 with Captain Antonio Chialastri was held on 28 May 2021 and can be found at https://youtu.be/IwMtnuUKfTQ. Part 2 with Captain Sebastian Allgaier was held on 25 June 2021 and can be found at https://youtu.be/ruasS_Q41KM.

EUROCONTROL IANS COURSES

The EUROCONTROL Institute of Air Navigation Services (IANS), located in Luxembourg, develops and delivers Air Traffic Management Training, Services and Tools for Air Navigation Service Providers, Airlines, Training Organisations and Civil and Military State Authorities worldwide. Building on over 45 years of expertise, the Institute provides a wide range of training courses, services and tools – from general introduction courses on ATM concepts through to advanced operational training. Here are some courses that may be of interest to readers on the topic of **digitalisation and human performance.**

Human Role in Future ATM [HUM-FUT-V]

Technological evolution will have a profound impact on many industrial sectors over the coming years. Many of the major drivers of transformation are expected to have a significant impact on the human role, ranging from the creation of new jobs to job displacement, and from heightened labour productivity to widening skills gaps. This course discusses the impact of technological trends on working practices and skills profiles, focusing on the ATM domain. It covers the fundamentals of Human Factors (HF) and is designed for a wide audience.

Duration

This course takes place over 3 days. You will have 3 virtual sessions. You need to plan 11 hours to complete this course.

Objectives

After completing the course, participants will have an understanding of the human role in an evolving technological and social landscape including current and future trends, and their impact on everyday life. They will learn about how technologies are impacting knowledge, skills and abilities (KSAs) required in new working scenarios, and the expected changes in ATM. Additionally, they will explore several solutions to anticipate shifts in employee skill needs, identify intervention areas, and set up mitigation measures needed to effectively plan and manage the transition process at both individual and organisational level.

Audience

This course is designed for ATCOs and managers interested in the profession evolution in mid and long term, and other roles involved in change management processes.

Integrating Human Factors in ATM Projects [HUM-HF-CASE]

The Human Factors (HF) case is a process developed by EUROCONTROL to systematically manage the identification and treatment of HF issues as early as possible in a project life cycle. The HF case methodology is designed to provide:

- an explicit way to manage HF issues
- a checklist and traceability for HF issues as the project evolves
- risk minimisation for HF issues occurring at a critical stage
- ownership within the project team for HF
- improved decision-making, resource and budget justification for HF.

The course is module-based and covers each of the 5 stages involved in the preparation of an HF case and the use of the HF case e-tool.

Duration

This course takes place over 4 days.

Objectives

After completing the course, participants will be able to apply the HF case as a practical HF integration process within ATM projects.

Audience

This course is designed for Human Factor (HF) specialists and other ATM personnel with HF knowledge and experience who are interested in applying the HF case in ATM projects.

Artificial intelligence in future ATM [GEN-AIFATM]

Artificial intelligence (AI) is a fast-evolving family of technologies inspired by human intellectual processes, such as the ability to reason, discover meaning, generalise, act flexibly or learn from past experience. By improving prediction and optimising operations and resource allocation, the use of artificial intelligence has already delivered breakthroughs in various applications and has the potential for a wide array of economic and societal benefits across the entire spectrum of industries and social activities, including aviation. AI can, however, also entail new risks or have negative consequences for individuals, organisations, or society. For this reason, the European Commission has recently issued a proposal for a regulatory framework, intended to define a set of harmonised rules for the use of artificial intelligence systems in the Union. The topic is also key for the aviation domain, as witnessed by the EASA Artificial Intelligence Roadmap which establishes the Agency's initial vision on the safety and ethical dimensions of the development of AI in the aviation domain.

Duration
This course takes place over 3 days.

Objectives
After completing the course, participants will have an understanding of the foundational concepts of artificial intelligence (AI), with a particular focus on the current and future applications of AI in the ATM domain. Participants will be able to describe possible applications and analyse benefits for individuals, organisations, and the overall ATM system, as well as the possible safety, ethical, and legal implications of using AI systems. Additionally, the course will raise awareness about the AI roadmap developed by EASA and the regulatory aspects of using AI systems at European level.

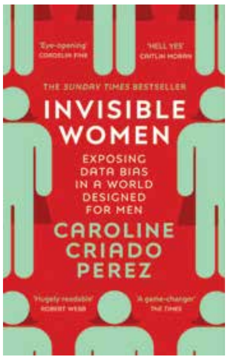
Audience
The course is designed for a wide audience, including but not limited to managers interested in ATM technological innovation, safety managers, ATCOs, engineers and system developers and ATSEPs.

