

Mats Ruste Holen

Design of an Electronic Flight Strip concept for Air Traffic Control

June 2019

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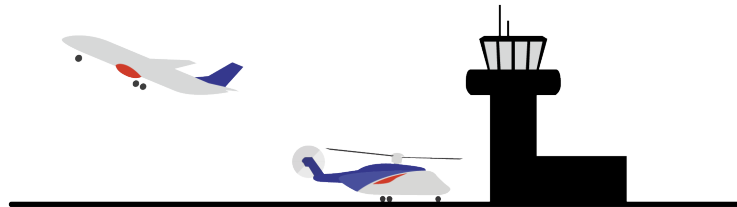
Industrial Design (Master's Programme)

Submission date: June 2019

Supervisor: Thomas Porathe

Norwegian University of Science and Technology
Department of Design

Design of an Electronic Flight Strip concept for Air Traffic Control



Using design methods to create a user-friendly interface
for Air Traffic Control towers, suited to their needs

A master thesis written by Mats Ruste Holen at the Department of Design,
Norwegian University of Science and Technology
Spring 2019

Preface

This master thesis is written at the Department of design, Norwegian University of Science and Technology the spring of 2019.

The project is a continuation of a subject I dug deep into the autumn of 2018. The concept and user feedback showed that there still was a lot to develop further. The project was given by Avinor Air Navigational Services (Avinor ANS) as something they wanted me to investigate within the Air Traffic Control (ATC) environment. With a great interest for aviation this collaboration and project was very interesting. I got to look at how to design a Human Machine Interface (HMI) for a safety-critical environment in an area I already had much experience in from the pilot side.

I would like to thank my supervisor, Thomas Porathe, for counselling during the project.

I also want to thank a few key persons in Avinor ANS that has been helping me through the thesis, mainly my contact in Avinor ANS, Christian Raspotnig for giving me the project and helping me during the project. Thanks to Stephanie for discussions and information and Elin for help with setting up and arranging observations at various airports and the user testing. Thanks to the Air Traffic controllers for letting me visit and observe them at Værnes, Gardermoen, Flesland and Sola. And thanks to everyone that have contributed in giving insights, testing and helping me in this project.

Thank you to my family and friends for support during the thesis. Thanks to my classmates for lots of fun, inspiration and motivation during this master.

Abstract

In cooperation with Avinor ANS in Norway I have looked deeper into designing an Electronic Flight Strip (EFS) solution for ATC Towers. The first chapter introduces the role of Air Traffic Control (ATC) and how they use the Flight Progress Strips. The next chapter describes the process of making an EFS design that is the basis for the work in this thesis. For user testing of that concept one of the main issues was sequencing of strips. Focusing on special airport needs, insights to Stavanger and Bergen airports gave insight to develop solutions for these airports. First Stavanger with crossing runways was investigated and a solution is created and presented. Then the design was adapted to Bergen with a single runway. This ends up in two design concepts.

Sammendrag

I samarbeid med Avinor Flysikring AS har jeg i denne oppgaven gått dypere inn i design av Elektroniske Flight Strips for flygeledere i flytårn. Første kapittel introduserer flygelederens rolle og hvordan de bruker Flight Progress Strips i dagens tårn. Neste kapittel tar for seg prosessen med å designe et konsept som kan ta systemet de bruker i dag over på en skjerm. Dette er grunnlaget for arbeidet som er gjort i denne masteroppgaven. I brukertester av dette konseptet ble det avdekket utfordringer med å se rekkefølgen på innkomne og taksende fly. Det har blitt sett på hvordan systemet kan legges opp best mulig for å løse dette. Fokuset i denne oppgaven har vært å se på hvordan et brukervennlig system kan designes og hvordan det kan tilpasses spesielle flyplassers behov. Spesifikt Bergen og Stavanger lufthavn, med besøk til begge flyplassene for å lære om deres behov og utfordringer.

Først vil jeg se på Stavanger, som med kryssende rullebaner gir spesielle utfordringer. Her har det blitt laget en prototype som ble testet på flygeledere. Dette ga tilbakemeldinger som endret designet før jeg så på tilpasning for Bergen lufthavn med én enkelt rullebane og kompleks trafikk. Resultatet tilslutt er to konsepter, et til Stavanger og et til Bergen.



Motivation

This master thesis started with the cooperation with Avinor ANS to work on something within aviation and ATC. This is a field I'm personally very interested in with flying gliders as a hobby and growing up around airplanes. When I was younger, I played a lot of flight simulator and was a part of an online community called VATSIM (Virtual Air Traffic simulation) where enthusiasts try to replicate real-life air traffic with ATC. This has given an advantage in knowing a lot about how operations work from the pilot side.

ATC is a very complex and safety-critical environment where creating an interface can be very challenging. When the design was finished in December 2018 for Design 9, it ended with a set of user tests and feedback. This gave a possibility to look further at this project in the master thesis. Together with Avinor ANS the possibilities to further development the concept were discussed with new and exiting challenges to investigate.

As a two-year master student, my experience has mainly been product design. During this two-year master program and a summer internship I have gotten more interested in working with the combination of product and interaction design in working with HMIs. This project has given me more experience in working with the tools and methods to develop the HMI and look at considerations for creating a system that supports ATCOs in their work.

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Abbreviations

ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ANS	Air Navigational Services
HMI	Human Machine Interface
FPS	Flight Progress Strip
EFS	Electronic Flight Strip
TWR	Tower
GND	Ground
GA	General Aviation (light aircraft operated by private pilots, non- commercial)
VFR	Visual Flight Rules (when a pilot can navigate in clear weather, usually non-commercial)
IFR	Instrumental Flight Rules
ATIS	Automatic

CTR	Control (Airspace in and around the airport)
SA	Situational Awareness
RWY	Runway
ILS	Instrument Landing System (final approach landing system)
Transponder code	Transmitted code in the aircraft to be identified on the radar display with correct information
SID	Standard Departure Routes (A set of possible routes to fly out of the airport via certain waypoints)
STAR	Standard Arrival Route (A set of possible routes to fly in to the airport via certain waypoints)
Touch and go	Training procedure where an aircraft lands and takes-off again immediately, as landing training.

Background

From Avinor ANS I got the problem statement of looking at today's Flight Progress Strips (FPS) and how this could be developed as a digital solution, called Electronic Flight Strips (EFS). There are already solutions on the market, but all of these are in some ways a digital representation of the FPS that already exists. To challenge this, I came up with a new solution that covers the same need, but in a different way compared to today's system.

The basis for making this design came from the article that was written as a literature review in the course Design Theory. The article investigated the existing FPS system, research on EFS systems, human factors, situational awareness and design implications for user interfaces. This boiled down to a set of design guide-lines that was followed to create the EFS concept in the course Design 9.

Design 9 ended with a prototype that was tested with Air Traffic Control Officers (ATCOs). Because of the timeframe I only got to discuss the feedback and not do anything with it. The master thesis has continued to look at the feedback from user testing to create a more complete system adapted to the needs of the selected airports.

To understand the concept and ideas for the work in this thesis, a short introduction to ATC, FPS and the first concept, named as iteration 1 is presented.

Together with Avinor ANS some focus areas were uncovered for how I could work further with developing the concept. This ended up in a problem statement, shown on the next page. As time progressed, it was more defined, adding more statements. It was pointed out that the traffic and layout of the airports in Bergen and Stavanger present different and challenging operations and these two airports were picked out specifically.

Problem statements

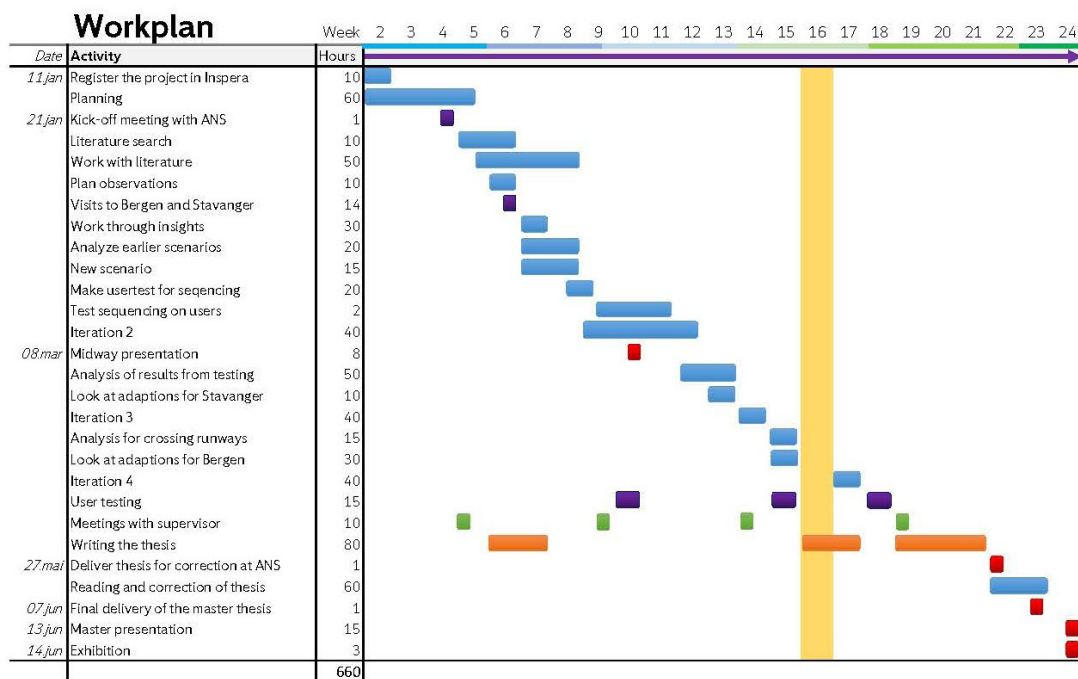
How to design a user friendly EFS system adaptable for different airport needs?

How can sequencing of strips give a clear understanding of the order of aircraft?

How does special user needs change the design?

How should a system be adapted to work in airports with a more challenging layout, like Bergen and Stavanger?

Planning



Masteroppgave for student Mats Ruste Holen

Utforming av HMI for flygeledere.

Design of HMI for Air Traffic Control (ATC).

I dag bruker de fleste kontrolltårn et fysisk system med Flight Progress Strips (FPS) til å holde oversikt over lufttrafikken. Flysikringsleverandører er på sikt interessert i å implementere elektroniske løsninger, slik de i dag kun har ved de største flyplassene (f.eks. Gardermoen i Norge), i flere kontrolltårn. Forrige semester så jeg på utforming av et digitalt system kalt Electronic Flight Strips (EFS), dette ble utformet gjennom en litteratur studie og et designprosjekt til en prototype.

Masteroppgaven vil ta dette arbeidet og prototypen videre og se på nye scenarier og vurdere andre kontrolltårns behov for å lage et system som kan tilpasses til ulike typer flyplasser.

Hovedfokuset i denne oppgaven vil være å se på ny utforming av HMI (Human Machine Interface) med utgangspunkt i mer utforskning, prototyping og brukertester. Den vil også se mer på kartlegging av ulike kontrolltårns behov og hensyn som må tas for å lage et helhetlig system.


Opgaven vil blant annet omfatte:

- Informasjonsbearbeiding, kartlegging av behov og analyse.
- Observasjon av flygeledere i kontrolltårn med unike forhold ift. trafikk og layout på flyplass.
- Se på flere scenarier.
- Videreutvikling av EFS konsept.
- Intervjuer og brukertester med flygeledere, sammenligne og analysere funn.


Opgaven utføres etter ”Retningslinjer for masteroppgaver i Industriell design”.

Faglig veileder: Thomas Porathe
Bedriftskontakt: Christian Raspotnig

Utleveringsdato: 11. januar 2019
Innleveringsfrist: 07. juni 2019


Thomas Porathe
Faglig veileder

Trondheim, NTNU, 11. januar 2019


Ole Andreas Alsos
Instituttleder

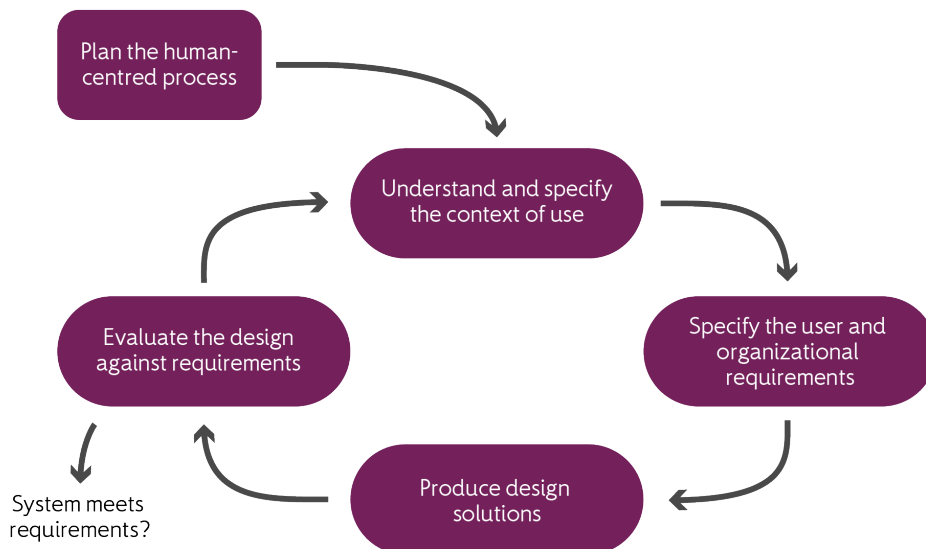


Methods

Human-Centred Design

The project was done following a Human-centred Design approach using design methods to create a solution that satisfies the end-users, in this case the ATCOs working in an airport control tower. The process and methods within ISO 9241-210:2010 was used to go into the users needs and find out what is required to make a solution that makes them solve their tasks (Norman, 2013).

The thesis has been done independently with help from Avinor ANS to do conduct meetings, observations and user testing. Looking back, it would have been nice with even more involvement from users in some of the design choices during the process. The first month was used for planning and defining the thesis. Then the process of getting more insight started to go deeper in defining user needs. This was used to develop the concept and test it on users to evaluate the design.



Ethnography

A two-day fieldtrip to Bergen and Stavanger was arranged to get more insights to the workflow and needs they have at the different airports. Sitting next to the ATCOs during their workday, I got more insights into how they work, and hear their opinions on the systems. This was a contextual inquiry with observations between the two stations, sitting down and talking to them as they worked. At the same time, I was careful with talking and stopping if they got a radio-call or something else happened that needed attention.

Observing in context to reveal underlying work structures helps to identify the real needs, and the opportunity to ask questions to understand why they do certain actions (Martin & Hanington, 2012).

The goal with these observations was to identify how they use FPS at these airports compared to previous observations. And to specify their operational user needs for later use in designing new iterations.

