Designing Electronic Flight Strips for Air Traffic Control

What considerations must be taken to design Flight Progress Strips for a digital system?

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ABSTRACT

To understand the use of Flight Progress Strips (FPS) in Air Traffic Control (ATC), this article presents literature and case studies of existing FPS, Electronic Flight Strips (EFS) and human factors for developing a new EFS system, and if a strip-less system could be designed. After the introduction of ATC and FPS, findings of moving from paper are presented by looking at research on FPS and lessons learned from earlier projects on EFS. Further on it goes into human factors and the cognitive processes in ATC. Taking design implications from various aspects of human performance and human factors such as cognition, attention, perception, memory and situational awareness to form a set of guidelines that will be used to design an EFS user interface. Discussing the different aspects of both FPS and human factors suggests options for an EFS system where it can be either a separate system or in combination with the radar display, but not completely strip-less.

KEYWORDS: Flight Progress Strips, Air Traffic Control, ATC, Electronic Flight Strips, User interface design, human performance, human factors, situational awareness.

1. INTRODUCTION

Air Traffic Control (ATC) is a demanding and safety critical activity where it is important that the Air Traffic Control Officer (ATCO) is fully aware of the traffic situation at all times (Berndtsson & Normark, 1999). In today's ATC, tower controllers are either using physical Flight Progress Strips (FPS) or Electronic Flight Strips (EFS) to manage all traffic movements together with radar displays and visual ques. Each strip represents an aircraft or other relevant traffic on the airport (Bos, Schuver-Van Blanken, & Huisman, 2011). Over the last decades a lot of work has been done in developing solutions for replacing FPS with the digital EFS solutions.

In the UK they began looking at electronic replacements for FPS in 1992 (Hughes, Randall, & Shapiro, 1992). The Federal Aviation Administration (FAA) investigated the effects of using EFS systems back in 2003, and their goal was to preserve the benefits of the FPSs and enhance the performance of the ATCO (Truitt, 2005). There are many solutions, but when looking into some of the new EFS systems, many seems to be adaptions of the old paper system with some new features (Wacom Europe, 2012). With the cost of display technology dropping, it is possible to do a lot more with display screens (Norman, 2013). This makes it interesting to see if there are other ways the FPS information can be displayed and used with the opportunities a digital surface gives, compared to the FPS that is printed strips of paper. To understand how FPS works and how humans process information, this article will look into existing FPS and human factors to set guidelines for designing a new EFS prototype.

Today Oslo Airport, Gardermoen is the only airport in Norway that is using an EFS system. The system was developed internally in 1999 and it has been used since they started operating at Gardermoen (Brenna, 2007). The system has gone through smaller changes through the years, but the overall design of the EFS system is the same as back in 1999. All other airports and air traffic control centres in Norway are still using the FPS, and Air Navigational Services (ANS), is interested expanding EFS systems to more Norwegian airports in the future (Personal communication with Avinor employee).

In relation to this, there is a desire to do the transition from paper strips to EFS in towers. However, is there a possibility to transit directly to what they call a strip-less system. A strip-less system will have to distribute all the FPS information over to other existing systems. Is that beneficial? Should all information be presented on one interface or be kept separate? And what are the pros and cons of having a EFS system compared to the paper strips?

2. Methods

This article presents a literature review on the use of FPS and the human factors that affect the ATCOs in their work environment. The sources are books, articles, journals, case studies within the ATC and FPS research, human factors and information visualization for graphical user interfaces and design.

Literature search was done mainly in Oria, Scopus and Google Scholar with key words such as; “Air Traffic Control”, “Flight Strips”, “user interface”, “situational awareness”, “control room”. The study has also included observations of tower operations at Trondheim Airport, Værnes and Oslo Airport, Gardermoen. The observations gave insight to the use of both FPS and EFS systems, and the differences between them.

3. Air Traffic Control

The role of ATC is to ensure safe and efficient flow of air traffic by instructing pilots. ATC can be divided into three categories; Tower, Approach and Enroute controls. Tower control is managing aircraft from take-off and landing, local aircraft around the airport, and traffic on the airport surface. The Approach control handles air traffic in a larger proximity around an airport, directing the air traffic in its climb or descend phase in or out from the airport. The en-route control manages air traffic to and from airports in its cruising phase (Avinor, n.d.).