Other courses relevant to digitalisation and human performance

- Automation and Liability in ATM [GEN-LIABILITY]
- Aeronautical Information in the Digital Environment [IM-AIDE]
- GEN-FUT – Future Mobile Data Links in Aviation (Webinar)
- Towards Voice over IP in Aeronautical Communications [COM-VOICE]

Check the prerequisites and dates for each course, and register at EUROCONTROL Training Zone. **https://trainingzone.eurocontrol.int/**

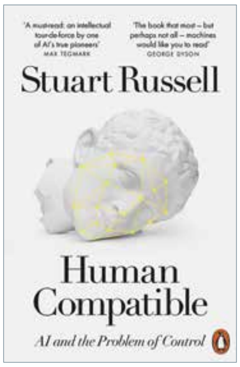
If you want to read more about some of the issues raised in this issue of *HindSight*, then these books might be of interest.



Invisible Women: Exposing Data Bias in a World Designed for Men, by Caroline Criado Perez (2019)

From the publisher: "Imagine a world where your phone is too big for your hand, where your doctor prescribes a drug that is wrong for your body, where in a car accident you are 47% more likely to be seriously injured, where every week the countless hours of work you do are not recognised or valued. If any of this sounds familiar, chances are that you're a woman. Invisible Women shows us how, in a world largely built for and by men, we are systematically ignoring half the population. It exposes the gender data gap – a gap in our knowledge that is at the root of perpetual, systemic discrimination against women, and that has created a pervasive but invisible bias with a profound effect on women's lives. From government policy and medical research, to technology, workplaces, urban planning and the media, Invisible Women reveals the biased data that excludes women. Award-winning campaigner and writer Caroline Criado Perez brings together for the first time an impressive range of case studies, stories and new research from across the world that illustrate the hidden ways in which women are forgotten, and the impact this has on their health and well-being. In making the case for change, this powerful and provocative book will make you see the world anew."

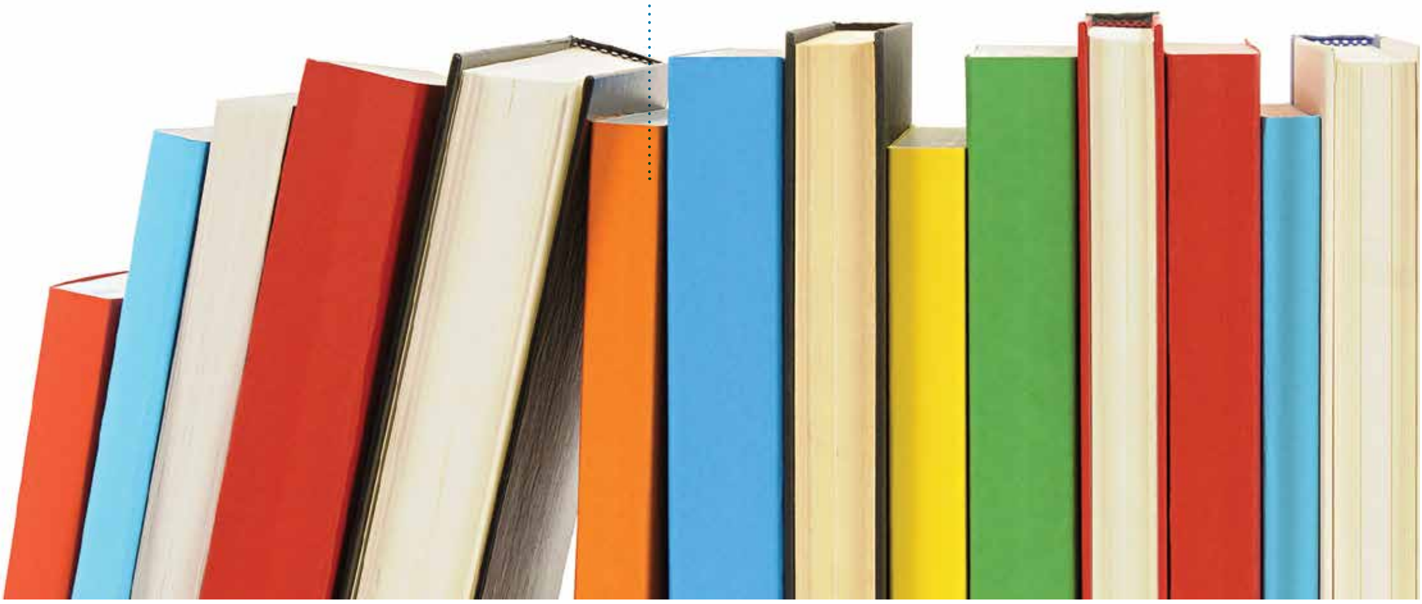
"Criado Perez doesn't set out to prove a vast conspiracy; she simply wields data like a laser, slicing cleanly through the fog of unconscious and unthinking preferences." (Eliane Glaser, The Guardian)