Literature review

A literature review is useful as a way of collecting and find published information to understand previous research that might help in the design project (Martin & Hanington, 2012). For this project it gave a set of guidelines to follow in the design process, learning from earlier projects within FPS and EFS. In the research on sequencing information and dealing with crossing runways, much information was discovered, but literature didn't help or give more insights into the challenges for designing the EFS system.

Sketching

Going back to sketching with pen and paper gives a fast way to ideate concepts and look at different solutions. Using a whiteboard with markers also gave the advantage of sketching in real size for more control over the opportunities within the space of a 40" screen.

Scenario

Scenarios are believable narratives that makes design ideas explicit and concrete (Martin & Hanington, 2012). For this thesis, scenarios have been used to define the situations for user testing and creating a framework of what should be included in the prototyping of information and details.

Prototyping

The process has involved both low-, medium- and high-fidelity prototyping. The first iteration done in this thesis (Iteration 2) was a low-fidelity prototyping presented on paper, reusing elements from iteration 1, making it simple to get comments on the functions rather than aesthetics. The next iteration had both a medium-fidelity and a high-fidelity prototype. The medium-fidelity prototype was a magnetic board with icons that made the users engage with the system and was free to move them as they would like. The high-fidelity prototype was based on the same scenario but made in Adobe XD to test on screen, making it closer to what a finished result would look like.

User testing

Usability testing gave the possibility to see how the ATCOs interacted with the prototype and to get feedback. The usability testing helps to identify problems and to see what should be improved to make the system better (Martin & Hanington, 2012).

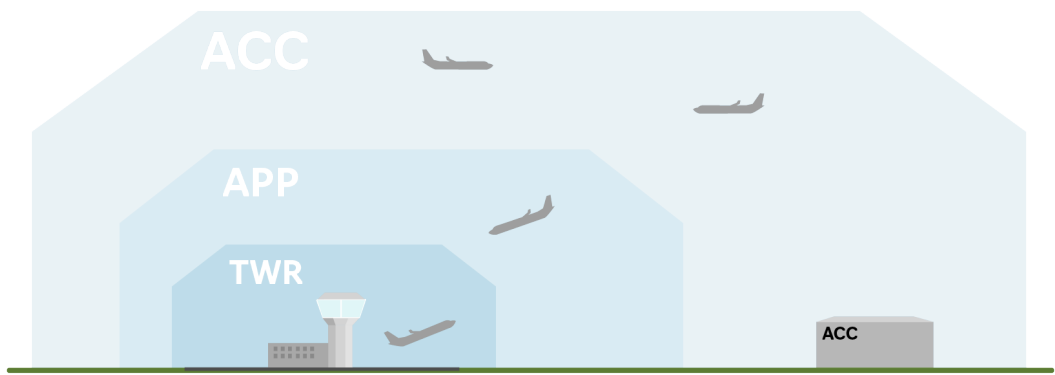
Testing was done face to face, sending out a questionnaire and digitally via Skype. To get feedback from as many users as possible a paper test was sent out. A full-scale physical prototype was created and tested to see how the users would interact with the prototype and how they interpreted the concept. The Adobe XD prototype was tested with users via a shared screen on Skype.

Wizard of Oz

The physical full-scale test was done like a Wizard of Oz test where I as a facilitator sat beside the user and “simulated” the screen and reacted to their actions. It’s not exactly a Wizard of Oz test, where the actions are simulated “behind the scenes” and appears to be real (Martin & Hanington, 2012). In the test users moved and pressed the “screen” and actions was changes physically by the facilitator.



Air Traffic Control



Air Traffic Control

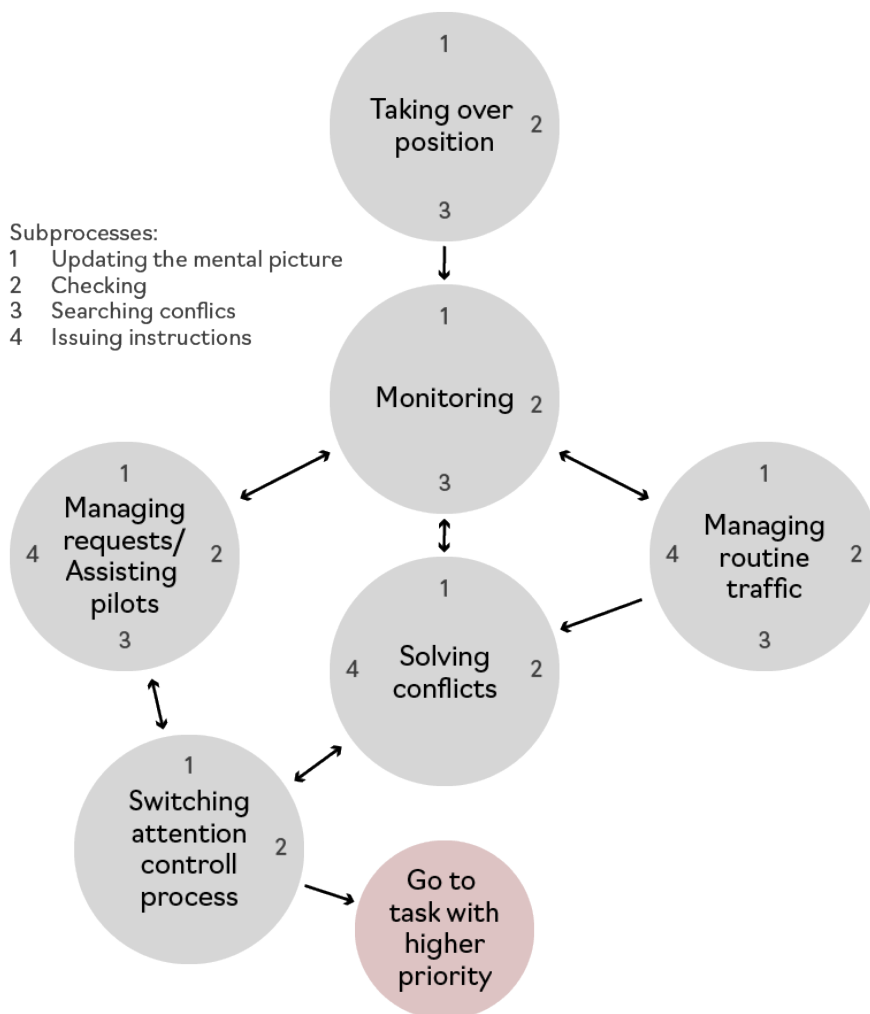
The role of ATC is to ensure safe and efficient flow of air traffic by instructing pilots. ATC can be divided into three categories; Tower (TWR), Approach (APP) and Enroute (ACC) controls. Tower control is managing aircraft in take-off and landing on the runway, local aircraft around the airport, and 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 enroute control manages air traffic to and from airports in its cruising phase (Avinor, n.d.).

The tower functions can further be divided into Tower (TWR) and Ground (GND). The Ground controller is responsible for ground operations. Controlling aircraft from they start with delivery clearance at the gate until they are taxiing to the runway. The Tower controller is responsible for aircraft on the runways and airborne in a proximity around the airport. Their responsibilities are described in more detail later.

In tower control the ATCOs actively need to look for information to build their mental picture and usually they adapt to the previous ATCO's plan of action. The tasks are mostly uniform and work in an automated and schematic way, with little room for individual preferences (Dittmann, Kallus, & Van Damme, 2000).

Pre-planning of traffic is on short-term basis in TWR and APP, they need to change their attention quickly and be able to change their plans (Dittmann et al., 2000).

To divide workload, airspace is divided into different sectors. As aircrafts moves 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).



EUROCONTROLs model of basic cognitive processes, illustrated by author (Dittmann et al., 2000, p. 8).

Eurocontrol has defined the basic cognitive processes of ATCOs in an integrated task and job analysis. 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 is visualized in the figure on the previous page (Dittmann et al., 2000).

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 their control**
- **support handover of flights between the ATCOs**

(Bos et al., 2011)



FPS at Værnes

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).

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). Blue strips represent departing aircraft and yellow strips represent arriving aircraft, the black strip represents a VFR-aircraft. In addition, they use strips for vehicles and birds.

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, Randall, & Shapiro, 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). The next pages describe general aircraft operations, the observations from visits to Værnes and Gardermoen airports, different types of strips and guidelines for the design.



Annotating on a strip

Aircraft operations



Delivery clearance

When an aircraft is getting ready for departure the pilot takes contact with GND to get an IFR clearance to their destination. Here the ATCO annotates and confirms the information with a clearance that is read back by the pilot.



Push and start

When the aircraft is ready the pilot gets a clearance from GND to push-back and start their engines.



Taxi

Next clearance is a taxi clearance from the gate and out to the runway intersection.

The same is given for arriving aircraft after landing, from intersection to gate or parking.



Runway intersection

The runway intersection is where the aircraft holds short before entering the runway. The aircraft can only enter the runway after the ATCO gives a "Line-up and wait" or "Cleared for take-off" clearance.



Runway

If the "Line-up and wait" is given, something is occupying the runway, and once the runway is free the aircraft will get "cleared for take-off".

For landings the operations are the same, the ATCO "gives cleared to land", together with wind information.

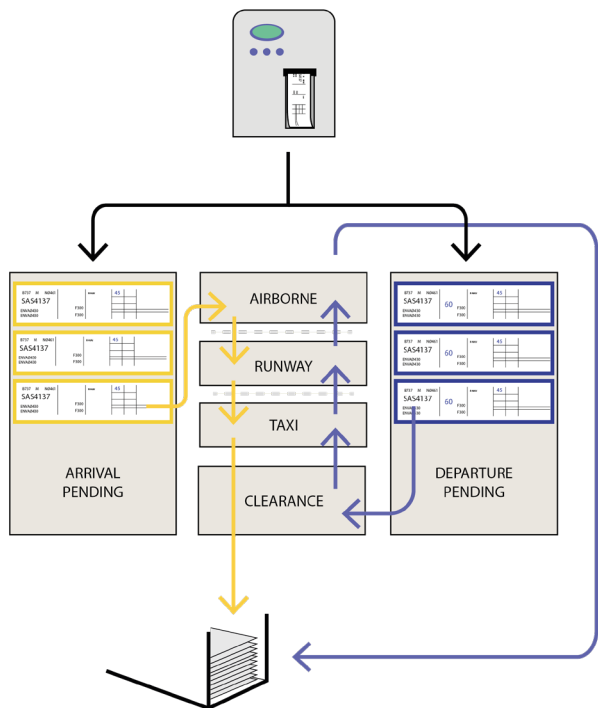


Airborne

When airborne and established on radar the aircraft is handed over to the next control sector, Approach, where they get further instructions.

Trondheim airport

Trondheim airport is one of many airports in Norway using paper strips to manage traffic. A visit to both TWR and APP gave more insight to the use of FPS, and how they annotated on the strips. On the shift I observed one supervisor in the background and one active ATCO for both tower- and ground operations. The operations were mostly uniform with similar instructions and annotations. When an operation was complete a checkmark or a line was put down on the strip. New paper strips came out of the printer and were placed in holders on the strip-rack. It then went to a pending box before it was moved to a clearance field when it was ready for departure. The strip moved upwards in steps for taxiing, being on the runway for take-off and last airborne before it was taken of the rack and stored in a shelf below the desk.



Gardermoen airport

Gardermoen has been using EFS since they started operating in 1999. On my visit, 5 ATCOs were on duty. In the middle is the supervisor position, with one ground and one tower controller for each of the two runways. 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.

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.

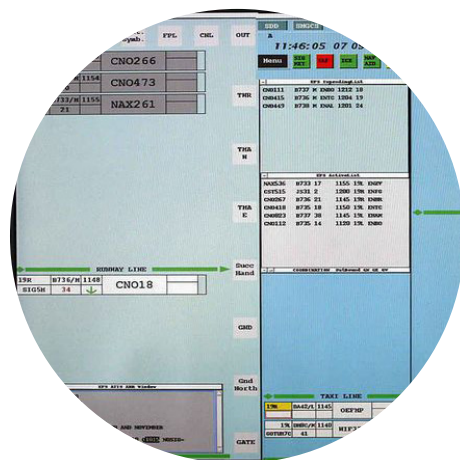
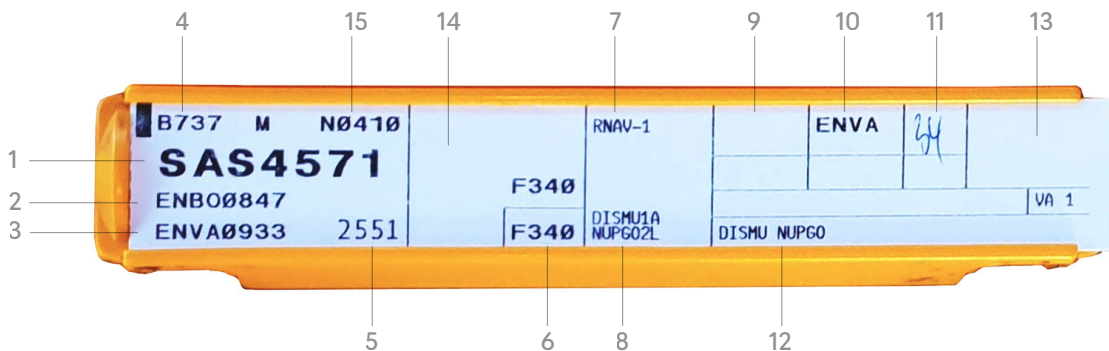


Photo: Digi.no

FPS at Værnes

- 1 CALLSIGN
- 2 DEPARTURE AIRPORT + TIME
- 3 ARRIVAL AIRPORT + TIME
- 4 AIRCRAFT-TYPE AND SIZE
- 5 TRANSPONDER CODE
- 6 REQUESTED ALTITUDE
- 7 AUTOPILOT INFORMATION
- 8 SID/STAR
- 9 TURN AFTER TAKE-OFF
- 10 CLEARANCE TIME
- 11 PARKING STAND/GATE
- 12 FLIGHTPLAN DATA
- 13 WARNING BOX
- 14 CLEARED ALTITUDE
- 15 SPEED INFORMATION



EFS at Gardermoen

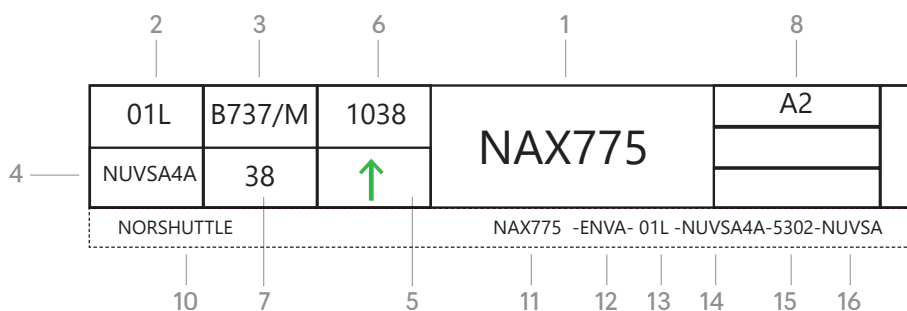
- 1 CALLSIGN
- 2 RUNWAY
- 3 AIRCRAFT-TYPE AND SIZE
- 4 SID/STAR
- 5 CLEARNACE BOX
- 6 ESTIMATED TIME OF DEP./ARR.
- 7 PARKING STAND/GATE
- 8 RUNWAY INTERSECTION
- 9 3 BOXES FOR DIFFERENT FUNCTIONS

SUBMENU

- 10 PRONOUNSIATION OF CALLSIGN
- 11 CALLSIGN
- 12 DESTINATION
- 13 RUNWAY
- 14 SID/STAR
- 15 TRANSPONDER CODE
- 16 WAYPOINT

POP-UP WINDOW

- 17 FLIGHTPLAN DATA



FLP

17

Selected EFS elements

The list on the next page is the elements of information I have chosen for the EFS prototype. It includes information from the EFS system that is used at Gardermoen including more information that you can find on the FPS at Værnes. The reason for this is to change what information is displayed to when it is relevant, but also to make sure the ATCO have “at a glance” availability of information.

