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?

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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?

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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.

References

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