Human Compatible: AI and the Problem of Control, by Stuart Russell (2019)

From the publisher: "Humans dream of super-intelligent machines. But what happens if we actually succeed? Creating superior intelligence would be the biggest event in human history. Unfortunately, according to the world's pre-eminent AI expert, it could also be the last. In this groundbreaking book, Stuart Russell sets out why he has come to consider his own discipline an existential threat to humanity, and how we can change course before it's too late. In brilliant and lucid prose, he explains how AI actually works and its enormous capacity to improve our lives - and why we must never lose control of machines more powerful than we are. Russell contends that we can avert the worst threats by reshaping the foundations of AI to guarantee that machines pursue our objectives, not theirs. Profound, urgent and visionary, Human Compatible is the one book everyone needs to read to understand a future that is coming sooner than we think."

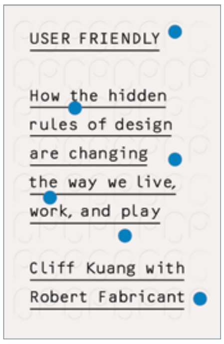
"This is the most important book I have read in quite some time. It lucidly explains how the coming age of artificial super-intelligence threatens human control. Crucially, it also introduces a novel solution and a reason for hope." (Daniel Kahneman, winner of the Nobel Prize and author of 'Thinking, Fast and Slow'.)



Fix IT: See and solve the problems of digital healthcare, by Harold Thimbleby (2021)

From the publisher: "New technologies like AI, medical apps and implants seem very exciting but they too often have bugs and are susceptible to cyberattacks. Even well-established technologies like infusion pumps, pacemakers and radiotherapy aren't immune. Until digital healthcare improves, digital risk means that patients may be harmed unnecessarily, and healthcare staff will continue to be blamed for problems when it's not their fault. This book tells stories of widespread problems with digital healthcare. The stories inspire and challenge anyone who wants to make hospitals and healthcare better. The stories and their resolutions will empower patients, clinical staff and digital developers to help transform digital healthcare to make it safer and more effective. This book is not just about the bugs and cybersecurity threats that affect digital healthcare. More importantly, it's about the solutions that can make digital healthcare much safer."

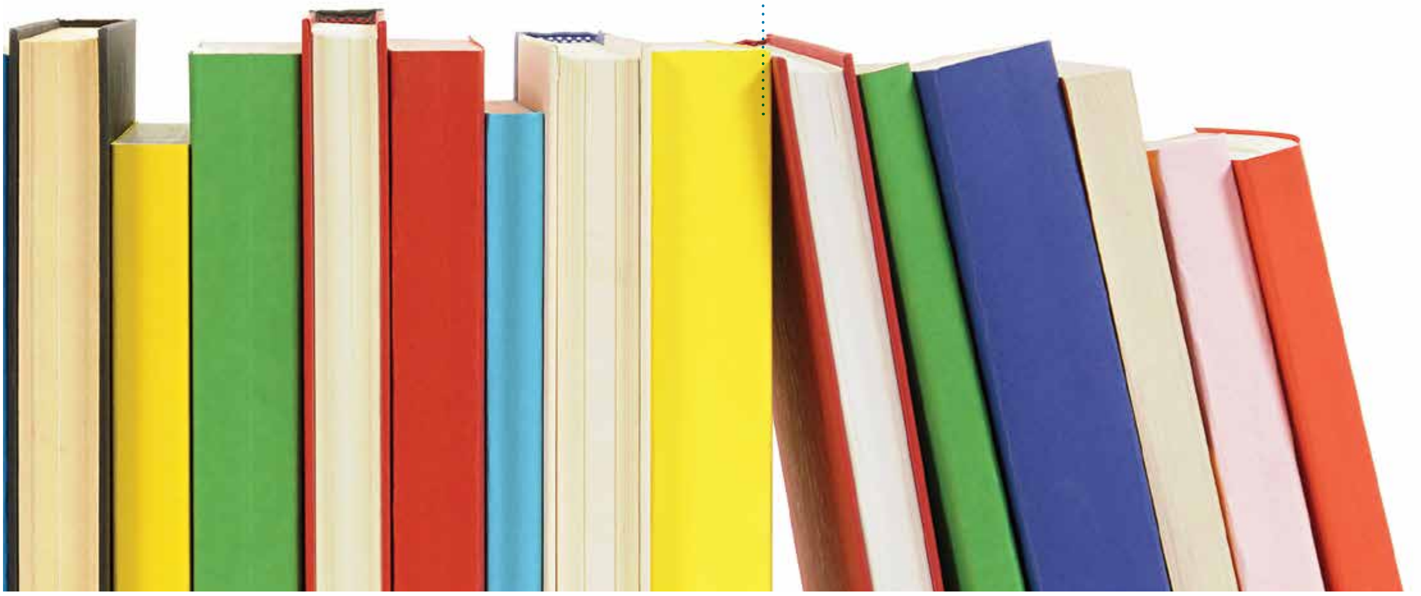
"This is an extraordinary book: a potent and engaging compendium of revelatory stories, bold insights, wise advice, and fresh thinking." (Daniel Jackson, Professor of Computer Science, MIT)