The article from Durso about use of paper in ATC also gave indications to what ATCOs mark on paper strips and I chose to focus on elements with a frequency of occurrence of over 500 or criticality of over 60 (rated from 0 to 100) (Durso et al., 2008), others on their list are also included when comparing with my own observations.

The paper makings with a frequency of occurrence over 500 are:

- Aircraft identification (ACID)
- Weather information/
Automatic Terminal
Information Service (ATIS)
- Flight plan route/destination
- Gate assignment/location
- Clearance to take off/land
- Operation complete

EFS information

CALLSIGN
TYPE AND SIZE
TRANSPONDER CODE
DEPARTURE OR ARRIVAL AIRPORT
SID/STAR
RUNWAY INTERSECTION
AIRCRAFT IDENTIFICATION/CLEARANCE
TURN AFTER TAKE-OFF
ESTIMATED TIME OF DEP./ARR.
PARKING STAND/GATE
FLIGHTPLAN MENU

SUBMENU

FLIGHTPLAN
-ROUTE
- SPEEDS
- REQUESTED ALTITUDES
- WAYPOINTS
- ALTITUDES



Photo: AVINOR

Findings from literature review

General design guidelines

- 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.

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.



Iteration 1

Design 9



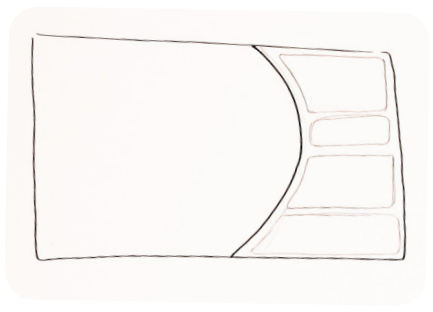
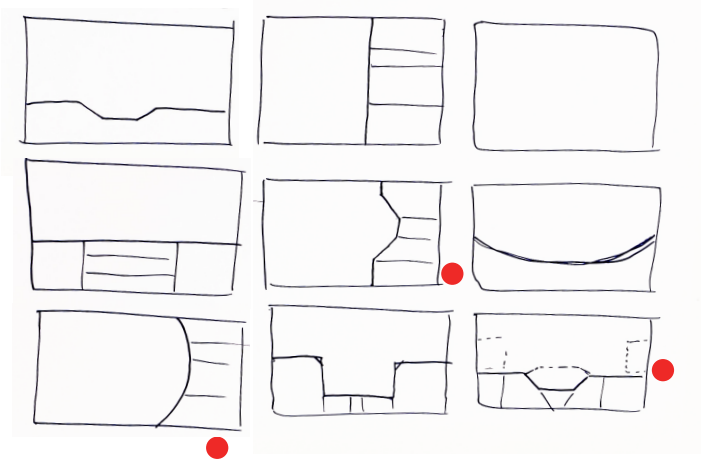
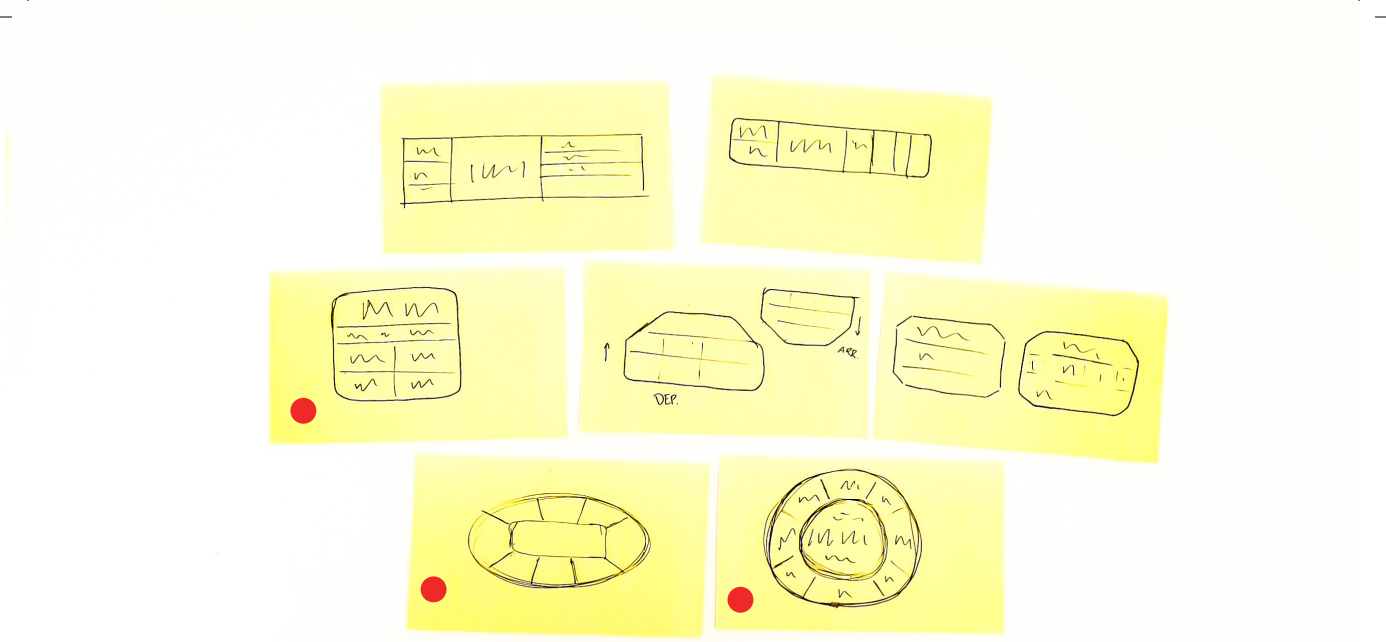
Creating a new EFS concept

The foundation for the concept in this master thesis is as mentioned a result of the work that was done in Design 9. This describes the ideas and functions behind the circular concept strip.

The literature review together with the observations gave a good insight to the use of and function FPS has for the ATCOs. In exploration of existing EFS solutions on the market, most of the products are adaptations of the FPS, only in a digital format. One goal with the design was to be innovative and look at how a system can be designed differently, using advantages you get on a digital interface compared to a paper strip.

The first step was sketching and coming up with ideas on how the strip itself could be shaped. Ideas on how to interact with the shape was considered. When the idea for the strip was coming together, the next step was to look at the screen and layout of the bays.

This was conceptualized into a paper prototype that could be tested on ATCOs to get the first feedback. The feedback was then used to develop a digital prototype in Adobe Illustrator that was tested using the prototyping tool, Adobe XD.



Design process

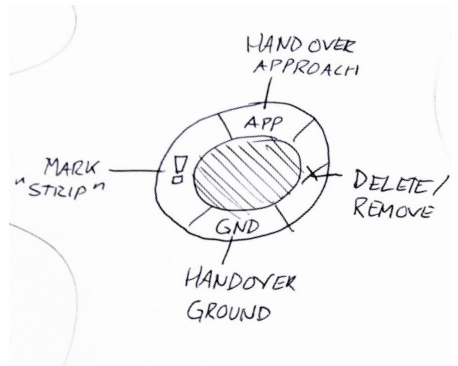
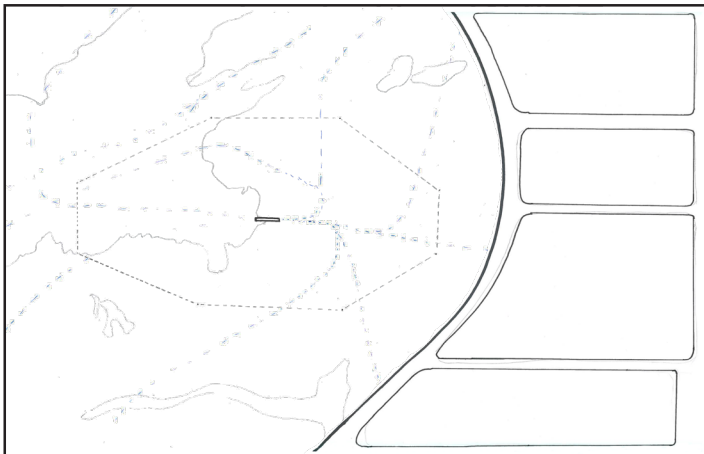
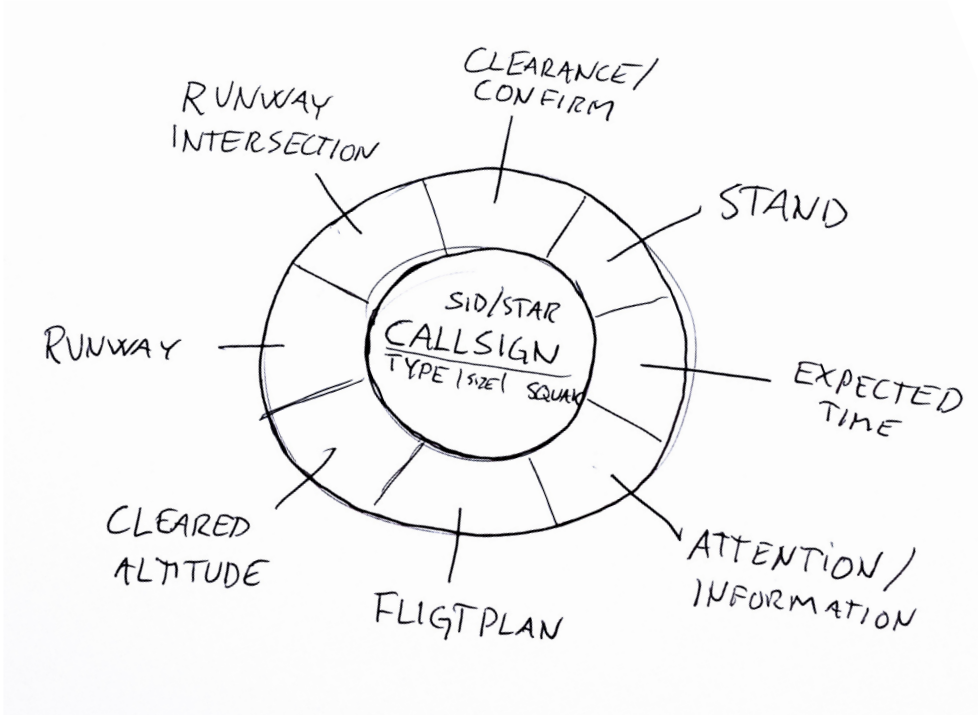
The ideation started with sketching many different shapes and thinking about how the strips could be designed. One of the early sketches was a quick sketch on a post-it where a circular shape was sketched. This is a very different approach than the rectangular shape used today, and it was interesting to explore further.

By having two circles, one inner shape and one outer shape, the information could be placed after importance and how it would be used. The inner circle contains information that is very unlikely to change, information such as callsign, aircraft type and transponder code. The outer circle contains information that either can be relevant to change during operation or fields that will actively change. This could be information such as runway, runway intersection, cleared altitude, gate, time and more. Then more ideas on how to change information in the outer circle was ideated as well as how to input numbers on the strip.

The next step was the display and the bays. The idea in this display was to simplify the workspace of the ATCOs by having more information on one big screen, having an EFS panel on one side and use a large part of the screen for the radar display.

The radar display is an additional tool the ATCOs use to track aircraft as they move around. On the radar display the aircraft position is depicted with a symbol the shows the aircraft identification, often with height information, and it can be expanded to contain more information. These symbols are referred to as labels (Hopkin, 1995).

This layout was chosen as it gives much room to the radar display and for the strip bay, the movements are logical as well. New aircraft start on the bottom and are moved upwards until they are in the air, and arriving aircraft are moved from the top and down, until they are on the ground and at the gate.

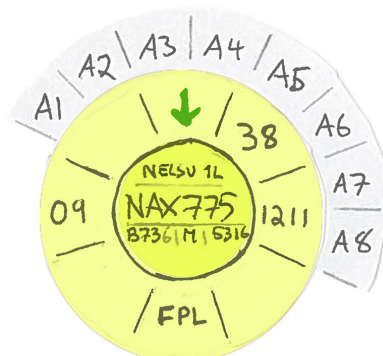
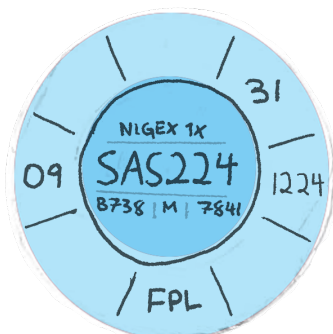


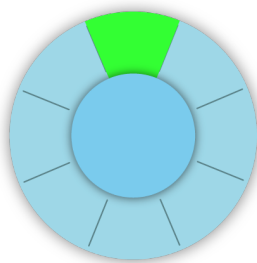
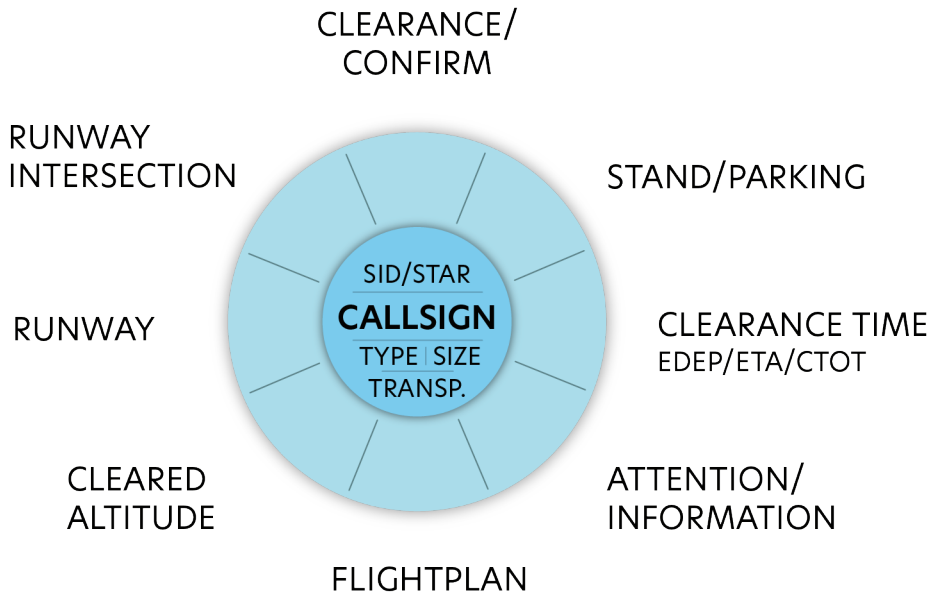
Low fidelity prototype

To find out if the idea of a circular strip could work and if it can work as a tool for ATCOs, a paper prototype was created. Using a paper prototype helps to quickly find out what parts of the interface works well, and which parts that are challenging. It also makes it easier to modify and make changes after testing. A paper prototype gives better feedback where the user gives feedback on function rather than a polished prototype where the user will focus on the details (Snyder, 2003). A simple scenario was created to cover as much as possible of the use of FPS. The scenario was set as a routine day with arriving and departing traffic and a VFR aircraft doing touch-and-go (landing training).