In tower control the ATCOs actively need to look for information to build their metal picture and usually they adapt to the previous ATCOs plan of action. The tasks are mostly uniform and work in an automated and schematic way, with little room for individual preferences. Pre-planning of traffic is on short-term basis and they need to change their attention quickly and be able to change their plan. In en-route control, long-term planning is an important part, as traffic is passing through and easier to anticipate (Dittmann, Kallus, & Van Damme, 2000). To divide workload, airspace is divided into different sectors. As aircrafts move from one sector to the other it’s important that ATCOs can coordinate with each other. This is done by having relevant information visible to other ATCOs, making it easier to handle traffic between different sectors (Berndtsson & Normark, 1999).

3.1 Flight Progress Strips

FPS are mainly used by ATCOs to present flight information, allow administration of instructions, maintain a mental picture of the aircraft under control and support handover of flights between the ATCOs (Bos et al., 2011). FPS are printed strips of paper containing information about one specific aircraft, such as the aircrafts flight plan, callsign, altitudes, speeds and more relevant information to the ATCO. These paper strips are put in plastic holders and divided in racks to organize the traffic (Berndtsson & Normark, 1999), see Figure 1. The FPS is an external representation of information that reduces the memory load to help the ATCOs in safe operations by remembering executed actions (Preece, Rogers, & Sharp, 2015). Even though the information is maintained in a database and shown on radar displays, the paper strips are the primary focus in managing air space (Dourish, 2001).

Figure 1 – Flight Progress Strips

3.2 Annotating strips

ATC is a dynamic activity and changes occur rapidly. With FPS, the ATCOs use pens to write down updated information. There are specific rules on how to annotate. These rules means that simple strokes with a pen can be understood as instructions between ATCOs (Mackay, 1999). For example, if an ATCO instructs a pilot to ascend to flight level 220, an upwards arrow and the number 220 is written on the strip. When the pilot acknowledges the instruction, the old flight level is crossed out. When the new level is attained a check mark is put beside it (Hughes et al., 1992).

With FPS this information is distributed to other ATCOs through a closed-circuit television system. This is overhead cameras that send a video stream of the strip-rack. An important aspect is "*at a glance*" availability, meaning that the ATCO quickly can look at the FPS and recognise the information needed (Berndtsson & Normark, 1999). Avinor has its own instruction on how to use and annotate on FPS, supporting the ATCOs with guidelines for common understanding of information, this was acquired through observational studies at Trondheim Airport.

4. Moving from paper

To move from the FPS to a digital system gives both challenges and opportunities. Presenting the information on a digital interface gives the opportunities of entering instructions in a central system that makes updated information available for more ATCOs and other actors (Bos et al., 2011). With a digital interface information can appear when it is most needed, removing unnecessary input and workloads (Truitt, 2005).

Dourish gives an example of how developers tried to make an electronic replacement for cards that were used for medical record treatment histories at hospitals. Their challenge was that the cards as physical artefacts contained valuable information in itself. How information was written, corrections and erasures, old, worn or dog-eared cards told a lot about the activity of that card. Describing not only information about the patient, but also the card itself and the surrounding activities (Dourish, 2001).

Bos, Schuver–van Blanken and Hans Huisman has conducted a research study of an EFS prototype at Amsterdam airport Schiphol. Their prototype is an interaction display where the EFS layout is maintained in a similar way to the physical system. Using design workshops with relevant actors they came up with a prototype that could be tested in a simulator. In the prototype new strips would appear in grey and be coloured after acknowledgement by the ATCO (Bos et al., 2011). In simulations they found that the ATCOs were more satisfied with the EFS because it meant they could stay in their seats and maintain the mental picture. It also reduced the noise without all the FPS in plastic holders. The simulations also uncovered that new strips were left unnoticed for a longer time than with FPS, this is suggested to be solved with a sound notification and familiarisation with the system. The EFS required more head-down time because the system required more visual attention (Bos et al., 2011).

Automating and digitalizing the FPS will ease the workload on the ATCOs, but it can also open for new challenges. Five key human factors issues are situational awareness (1); workload (2); boredom, vigilance, and monotony (3); motivation and stress (4); and trust, complacency, and overreliance (5). Putting the ATCOs in a monitoring position rather than an active control can lead to a reduction in situational awareness (SA), that may result in Out-of-the-loop performance problems. This state can reduce the ATCOs ability to detect problems, understand what has happened and react to a situation (Langan-Fox, Sankey, & Canty, 2009).