User Friendly: How the Hidden Rules of Design are Changing the Way We Live, Work & Play, By Cliff Kuang and Robert Fabricant (2020)

From the publisher: "User Friendly is a must-read for anyone who loves well-designed products-and for the innovators aspiring to make them. It seems like magic when some new gadget seems to know what we want before we know ourselves. But why does some design feel intrinsically good, and why do some designs last forever, while others disappear? User Friendly guides readers through the hidden rules governing how design shapes our behaviour, told through fascinating stories such as what the nuclear accident at Three Mile Island reveals about the logic of the smartphone; how the pressures of the Great Depression and World War II created our faith in social progress through better product design; and how a failed vision for Disney World yielded a new paradigm for designed experience."

"User Friendly is a tour de force, an engrossing fusion of scholarly research, professional experience and revelations from intrepid firsthand reporting." (Edward Tenner, The New York Times Book Review)



Would you like to write for HindSight magazine?

HindSight is a magazine on human and organisational factors in operations, in air traffic management and beyond.

As such, we especially welcome articles from air traffic controllers and professional pilots, as well as others involved in supporting them.

Here are some tips on writing articles that readers appreciate.

1. Articles can be around 1500 words (maximum), around 1000 words, or around 500 words in length. You can also share your local good practice on what works well for you and your colleagues, on the theme of each Issue, in up to 200 words.

2. Practical articles that are widely applicable work well. Writing from experience often helps to create articles that others can relate to.

3. Readers appreciate simple and straightforward language, short sentences, and concepts that are familiar or can be explained easily.

4. Use a clear structure. This could be a story of something that you have experienced. It helps to write the 'key points' before writing the article.

5. Consider both positive and negative influences on operations, concerning day-to-day work and unusual circumstances, sharp-end and blunt-end.

If you have an idea for an article that might be of benefit to others, we would like to hear from you.
Please write to **steven.shorrock@eurocontrol.int**

HindSight

Human and organisational factors in operations

The theme for HindSight 34 will be

HANDLING SURPRISES: STORIES FROM THE SHARP END

HindSight is a magazine on human and organisational factors in operations. The magazine is aimed primarily at operational staff, but also at other practitioners, in air traffic management and beyond.

We welcome articles and short contributions by **Friday 6 May 2022.**

We especially welcome articles written by or with operational staff on any aspect of handling surprises in operations in air traffic management and other sectors where lessons may be transferrable. Articles may concern the tactical and strategic aspects of the handling of surprises, or coping with situations that did not turn out as expected (whether or not there was an incident). Surprises may involve interactions between people and other people, information, technology, vehicles, infrastructure, the environment. Examples include handling of surprises involving operational incidents, emergencies and unusual situations, functionality problems (loss of data or functionality, extra data, loss of data integrity), aircraft performance, and natural events.