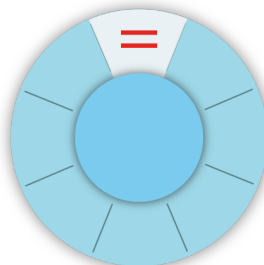
The size of the circle was tested in different paper sizes to make sure the buttons would be large enough that an ATCO won't aim for one button and hit another. With a diameter of 55 mm on paper the buttons should be wide enough to have a good space to touch for each button.

If the test was done live with paper it would be interesting to see how they moved the strips around, but since this was done via Skype a simple wireframe was created in Microsoft PowerPoint. The test went through the scenario step by step. The ATCO looked at the Powerpoint through a shared screen, commented actions and gave feedback.

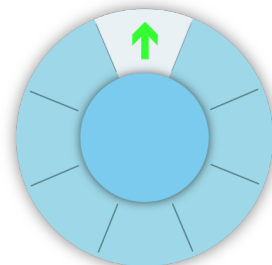




READBACK CORRECT/
CLEARED



ON RUNWAY
LINE UP and WAIT

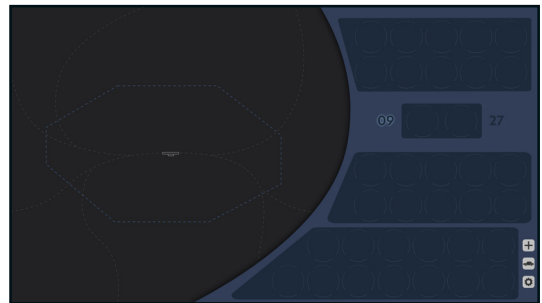


ON RUNWAY
CLEARED FOR T/O

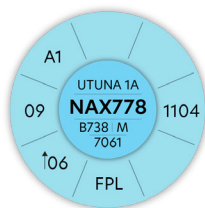
Improving the concept

The user testing of the paper prototype gave interesting results and feedback that gave room for improving the concept. The prototype was designed further with a 40" touch monitor, like what is used in another Avinor ANS project, "Remote Tower". The feedback from the user testing gave more insights to things that were good, and things that needed improvement. For instance, that VFR strips are either black or used to be pink. Remove elements when they are no longer valid, like the stand information that can be removed when the strip is moved to the taxi bay.

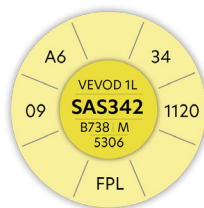
The guidelines for colours said a maximum of six colours with a unique meaning. Even though it is some variations within the colour the concept has six distinct colour variations that assign meaning to the strip, including three for the display to separate different fields.



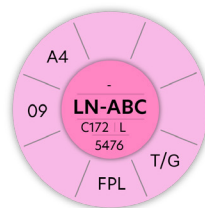
DEPARTING



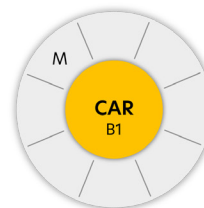
ARRIVING



VFR



VEHICLE



High fidelity prototype

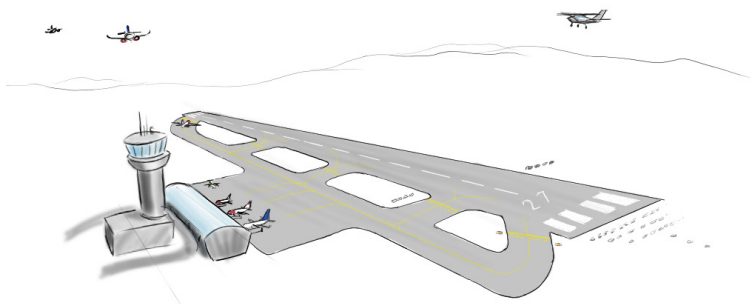
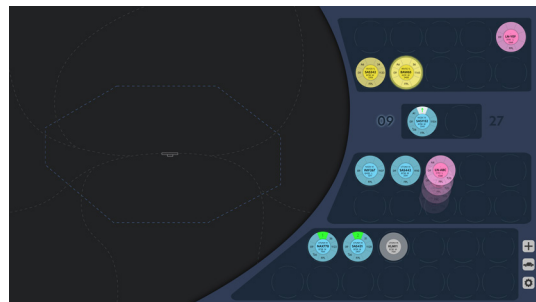
A high-fidelity prototype was made using Adobe XD and tested on ATCOs via Skype. After defining a simple scenario each step was designed and put in a wireframe in XD. An interview guide was written to give the correct flow and order of actions during the user testing.

User testing

By sharing the screen via Skype, the ATCOs were asked to think out loud and describe how they would interact with the prototype. During the test they gave a lot of good feedback on the prototype and what needed improvement.

Scenario

- one Boeing 737 landing
- one Boeing 737 taking-off
- Cessna VFR aircraft - touch and go
- Car driving on the taxiway



The user testing gave interesting feedback on areas that could improve the concept. Feedback from the tests will be looked at more in the next chapter and later in the concept development.

The work done in this project was a good foundation to build on with developing the concept further and exploring how it can fulfil the tasks it is intended to.

More details of the concept and the Flight Plan menu is presented in appendix 2.





Iteration 2

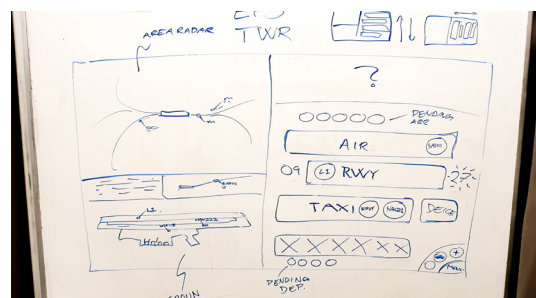
Sequencing

User feedback

One of the challenges during the testing of iteration 1 was the sequencing of aircraft in the bays. It was unclear to users who was first in line, and that this was more visual with strips laying on top of each other. Therefore, more testing was needed to see how the bays could be configured to sequence the strips in a more logical way.

To begin with, a literature search was conducted to look for research or information in sequencing and ordering of information. This was a challenge. Using keywords such as “sequencing”, “order”, “information” and other keywords gave results linked to other research fields and weren’t relevant for this project. Then the decision was made to look at different ways of placing the bays for the best presentation of information and test this on the users.

Sketching on a whiteboard with the correct screen size it was possible to see how much room was available for the strips. This gave some more insight into how the bays could be organized. In new observation it was observed that the ATCOs have two types of radar displays. One to show airborne traffic inside the controlled airspace (CTR), later referred to as CTR radar. And one radar display that shows ground movements, later referred to as ground radar. Therefore, both were added to the concept.



Visualizing the space and drawing in the actual size made it easier to think about different possibilities. One key to this was that the EFS panel should take more space than in the first iteration to get enough strips in the bays.

Sketching

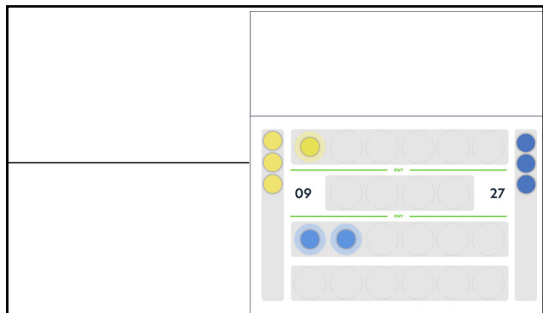
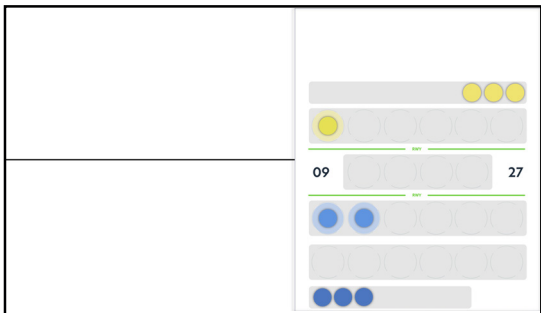
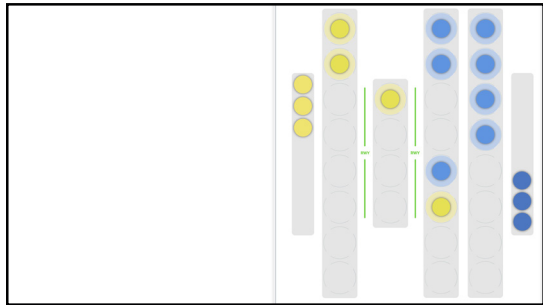
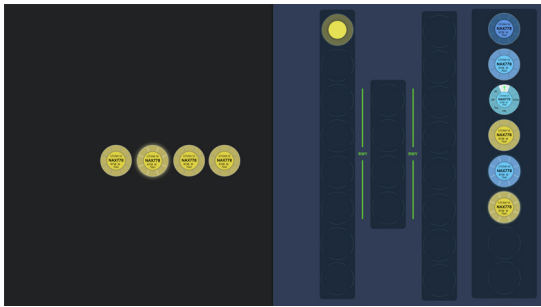
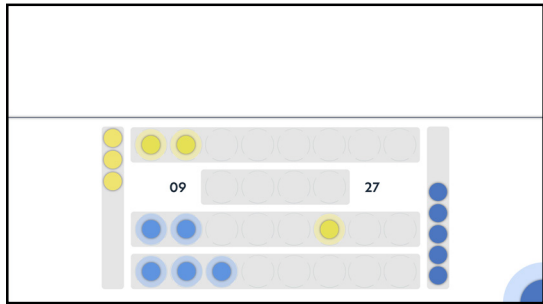
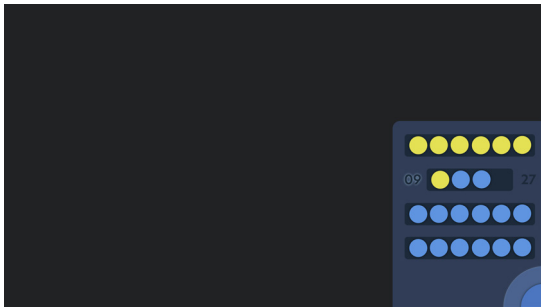
Pen and paper were again used to get ideas on how to set up the panel with a good flow for sequencing the strips in mind. Feedback from the user testing was to have the strips as labels, directly on the radar display, but in the sketches this idea seemed to acquire too much space to make it work in a good way.



After sketching different layouts, three styles with horizontal and vertical bays were chosen to see which were preferred by the ATCOs. To minimize confusion bays with two rows was changed to one row.

The horizontal bays were a simplification of iteration 1 with more space for radar displays and additional information. The point of these are also to have a similar picture on the screen as the visual look-out from the tower. The vertical strips were included to test a representation similar to how FPS is moved today, by moving up and down the bays.