In an observational study of Maastricht control centre, the host said they had gotten rid of paper. More of the information had been moved over to the radar display. They also used a monitor with system-controlled information that usually was on the FPS, but this information was ignored by ATCOs. Their explanation was that the EFSs arranged themselves automatically and “made them useless”. To compensate they used notepads and new unstructured paper notes emerged (Mackay, 1999).

To understand what marks ATCOs are putting down on the FPS, Druso et al. did a study where they observed and rated the different annotations done on FPSs. These where rated after ATCO position, occurrence rate, importance and criticality. Some of the most critical marks were aircraft identification, ATIS (weather information), flight plan/destination, altitude, runway and initial clearance (Durso et al., 2008). This study can be used to assess what information is important to preserve in an EFS system.

4.1 EFS at Gardermoen

As mentioned the only airport in Norway with EFS is Gardermoen. The system was developed by the IT department at Avinor. When this system was designed the focus was on function with the old FPS system as a foundation. Brenna mentions that the system looks old fashioned, and it doesn’t look very appealing, but it is functional and well considered. In this system the ATCO has two screens, one for EFS and one for radar information. The EFS is a click-and-drag system and they have a keyboard, but if something needs to be written it’s usually done on small paper notes. New strips appear as grey before they are approved by the ATC that makes a green mark when clearance is given. The ATCO then has control over that aircraft until it is handed over to the next ATCO via a button (Brenna, 2007).

The system windows are coloured in blue for departing aircraft and yellow for arriving aircraft, this is adapted from the FPS where the plastic holders use these colours. In addition to the EFS itself they also have other information visible on the EFS screen, such as lists of upcoming departures and arrivals, flight plans, coordination windows from ground and approach, weather information and general notifications that can be of interest. The system requires an understanding of the system as it has several hidden buttons. A blue box in the strip indicates de-icing, but this isn’t possible to understand unless you know the system (Personal communication with Avinor employee).

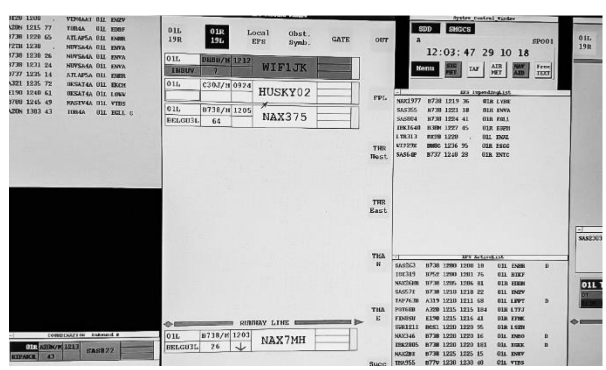

Figure 2 – EFS at Gardermoen

5. Human performance

5.1 Human factors

Designing for ATC means to design for safety in a high-stress environment and it is important to understand human factors and design with this in mind (Langan-Fox et al., 2009). Meister (as cited in Wickens & Hollands, 2000) defines human factors as "*the study of how humans accomplish work-related tasks in the context of human-machine system operation, and how behavioral and nonbehavioral variables affect the accomplishment*" (p.2). Norman defines the behavioral level of processing as the home of learned skill, where every action comes with an expectation, and feedback gives reassurance about selected action (Norman, 2013).

Wickens and Hollands presents a model for human information processing, shown in Figure 3. This model is a framework for analysing the various aspects of human performance. Analysing these psychological processes can identify different design solutions (Wickens & Hollands, 2000, p. 11).

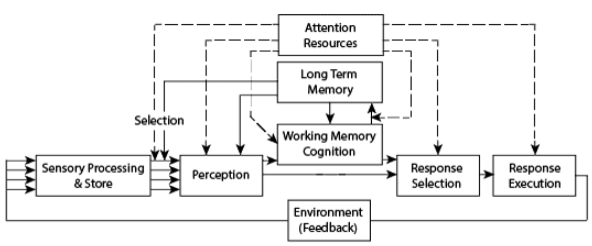

Figure 3 – A model of human information processing stages.

Endsley and Jones also present a model of dynamic decision making, similar to Wickens and Hollands model. Both describe the links for assessing information and making decisions. In addition, Endsley and Jones defines *task/system factors* such as; system capability, interface design, complexity, stress and workload. And *individual factors* such as; goals and objectives, preconceptions, abilities, experience and training. (Endsley & Jones, 2012).