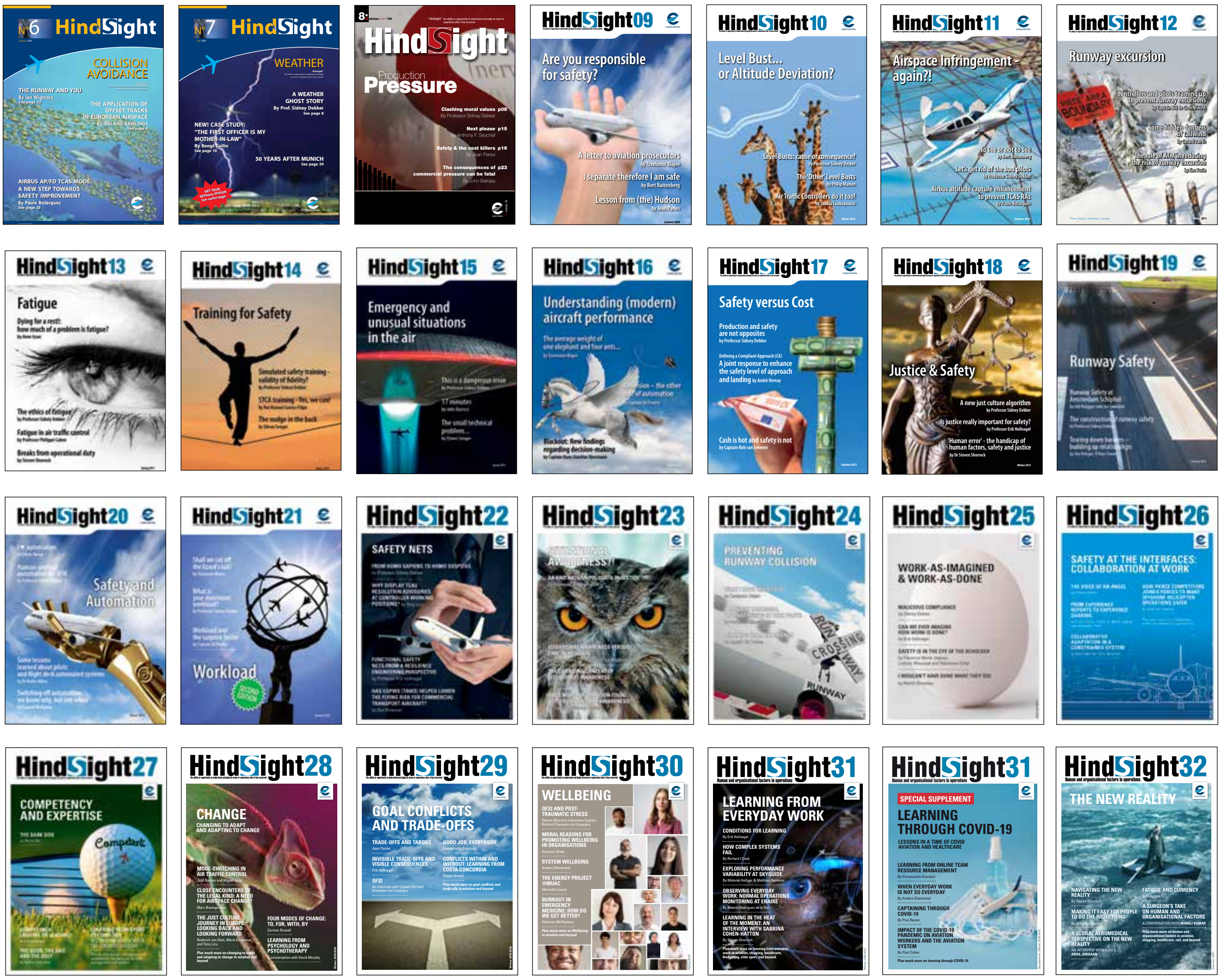
Stories by and with front line operational and technical staff are encouraged. They may include any aspect of handling surprises, such as: marshalling resources, coordination, tactical decision making, overcoming constraints, prior learning and training, procedures, supervision, and management. The outcome may have been desirable, or not. There should be an emphasis on what was learned from the experiences.

Draft articles should be a maximum of 1500 words, but may be as little as 200 words for examples of experiences or good practice. All contributions should:

- be relevant to human and organisational performance in air traffic management
- be presented in 'light language' keeping in mind that most readers are operational staff in ATM, and
- be useful and practical.

Please contact **steven.shorrock@eurocontrol.int** if you intend to submit an article, to facilitate the process.

If you are interested in downloading back issues of the **HindSight collection**
http://www.skybrary.aero/articles/hindsight-eurocontrol



In the next issue of HindSight:
"HANDLING SURPRISES: STORIES FROM THE SHARP END"

This publication has been prepared under the auspices of the Safety Improvement Sub-Group (SISG) and Safety Team of EUROCONTROL.The Editor in Chief acknowledges the assistance given by many sources in its preparation.