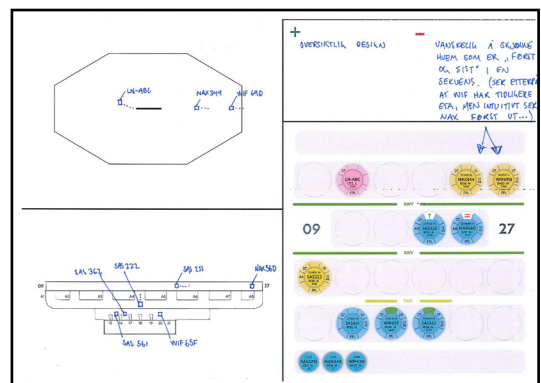
Testing sequencing

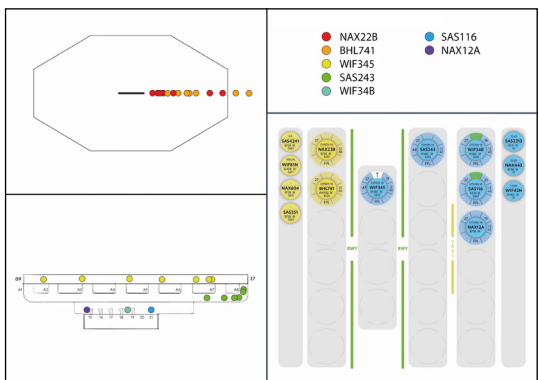
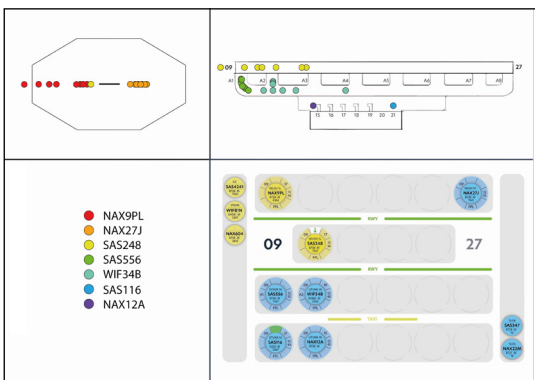
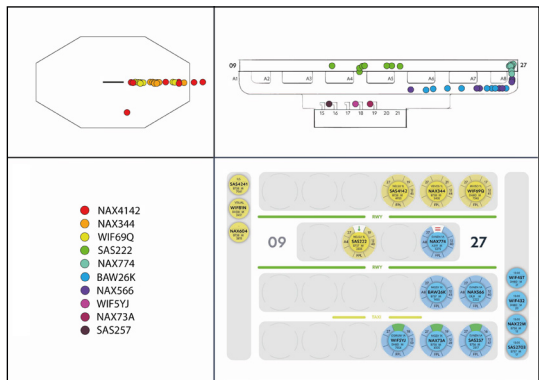
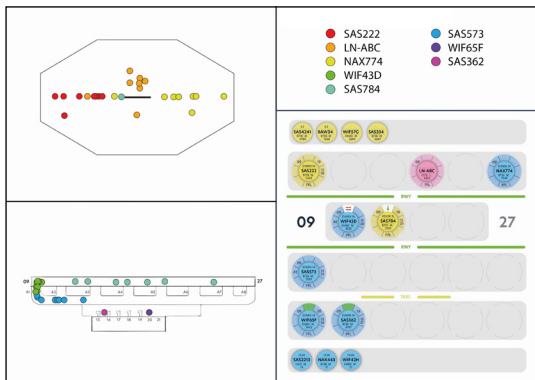
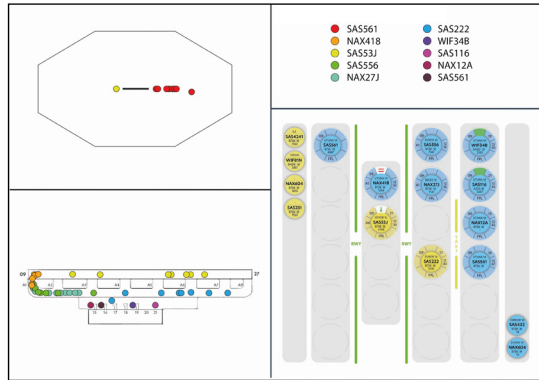
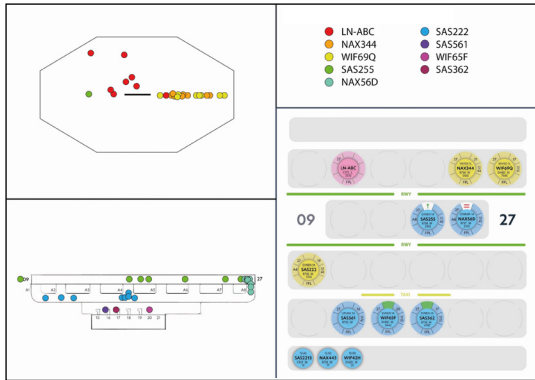
With multiple layouts and ideas, the choice was simple and straight-lined bays. But because of the challenge with understanding the order of aircraft a test was created. The test looked at what layout would be best to perceive the traffic situation. The test showed different kinds of traffic in different bay configurations.

The test consisted of eight pages. First a description with information about the project and the goal with the test. The main test presented six different configurations of an EFS panel with strips placed at different places, and blank “radar displays”. The task for the ATCOs was to look at the EFS panel and draw up the traffic in the radar displays. By doing this, it was possible to see if the ATCOs got a correct mental picture of the traffic situation, based only on the EFS panel.

With different configurations it was possible to see what layout gave the best result. To reach as many ATCOs as possible the test was created to be filled out on paper like a questionnaire. This meant that ATCOs were free to take the test when it suited their schedule.

On each page the ATCOs had the possibility to write positive and negative feedback about the configuration. The last page of the test had a set of questions to give general feedback of the whole test.





Analysis of results

Going through the results, it was interesting to see that the design gives a good presentation of the air traffic. This is based on how the participants placed the labels only by looking at the presented EFS-panel.

The results from each test sheet was plotted into one sheet giving each strip a separate colour. This gave a good visualization of how each participant had placed the labels compared to each other. Collecting all answers reveals clusters and small variations in where the labels were placed. A weakness with the test is that the variation on placement and amounts of strips makes some sheets simpler and doesn't give the same trouble with sequencing.

Both horizontal and vertical strips seem to give good representations of the traffic based on placement of labels. The main challenges are still to sequence strips in taxi and airborne bays. The results show that most labels are sequenced correctly, but still a few perceive the order wrong. One way to solve this can be to use arrows in the bays, as suggested by one participant. The results are presented better in appendix 3.

With these findings, the next step was to go into specializing the system for different airport's needs, starting with Stavanger airport, Sola.

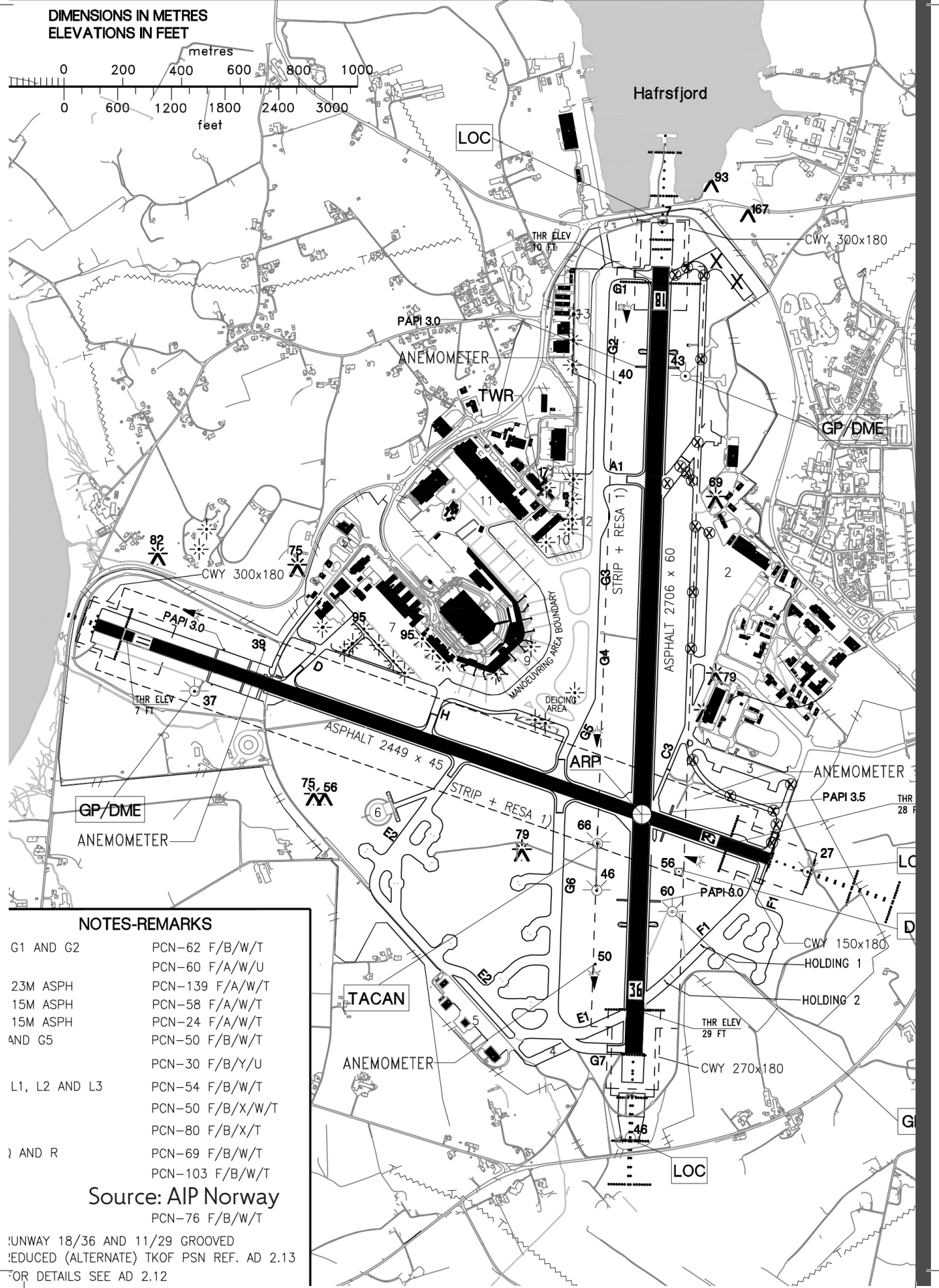
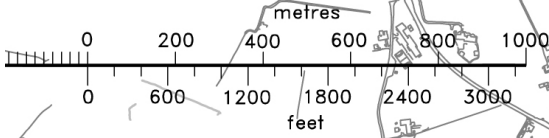
Presentation of "strips" horizontally was easiest to understand because this was most intuitive.

Would like more Flight plan information in the VFR strip.

The horizontal bays with vertical pending bays worked best as the active bays corresponded with my perception of runways, and it was cleaner with separated pending bays.

NOT the vertical bays

**DIMENSIONS IN METRES
ELEVATIONS IN FEET**



G1 AND G2	PCN-62 F/B/W/T
	PCN-60 F/A/W/U
23M ASPH	PCN-139 F/A/W/T
15M ASPH	PCN-58 F/A/W/T
15M ASPH	PCN-24 F/A/W/T
AND G5	PCN-50 F/B/W/T
	PCN-30 F/B/Y/U
L1, L2 AND L3	PCN-54 F/B/W/T
	PCN-50 F/B/X/W/T
	PCN-80 F/B/X/T
) AND R	PCN-69 F/B/W/T
	PCN-103 F/B/W/T
	PCN-76 F/B/W/T

Source: AIP Norway

UNWAY 18/36 AND 11/29 GROOVED
 REDUCED (ALTERNATE) TKOF PSN REF. AD 2.13
 FOR DETAILS SEE AD 2.12



Stavanger Airport

Crossing runways and
complex traffic

Stavanger Airport, Sola

The airport has two runways, one facing north - south, and the other facing east - west. The runways are crossing which presents an extra challenge of keeping track with the traffic and operations on the runways. Sola has a complex traffic situation with both commercial aircrafts, offshore helicopter traffic, general aviation aircraft, and an air force base for the rescue helicopters. They also have much helicopter traffic that isn't offshore. This is both tourist traffic and other helicopter activities, with a base for several helicopter companies. The general aviation community is also very active. They also have a lot of birds around the airport.



Photo: Google Maps



Observations

In February a trip was arranged to learn more about two of the airports in Norway that has a challenging traffic situation and with special needs. These two airports were Bergen airport Flesland and Stavanger airport Sola. Both airports have challenges in operation and traffic that are interesting to look at in this thesis.

The biggest challenge to address is at Stavanger where the airports has two crossing runways that are affected by each other. The intention was to look more at the four biggest airports in Norway, Oslo, Trondheim, Bergen and Stavanger and look at how the needs for the different airports changes the design. But working with crossing runways and design for Sola has been a lot in itself. Because of the research and observations of Flesland a design proposal for this airport will also be presented later in iteration 4, to show how the system could work in a single runway airport.

In the observations at these two airports, visits to both towers gave insights to their use of FPS and how their workflow and challenges are different from other airports. One of the main differences is the complex traffic situation, especially in combining fast jets with slow helicopter traffic.





Observing from the cockpit

Along with the observations in the towers at Bergen and Stavanger there have also been some observational studies from the other side of radio communications.

By asking the crew members on board the flights I got the opportunity to sit in the cockpit from Bergen to Stavanger, Stavanger via Bergen to Trondheim, and later on a flight from Oslo to Trondheim.

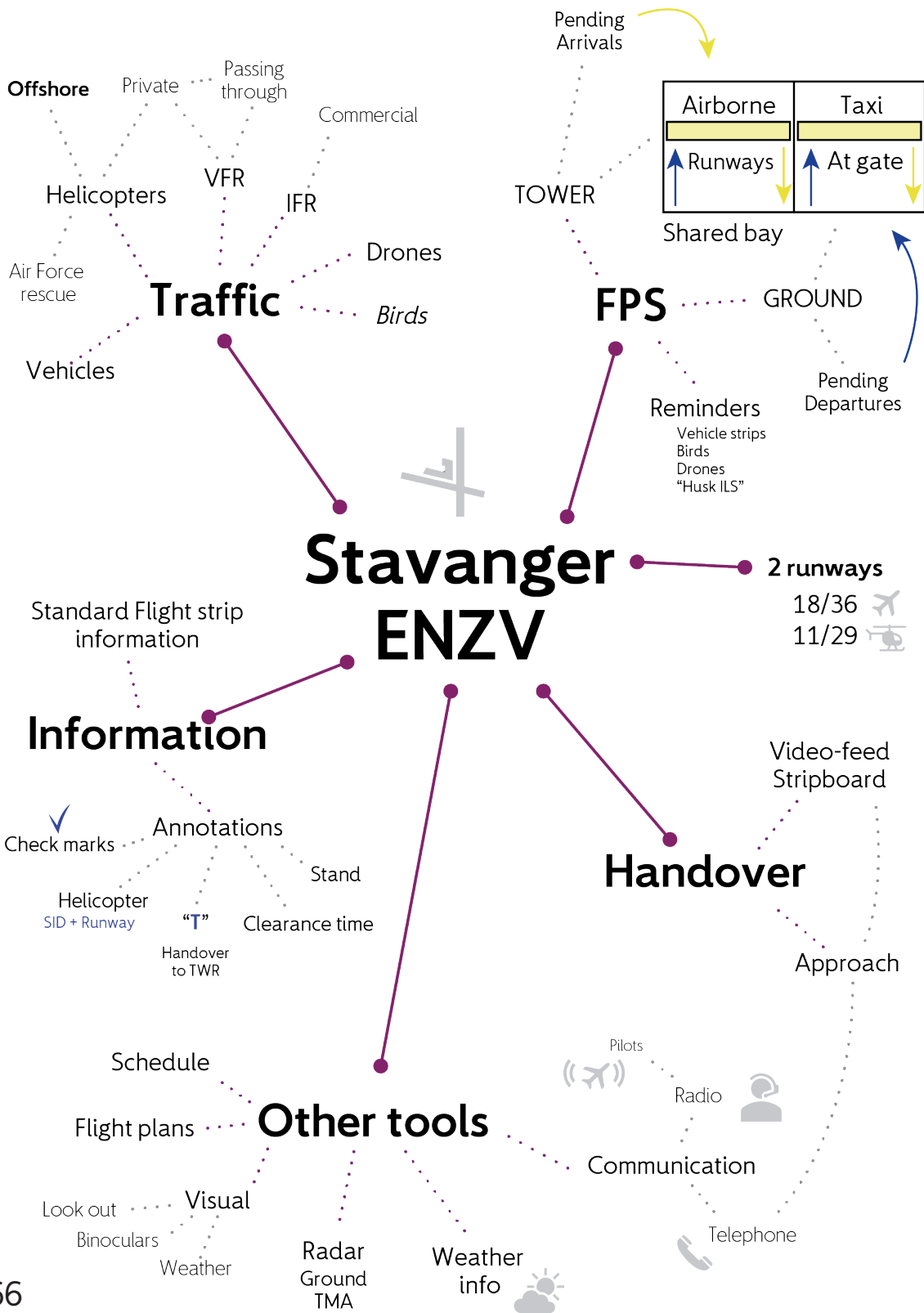
The flight with Widerøe to Stavanger gave insights to the operations during approach and landing at Stavanger.