5.2 Cognitive processes

The ATCO's job is mainly cognitive, and all systems have an impact on the cognitive activities. When introducing new concepts in ATC it will affect the cognitive activity and introduce a new mental model for the ATCOs (Dittmann et al., 2000).

Dittmann et al. has defined the basic cognitive processes of ATCOs in an integrated task and job analysis for Eurocontrol. They identified five task processes, one control process and four sub-processes. The five task processes are:

- Taking over a position / building a mental picture
- Monitoring
- Managing routine traffic
- Managing requests / assisting pilots
- Solving conflicts

The control process is:

- Switching attention

With the four sub-processes:

- Updating mental picture / maintaining situational awareness
- Checking
- Searching conflicts
- Issuing instructions

The interrelations between the processes can be seen in Figure 4 (Dittmann et al., 2000, p. 8).

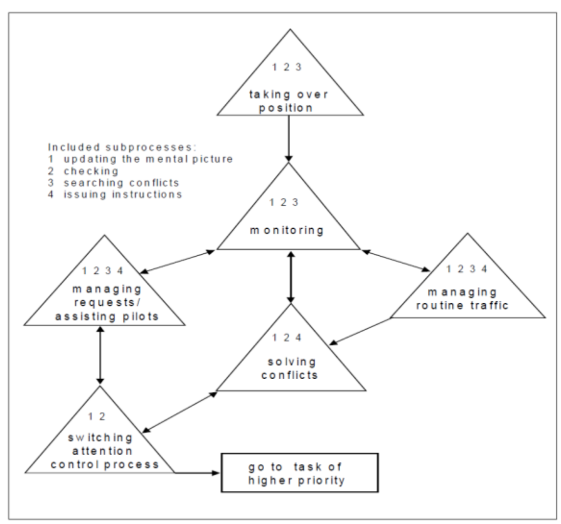

Figure 4 – Basic cognitive processes in ATC.

Preece, Rogers and Sharp has set a number of design implications for interaction design based on cognitive processes such as *attention*, *perception*, *memory*, *learning*, *problem solving and decision making* (Preece et al., 2015). These are all elements that can be found in Wickens and Hollands model.

5.2.1 Attention

Attention is selecting things to concentrate on based on our auditory and visual senses. How information is displayed can greatly influence if it is easy or difficult to interpret. Some of the implications for attention is to make information salient when attention is needed. Ways to achieve this is to use animated graphics, colours, underlining, ordering, sequencing of different information and spacing of items. It is also important to avoid cluttering too much information (Preece et al., 2015). Preattentive processing can be a way of catching attention with basic visual features. This can be shape, colour, orientation, motion and depth, as well as other factors. A task that can be done in 200-250 milliseconds is considered preattentive. These features used correctly can guide attention when it is needed (Healey & Enns, 2012).

5.2.2 Perception

Perception is described by Preece et al. as how information is acquired in the environment using vision, audio and tactile senses. Enhancing perception can be done with icons and graphical representations to distinguish meaning. Effective ways of grouping information are to use bordering and spacing to make information easier to locate and perceive. If using sound, it should be distinguishable in what it represents. Text should be legible and distinguishable from the background. Tactile feedback should be distinguishable in the various meanings of touch sensations (Preece et al., 2015).

5.2.3 Memory

Memory can be divided into “Knowledge in the world” and “Knowledge in the head”. Knowledge in the World is external and is a valuable tool for remembering, but it must be available at the right place, at the right time, in the appropriate situation. Knowledge in the head is in the mind. It can be divided into working memory (short-term) and Long-term memory. Working memory is based on recent experiences or about the present. If information is repeated or rehearsed it can make it into long term memory (Norman, 2013).

Compared to Normans example (p.105) of pilots talking to ATC (Norman, 2013), *flight strips* are a combination of knowledge in the head and in the world. Through education and training the ATCOs follow procedures that are learned as knowledge in the head. Giving instructions and clearances are instant and easy to forget. By annotating and moving FPSs they help the ATCOs with reducing memory loads. Preece et al. give some design implications to this as well. Don’t overload users’ memories with complicated procedures for tasks, promote recognition and provide ways of accessing information through categories, colour, tagging, time stamping, icons etc. (Preece et al., 2015).