Operational factors

Following the guidelines that was set in the literature review, the user needs at Sola are set into operational and environmental factors. An overview is shown in the mind map on the next page with more detail in the bullet points.

- Operations are divided in TWR and GND.
- They use one shared FPS panel for all active aircraft on runway and taxiways. This panel is videostreamed to Approach.
- The strips are handled in one runway bay. And because of the two runways it can be as much as **four** strips in the active runway bay at once.
- Different strips for dividing the bays to show which runway is in use. With TAXI to either RWY 18, 11, 36 or 29, in addition they have one extra for 18 or 36 that says the active runway for helicopter operations.
- It may happen that they change from RWY 18 to 36 for one aircraft that requests that. For ILS to work, it has to be changed from 18 to 36, because it only works in one direction. As a reminder a strip marked with “Remember ILS!” is used to remind the ATCO to change the ILS system back to 18 after the aircraft has landed.
- Both GA traffic and the Air Force may do touch-and-go landings, and this is counted by marking the strip with [TG: IIII] and putting a line for each T/G.
- The Air Force rescue helicopter may conduct exercises that require fields for inserting information about what exercises they are doing around the airport.
- If De-icing is needed a strip is put in the rack to create a new de-ice bay.



Runways



Runway 11/29 is used for helicopter operations.

- Helicopters taxi to the runway intersection and lines-up before taking-off from the runway.
- For RWY 11, take-off is done via intersection H*, and for RWY 29, it is done via intersection D*.

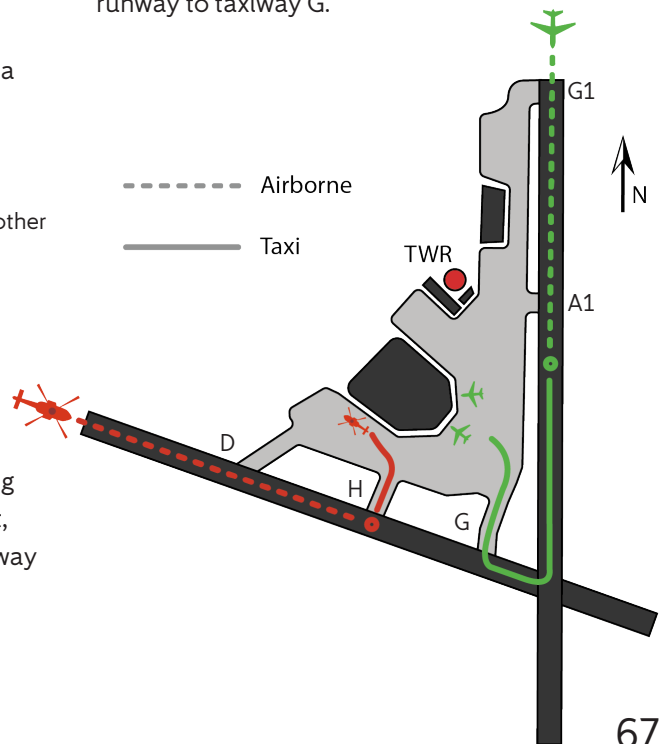
*Helicopters can get taxi form the other intersection as well if it's available.

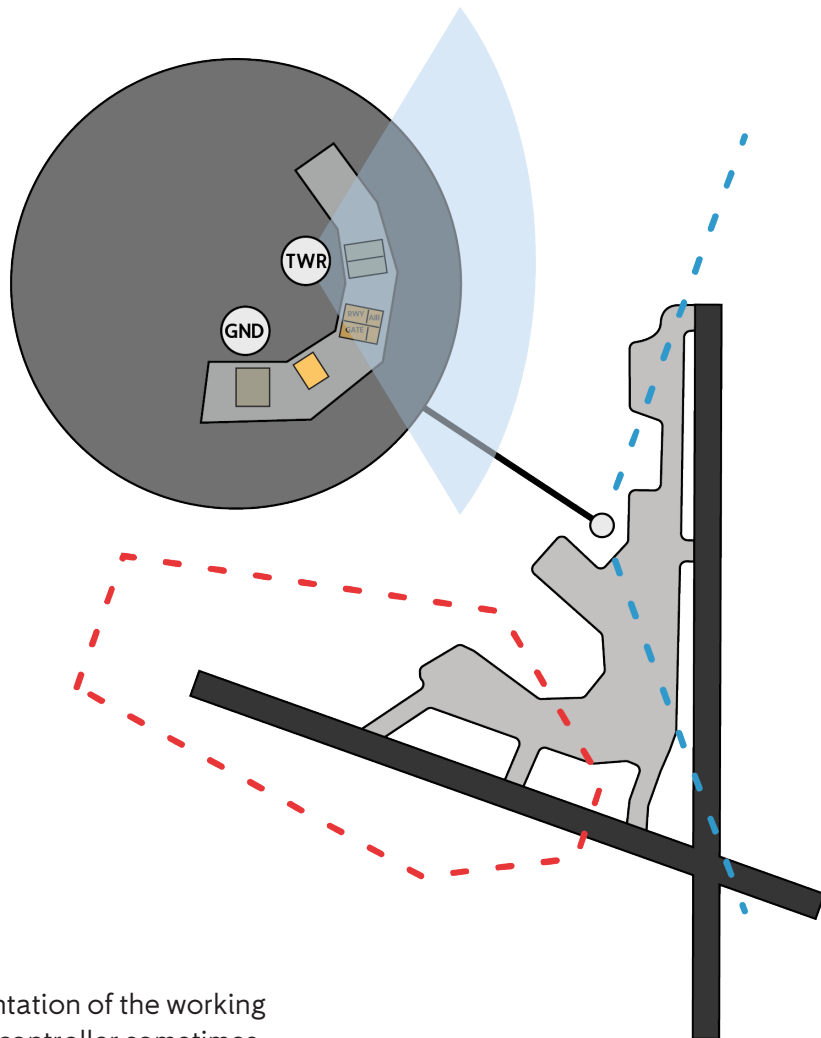
- Helicopters fly the same landing approach as fixed wing aircraft, touching down beside the runway intersection.



Runway 18/36 is used as the main runway for fixed wing traffic.

- Aircraft taxi from parking via taxiway G to intersection G1 or A1.
- Aircraft landing 18 touches down and turn right on to Runway 11/29 before making another turn of the runway to taxiway G.





Because of the orientation of the working positions the tower controller sometimes needs to stand up and turn around to get visual look-out of traffic coming in on runway 11, this means moving away from the table and radar displays for some time. Radio communications are on loudspeakers and the ATCO can quickly get back to position to respond to a call.



Special annotations

Delivery: time of contact, stand number, flight level/altitude, line under transponder code. Helicopter strips are also annotated with SID and Runway.

During taxi: “T” = handover to TWR.

Take-off/Landing: Line crossed over the callsign square.

VFR: Contact time, waypoint/passingpoint. Arriving aircraft: Stand (with circle after read-back), some have an arrow down for “cleared to land” as well as a line over the callsign.



Team operation

In the observations at Værnes, one ATCO was working both the TWR and GND position with support from the supervisor. In the observations at Gardermoen, Bergen and Stavanger the work stations were divided with one ATCO controlling TWR and one GND.

At this point a decision was made to look at two types of the design. Because of the working load at bigger airports they should be split in two positions, and the focus for airports like Stavanger and Bergen should be to design screens that are suited for each position. A single operation design will be made because it can happen that only one ATCO is controlling everything. This also allows user testing of the whole scenario with one ATCO.



Shared situational awareness

When two ATCOs are working together to control traffic at different places at the airport it is important that they can coordinate with each other. Having this team operation, the situational awareness (SA) needs to be high. SA is defined in Appendix 1. Endsley and Jones have looked closer on what is necessary to achieve shared SA in teams. They define three important features when working in teams. Teams have a **common goal** where each person has **specific roles** and the roles are **independent** (Endsley & Jones, 2012).

Endsley and Jones continues to define Team SA as “the degree to which every team member possesses the SA required for his or hers responsibilities” (Endsley & Jones, 2012).

For this thesis it is important to look at the shared SA requirements between the GND controller and the TWR controller. Using the operational factors and observations done in the project some individual and shared SA requirements are defined below.

TWR

- Handle airborne traffic
- Handle traffic on the runways
- Takes over aircraft as they taxi to runway intersection
- Give clearances to go onto or pass the runway
- Give take-off/landing clearance
- Handover traffic to Approach
- Handover arriving traffic to Ground

BOTH

- Use ATIS and weather information
- Handles and talks to vehicles
- Safe operation
- Create new strips

GND

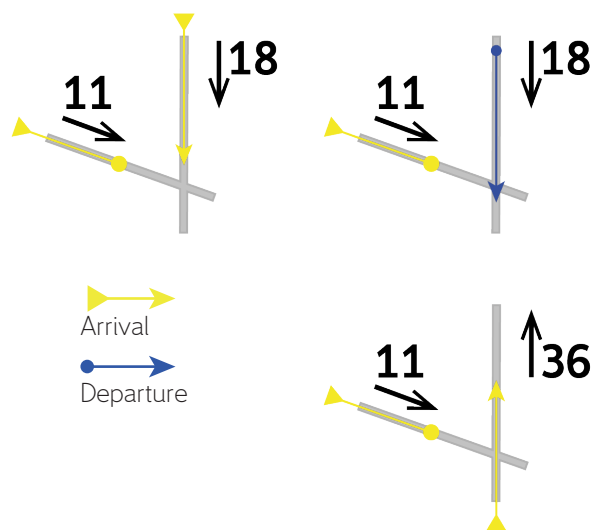
- Handles ground movements
- Give delivery clearance
- Give push and start-up clearance
- Give taxi clearance
- Handover to Tower
- Guide aircraft from runway to gate/parking

Runway incursions

The ATCOs at Stavanger told that they can have as many as four (4) strips in the active runway bay at once. One challenge is to make it clear what aircraft is on or cleared to which runway. If this isn't done it can potentially give a runway incursion. Schönefeld and Möller describes a runway incursion as “occurrences at an aerodrome that involve the presence of an aircraft, a ground vehicle or a person on the protected area designated for the landing and take-off of aircraft” (Schönefeld & Möller, 2012).

In addition to a runway incursion, another challenge at Sola is that two runways are used mainly by two different types of aircraft. While the fixed wing aircraft has a touch-down point and rolls to a near stop before turning off the runway, helicopters can hover, touch-down and stop at the same point. This means that different scenarios can define if multiple runway operations are possible or not.

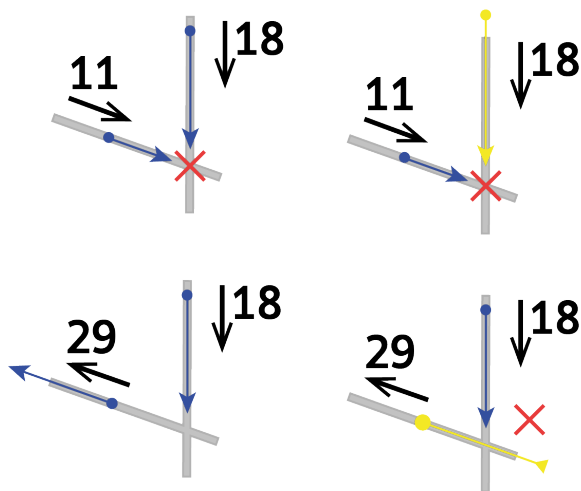
The following definitions are based on observations and assumptions made by the author based on own knowledge within aviation. Depending on what traffic is arriving or departing from the different runways there are many scenarios where both can take-off or land without affecting each other, but there are also situations that can create a conflict. This is when looking at the given operational factor of fixed wing aircraft at runway 18/36 and helicopters at 11/29.



Example:

An aircraft taking-off from runway 18 and a helicopter taking-off from 11. If they both get clearance for take-off it can create a conflict in the air as both take-off and fly towards the point where the runways meet before making their respective turns. Therefore they can't get clearance at the same time and the system should have restriction to prevent this from happening.

But a lot of the time multiple actions can be possible where the ATCO can operate with aircraft landing or taking off on the main runway at the same time as helicopters take-off or land. All possible combinations aren't defined here, but all scenarios should be defined and programmed, so that under the circumstances the system can recognise and warn the ATCO of a potential conflict. In the next chapter, different approaches to how to distinct the individual runway operations are made in designing a solution for Stavanger.

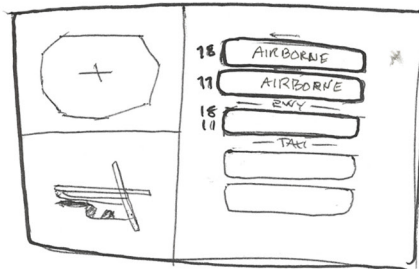
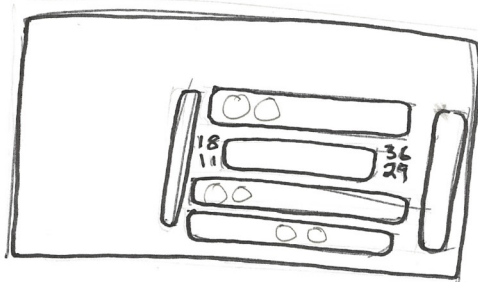
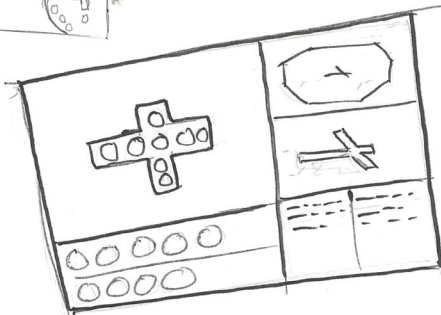
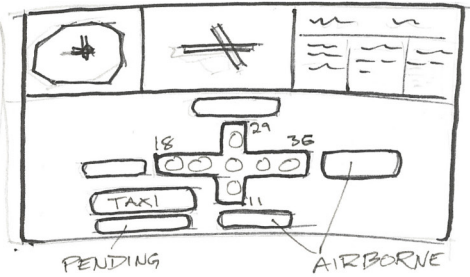
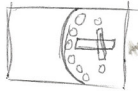
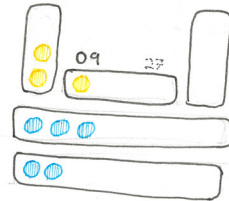
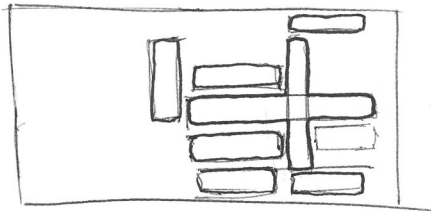
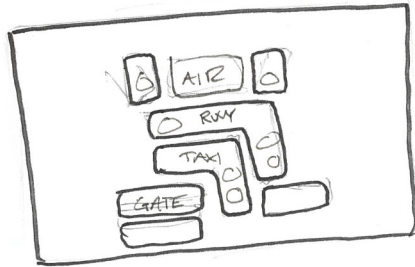
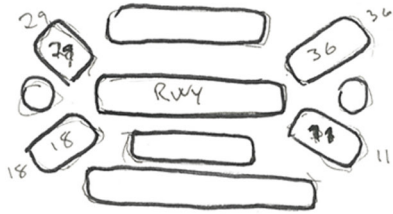
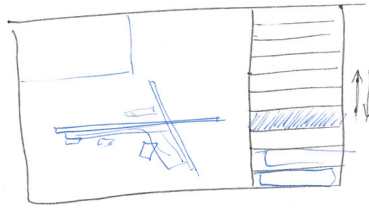
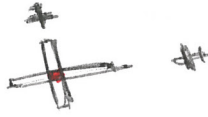
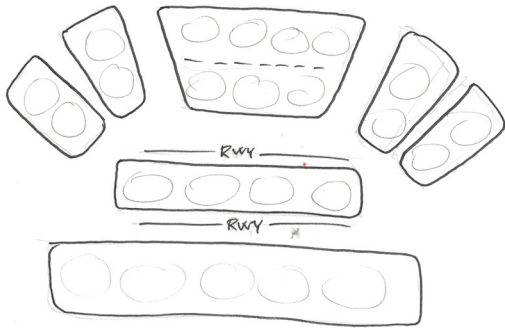