5.3 Situational awareness

Situational awareness is key to operating safely and prevent errors. Endsley and Jones defines situational awareness (SA) as “*being aware of what is happening around you and understanding what that information means to you now and in the future*” (Endsley & Jones, 2012, p. 13). They define three levels of SA:

- Level 1: *Perception* of the environmental elements.
- Level 2: *Comprehension* of the current situation.
- Level 3: *Projection* of future status.

In short, these levels describe that to achieve SA a person needs to perceive the environment (1) and understand what the perceived information means in relation to relevant goals and objectives (2). Then to use this information to predict the result of a future action (3). Fulfilling all these levels lead to an understanding of a situation that will end with the execution of an action (Endsley & Jones, 2012). When designing for SA and for ATCOs it requires a holistic approach. In addition to creating a set of rules and looking at one system in isolation, it has to be looked at as a whole (Endsley & Jones, 2012; Langan-Fox et al., 2009). To do this, an *operational concept* should be developed to describe the intended use and functions of the system. It is also important to define the *environmental conditions* where the system will be used (Endsley & Jones, 2012).

To improve the SA of system users, Endsley and Jones has 50 design principles. These principles are general towards SA and on complexity, alarms, automation, multioperation and training.

5.3.1 Complexity

Display complexity is how information is presented to the user. Four factors for this is overall density, local density, grouping and layout complexity. Icons on a radar display will have greater degree of perceptual density. With a system of multiple displays, it is important to have consistent presentation. Principle 19; *Map system functions around the goals and mental models of the users*. Principle 21; *Group information based on level 2 and 3 SA requirements and goals* (Endsley & Jones, 2012). For EFS it means to map the functions in a way that makes them available when they are needed and predict the traffic flow.

5.3.2 Automation

Automation of systems can simplify operations, but also be the cause of problems. One big challenge is if the user ends up in a monitoring position and too much is automated. This Out-of-the-loop syndrome can make operators incapable to detect or diagnose problems. Within automation they present these principles: Principle 34; *Automate only if necessary*. 36; *Provide SA support rather than decisions*. 37; *Keep the operator in control and in the loop* (Endsley & Jones, 2012). They have 50 principles where more of them should be considered but these are some of the relevant ones for EFS.

5.4 "Human error"

With the introduction of new systems and new ways of doing an operation there is a risk for "human error". "Human error" can be divided into slips and mistakes. Slips are when a person intends one action and but ends up doing something else. Mistakes are when the wrong goal is established. An accident rarely has one cause. James Reason uses a Swiss Cheese Model to explain how errors occur. Slices of cheese represents the condition of the task being done. And accidents happen when the holes in the cheese line-up just right. To reduce the risk of error is to reduce the number of critical safety points and design redundancy and layers of defence, adding more layers of "cheese" (Norman, 2013).

6. Guidelines

With the lessons learned from other research and the human factors involved, some design guidelines can be set:

- Use goals to form the functions. Define operational and environmental factors that forms the use and system.
    - Design with all factors in mind.
- Use graphics or icons to display meaning.
- Use bordering and spacing to group information.
- Have "at a glance" availability of information for the ATCO to comprehend and project the current and future status of air traffic.
- Make the ATCO engage with the EFS, using it to register and confirm instructions.
    - Give feedback on registered instructions.
- Make less important and historical information available in submenus.
- Use sound and/or animation to notify the ATCO about new strips.
- Automate only if it helps the operations, don't put the ATCO in a passive monitoring position.

6.1 Colours

As mentioned earlier colour is a visual feature that can be used in preattentive processing to catch or focus attention. Vision is optimized to detect contrast. How able we are to distinguish colour depends on how colours are presented. Paleness, colour patch size and separation are ways of doing this (Johnson & Johnson, 2010).

Cardosi and Hannon has done research for FAA to define a set of guidelines for use of colour in ATC displays. Special consideration should be taken for tower displays as the environment is exposed to a wide range of ambient lightning conditions, especially direct sunlight can affect the appearance of colours. Other factors such as physical placement, shades and sunglasses can affect the display appearance (Cardosi & Hannon, 1999). They present the following guides for use of colour:

- When colour is used with critical information, other methods of coding must also be used.
- Six colours should be the maximum number of colours when assigning a unique meaning to a specific colour. Each colour should have only one meaning to avoid confusion.
    - Recommended colours are red, green, blue, yellow, cyan and magenta. Including black, grey and white in addition depending on the background.
- Text that is colour-coded must be presented with sufficient contrast.
- Pure blue should not be used for text, small symbols or fine details, as the colour can be difficult to perceive. Light blue will appear closer to white, and yellow and white are easily confusable.
- Pure, bright highly saturated colours should be used sparingly.
- The colours need to be consistent with other displays the ATCOs use.