Iteration 3

Designing for Stavanger Airport Sola

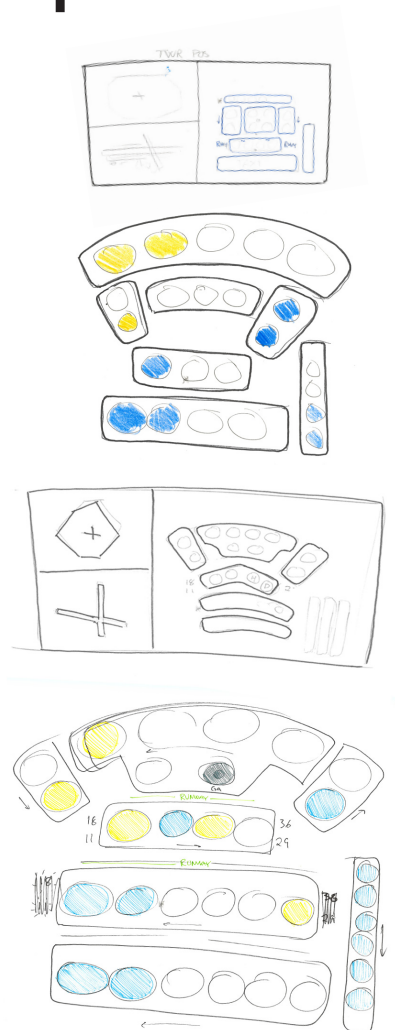
Photo: Tommy Bernes

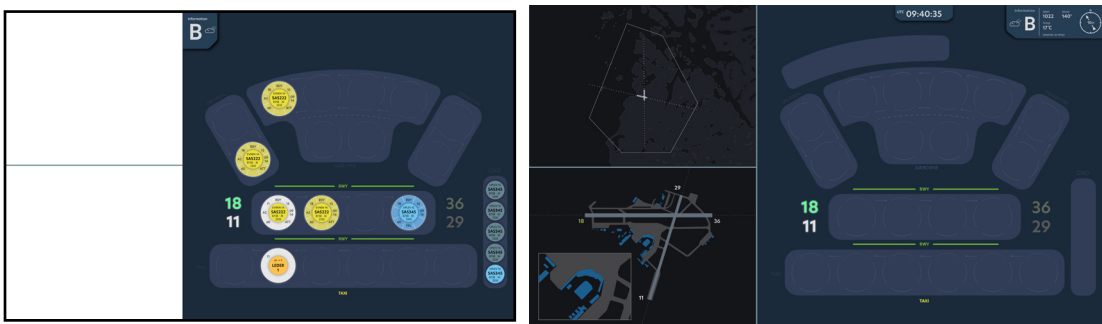
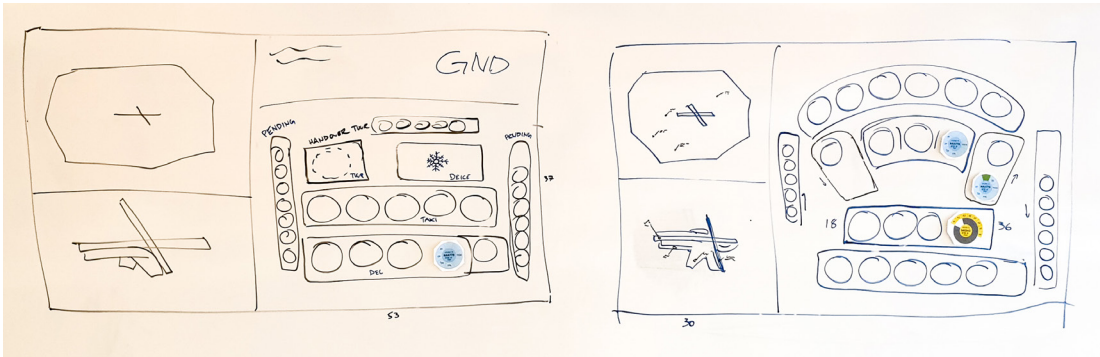


Redesigning the EFS-panel

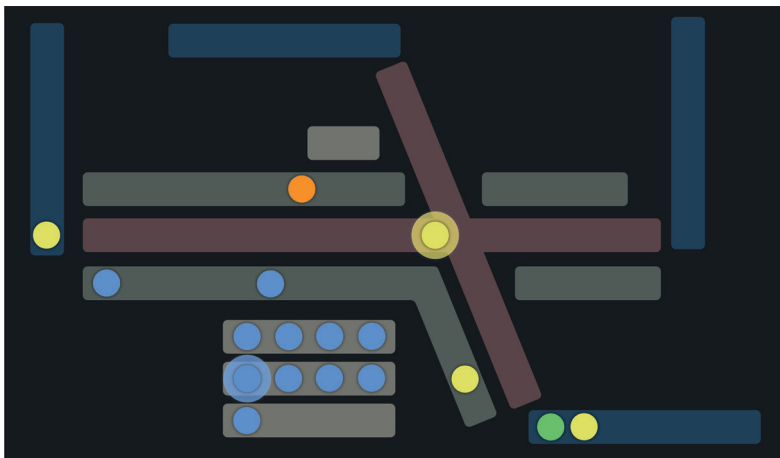
In the user tests so far, presenting the sequence of aircraft in the airborne bay has been a challenge. This was an aspect to look at when designing a new layout that could suit the operations at Stavanger.

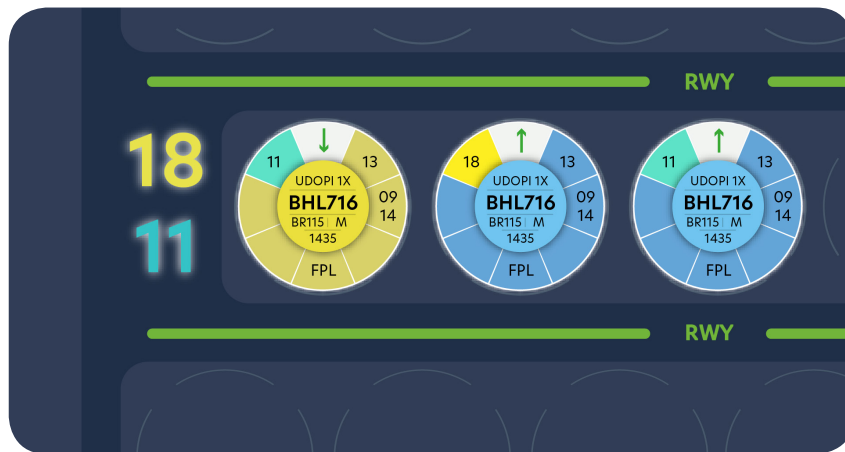
Many different iterations were looked at with everything in one bay, using one approach bay for each runway or variations of this. Some of the iterations are shown on the previous page. Dividing the runways and airborne bays to each runway made the panel messy compared to having it in the same bays. Having a bay for each the approach to each runway takes more space and limits the space for other bays such as the taxi and pending bays.



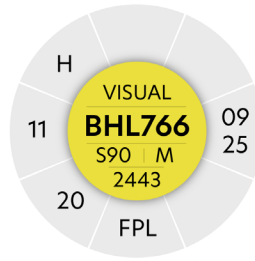
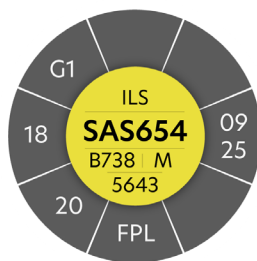
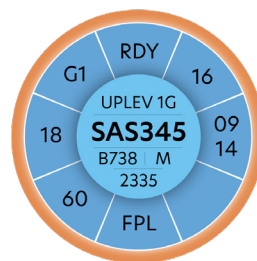
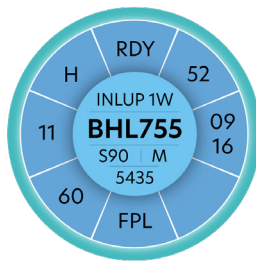


One of the comments during the user testing of both iteration 1 and 2, was that it could be used as the label, directly on the radar display. This was tested using an airport layout with only the small circle displayed. This was not taken further as it means less information is available “at a glance” and it is a question of how the ATCO would engage with the strips and not end up in a monitoring position.





18
11

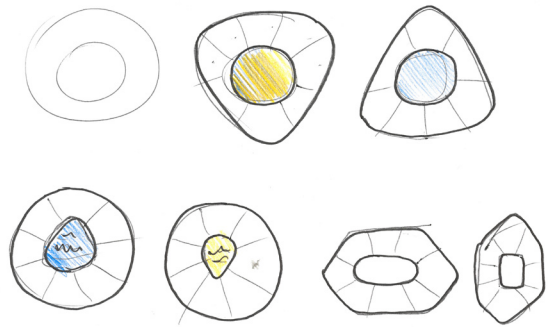


Redesigning the EFS-”strip”

Another way to look at variations for separating strips for different runways was to look at alternative way to design the circular strip. Using shapes to apply meaning to arrival or departure by having a slight arrow shape to them and testing the use of colour.

Testing variations of colour was challenging, as many colours in ATC already display a certain meaning. This made it challenging to choose two colours to define each runway to use on the strips. It was tested as shown, by having a colour for each runway and displaying it in the strip and on the runway numbers. In the end none of these options were developed further.

After some testing the decision was to use the same design with a circular strip, but to have the alternative runway stand out more in the runway space. Some variations on colour was also tested to see different ways of separating the strips. Using icons to define the runway space was tested as well.



Developing the design

For the user testing it was important to be able to test the whole scenario from both the TWR and GND operations. To do this it was easiest to create a single operation design where the ATCO has control over all tower operations, and that these can be divided to the individual positions tasks when the operations are split. During development, both single and team operation has been looked at. After presenting the overall concept, differences in split operations are described. The focus has been the tower part of the design, as this is challenging with both airborne and taxi sequencing.

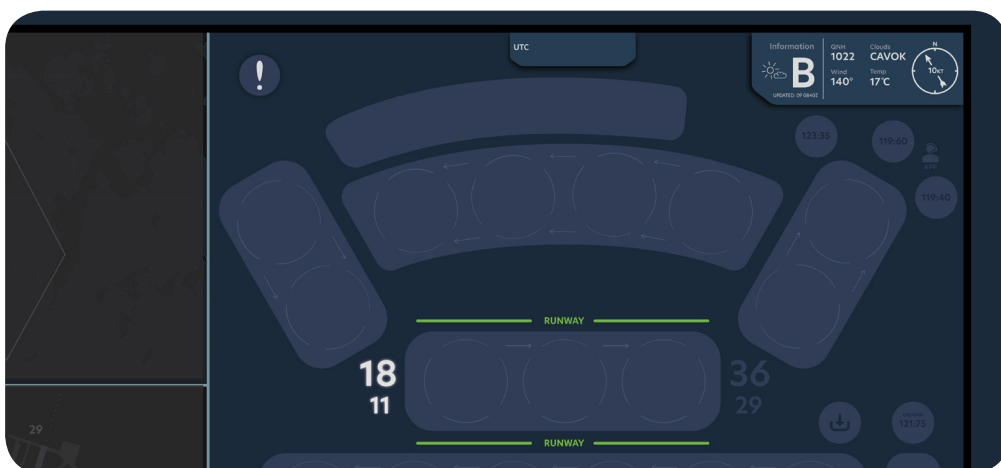
Compared to the first iterations this prototype has more added features that are described more in detail. These added features give more input on the strip to support the ATCO with better SA and administration of given instructions.

New EFS Panel

Bays

Using the results and feedback the design of the EFS panel was made with a vertical bay for the pending departure strips and the delivery, taxi and runway bays horizontally. To better visualize the airborne aircraft this bay was split in three different categories. Two of them are angled 60 degrees out from the runway bay. This is visualizing the way the aircrafts either climb after take-off or descend for final approach when landing, shown in the figure to the right.

Between is an arc shaped bay to have space for traffic that is under control, but not immediately landing or taking-off, or passing inside the control zone. This can also be VFR traffic on touch-and-go, or if there are more aircraft coming in at once.



The two runways are represented on one bay, this is because they overlap and splitting them can make it harder to spot a runway incursion or possible conflict, as described earlier. For the single operation design the runway bay is limited to three available spaces, as there is more traffic to control than in a split configuration.

To get a systemized flow to the sequencing, small arrows are added to give direction and a line for the que.

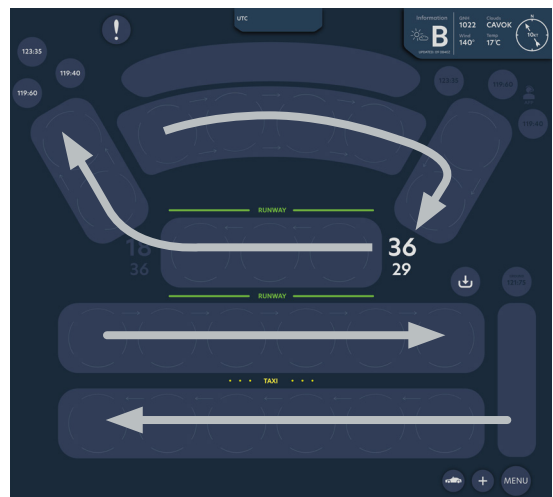
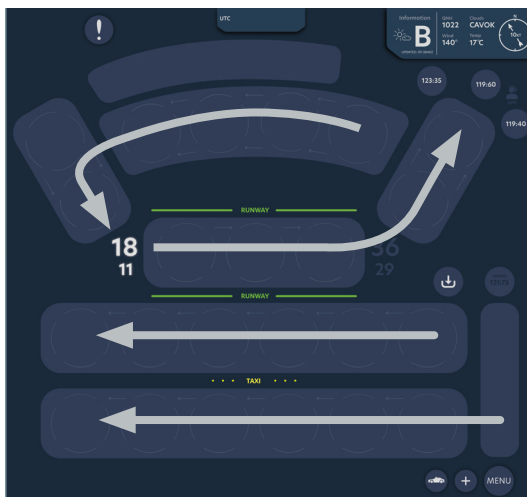
The space between slots for strips is increased to prevent a window from overlapping with another strip when it is opened.