6.1.1 Display background

A background does not contain any information, it can either be very dark or very bright to achieve maximum contrast. A wider range of colours will be identified on a dark background than on a light background. Because a black background can produce a glare problem, dark grey is preferred as a background colour. Very light or very dark blue can also be used as background if it's carefully designed. Tower displays should have a daytime and night-time configuration of background and display colours, with brightness controls easily accessible (Cardosi & Hannon, 1999).

6.1.2 Alerts and warnings

When alerts and warnings must be displayed they should be presented with high contrast with colours that are highly saturated. Because of the cultural associations to danger and caution, *red* and *yellow* should be reserved for this use (Cardosi & Hannon, 1999). The design implications for attention presents more effects that can bring focus to an alert or warning.

6.2 Symbols and icons

The ATCOs has a set of procedures and rules to follow when managing traffic. As mentioned earlier Avinor has a general standard for annotating on FPS. This standard contains abbreviations and symbols that are used to manage the given instructions on the FPSs. This can be to put arrows beside flight levels to show an instruction up to a certain level. Or another crocked arrow beside the runway information describes a right or left turn after take-off.

7. Discussion

With the design guidelines and implications described in this article, a possible user interface design can be developed. Earlier research, case studies and annotation on FPS, and lessons learned from previous works on EFS systems gives valuable insights into the goals and priorities of the ATCOs. The FPS is a tool that supports the cognitive processes of ATCOs as listed by Eurocontrol. Especially when taking over a position and building a mental picture this is used to understand the air traffic situation and current workload. In the four sub-processes FPS is used to check and put down information to reduce memory loads.

The guidelines proposed in this article are based on lessons learned from the use of FPS as well as general guidelines for human factors and SA. The guidelines are somewhat general, but these are overall definitions that are described more in detail in the literature review itself. Further specifications will also be done when creating a prototype.

By moving from FPS to EFS some elements will get lost in the transition. The engagement with the tactile FPS gives a different kind of interaction then what you get on a digital surface. The ability to move strips and have attention elsewhere, as well as the freedom to annotate directly on the strips helps the ATCOs with maintaining SA and reducing memory load. As tower control is very uniform and follows a similar pattern every time, a digital system will give more advantages than what gets lost with paper. It is also on a short-term basis, making the need for visible historical data less important. The important aspects to preserve is the goals of the ATCO, helping to develop a mental picture of traffic with a functional and intuitive system. Finding a balance in automation is also important, making sure the ATCO is "in-the-loop". This should be done by making sure the ATCO have the needed information displayed and control the operations without the need to make separate notes.

Designing a "strip-less" system is more challenging than creating a separate EFS system as a lot of the information from the strips should be available for the ATCOs in other systems. The challenge is that other systems such as radar displays also contain a lot of information and there is a danger of information cluttering and missing out on the information they usually look for in the radar display. If an aircraft is missing on the radar display, is it harder to notice that with a strip-less system? FPSs also works as a confirmation of what they see on the radar display, supporting SA and status of traffic, and merging it could reduce this ability. It might result in the removal of a "layer of cheese" increasing the likelihood of "human error". To make this kind of system will require more research, prototyping and testing with actors within the ATC environment.

A possibility is to combine an EFS system to a part of the radar display, keeping everything on one screen, but still as separate sections that work in conjunction. These two systems are used together already with FPS, meaning that a combination can help to build a mental picture. The EFS at Gardermoen used a click-and-drag system which makes it easier to hit buttons than with a touch screen, if a touch screen would be used the buttons need to be bigger and easier to hit correctly for the ATCOs. There are also a lot of considerations to make about how sub-menus and changing values should be done without taking too much heads-down time.

8. Conclusion

The critical thing about making a design to replace an already functioning system is to present a better system that preserves safe operations. I think a solution is to make a system where both radar display and EFS is combined in one screen and the EFS visualizes the workload and air traffic under the ATCOs responsibility. Still, it will require testing and approval through simulations with ATCOs in both routine and emergency scenarios. A new system will affect the way the ATCOs work and it should be a simple transition from FPS to EFS and a strip-less system might make the transition too big. Further research on this should, as mentioned, involve more actors within ATC.

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