As Runway 18/36 is used as the main runway these numbers are made larger than the crossing runway 11/29.



To represent the traffic, the idea is that when the main runway is switched, the flow of strips changes to follow the orientation as it is viewed outside. It means that departure becomes final, and the same the other way around. This hasn't been the focus in this thesis, but it would require simulator testing to see if this would work and how things should change when re-orienting. Will it be logical or very confusing?

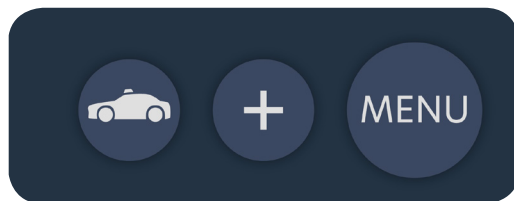
During preparations for user testing it became clear that the design was made towards the scenario and observations made at Stavanger. The pending bay and handover bays were only designed for operations using runway 18. Changes were made to make it more symmetrical with a centred arrival pending bay and handover bays on each side of the panel.



Buttons

On the top left side is an attention button, where important notifications to the ATCOs can be highlighted and shown in a textbox. The buttons in the low right corner are redesigned to fit more with the concept. The menu has not been defined, but the idea is to get a more detailed menu to edit configurations and systems.

To separate the buttons and info boxes from the bays in the EFS-panel, they have a drop shadow effect. This effect is called skeuomorphism, and is defined by Rose as, “visual metaphors that are aspects of design used to aid the user in perceiving affordances based on prior knowledge and experience of interaction with physical objects”. This means that digital surfaces get traits from real life objects to make them easier to understand (Rose, 2013). Shadow can be useful to emphasize the affordance for buttons to make them look like objects that can be manipulated (Ware, 2004).





*This is Værnes information ALFA
Runway in use 27
Transition level 75
Met report time 0820
Winds 260 degrees 06 knots,
visibility 10 km, scattered 1500
feet, broken 2500 feet,
temperature 14, dewpoint 10,
QNH 1003,
departing traffic contact tower on
119,4 for start up
This was information ALFA*



(Hårstad et al., 1999)

**”Tower, Scandinavian 225,
request clearance to
Gardermoen with
information ALFA**

Weather information

ATIS (Automatic Terminal Information Service) is an automatic information provider on the airport that gives metrological and operational information. This information starts with an alphabetic letter, followed by runway in use, winds, clouds, temperature, pressure and radio contact information. This is used to reduce radio communication by making all information available through a radio message. When the pilot calls-up the tower for its clearance, they call up with the information they have from the ATIS. Depending on the letter they give, the ATCO knows if the pilot has the most updated airport information (Hårstad et al., 1999).

This information is used when giving clearances and is useful to have displayed on the panel. It shows the information letter with the time it was updated and an icon to describe the weather. Divided with a border, the menu shows real-time weather information with pressure, clouds, temperature, wind direction with a compass symbol to visualize the wind direction and the strength in the arrow. The idea is also to make it possible to tap the box to get more detailed information if needed.

Information  B	QNH 1022	Clouds CAVOK	
	Wind 210°	Temp 19°C	
UPDATED: 09 0840Z			

The information box with information about weather conditions can have features to alert the ATCO of changes that affect traffic, like if the wind direction changes and they need to change runway. An idea to display this is to turn the wind-arrow yellow when the direction deviates much compared to the information in ATIS. If the information is unchanged for a long period of time without being noticed, the arrow can turn red to take more attention. This should only be presented when the weather changes significantly.

Information	QNH	Clouds	
	1022	CAVOK	
	Wind	Temp	
	140°	19°C	
B	UPDATED: 09 0840Z		

Information	QNH	Clouds	
	1022	CAVOK	
	Wind	Temp	
	210°	19°C	
B	UPDATED: 09 0840Z		

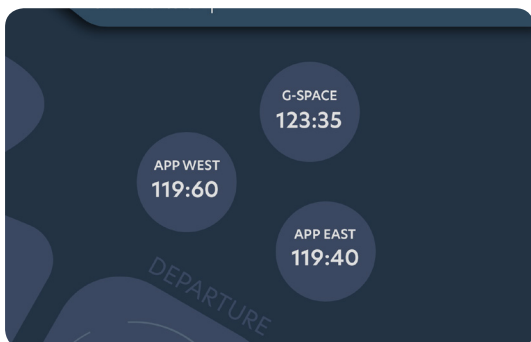
Information	QNH	Clouds	
	1022	CAVOK	
	Wind	Temp	
	210°	19°C	
B	UPDATED: 09 0840Z		

Information	QNH	Clouds	
	1022	CAVOK	
	Wind	Temp	
	210°	19°C	
B	UPDATED: 09 0840Z		

Information	QNH	Clouds	
	1022	CAVOK	
	Wind	Temp	
	210°	19°C	
C	UPDATED: 09 0915Z		

Handover

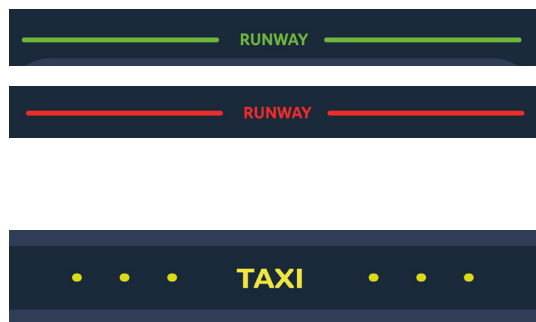
When handing over aircraft to Approach or other frequencies it was mentioned during user testing that it should be registered what frequency the aircraft is dispatched to. An idea to solve this is inspired by the way they use the EFS system at Gardermoen, where they click and drag the strip from the bay, over to different squares that hands over the strip. In this design the handover bays are designed as small circles with a description or icon with a frequency. Then the strip can be dragged from a bay and only be displayed as a small circle until it's approved from the next ATCO.



Taxi and Runway line

The design is divided in bays for each action like the FPS bays today. The runway bay is inspired by the EFS at Gardermoen, using lines above and below the bay with the runway text in the middle to have it clearly defined what is the runway bay. The same divider is made for taxi bay, but here circles are used to separate them from each other, yellow is used based on the taxiway lines at the airport.

The runway line can also turn red to close the runway, if something occupies it, that shouldn't be there, or when vehicles are on the runway.

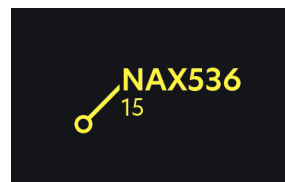


Ground radar

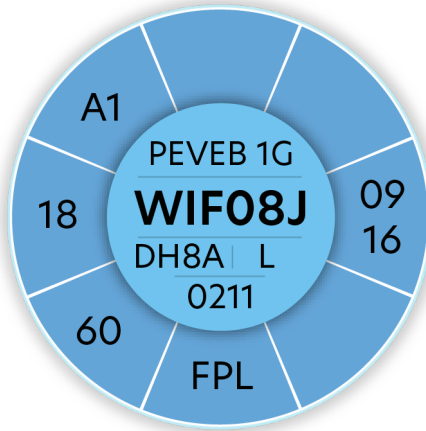
Compared to the first iteration, there is also a ground radar. Not all airports have this, but for the airports that are focused on in this thesis, they have this tool available. This works to give more information in addition to the CTR radar display. The ground radar is placed in the low left corner and shows the traffic movements on the ground, with labels on traffic at the gate, taxiways and runways. For the test this radar was oriented facing east to replicate the orientation the ATCOs see outside their windows, making it easy to visualize traffic as it is out of the window.

The two runways might change the need for orientation and face the map north instead. This is simpler for a single runway airport where the only runway is in front of and parallel to the orientation in the tower. This was tested to see the feedback from the ATCOs.

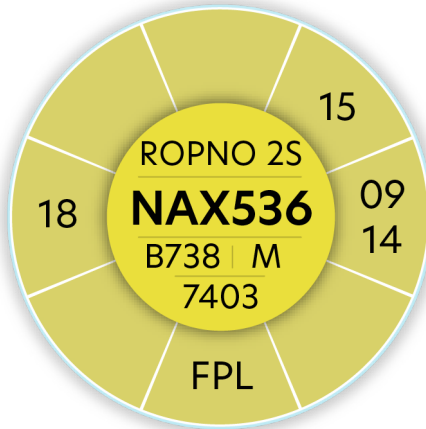
The picture shows the label that identifies the aircraft with the callsign and additional information. Here it shows the stand number, but it can also show the runway intersection, altitude, speed and more.



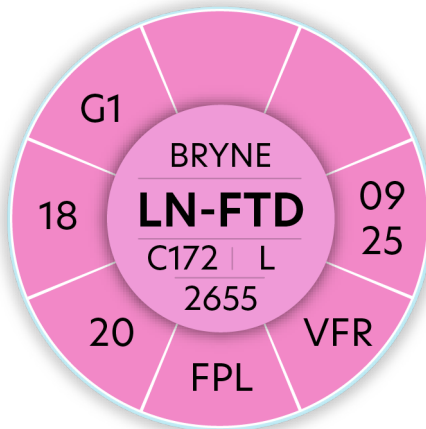
Departing
aircraft



Arriving
aircraft



VFR
aircraft

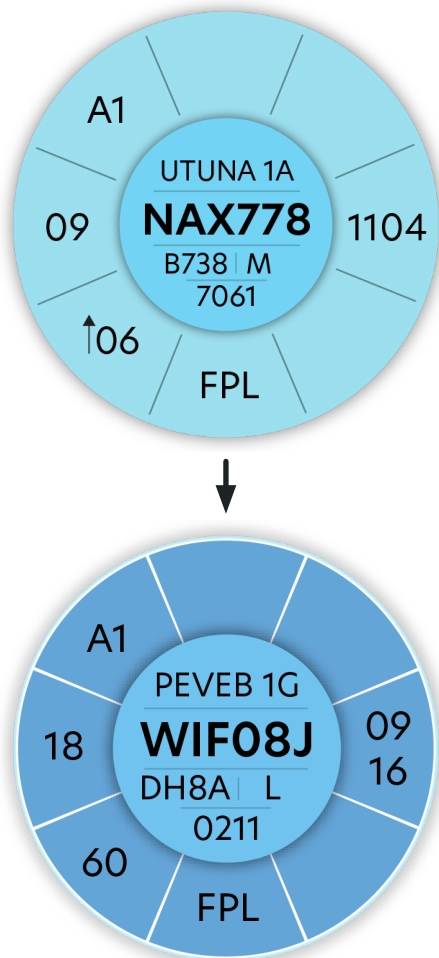


New EFS Strip

Refining the design of the circle

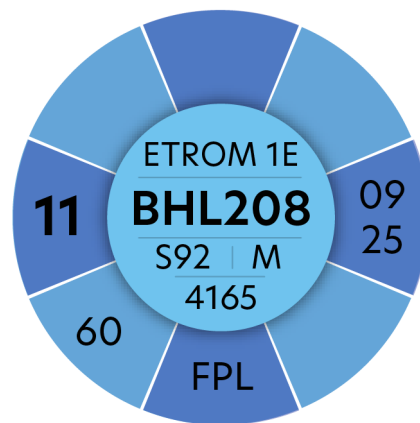
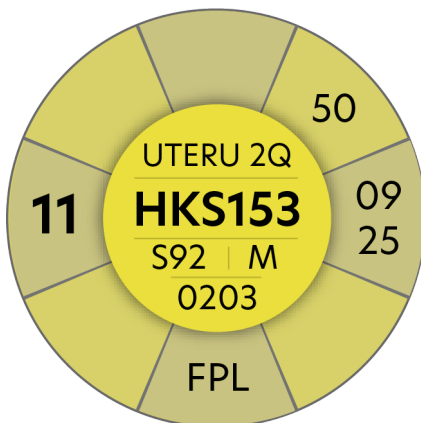
The new design has a more defined edge using white to distinct the circle and have a solid edge for each button on the outer part of the circle. The middle is made bigger to have the text more clearly with more space. The information in the boxes is unchanged. To get a larger text size on the time button, the numbers are displayed on top of each other, like how many smartphones display time.

Without looking more at touch and go's in this iteration, a counter for this can be displayed in the attention field or in the clearance field if other information is needed in the other field.



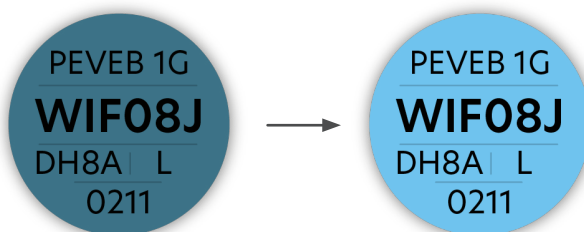
Crossing runway strip

When looking at the ideas for separating the strips for different runways the result was a combination of having the runway number highlighted with bold text and a colour variation in the outer circle.



Pending

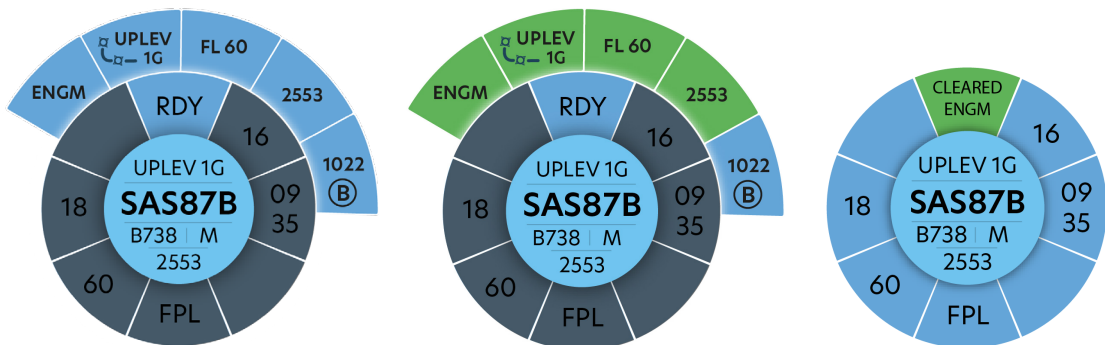
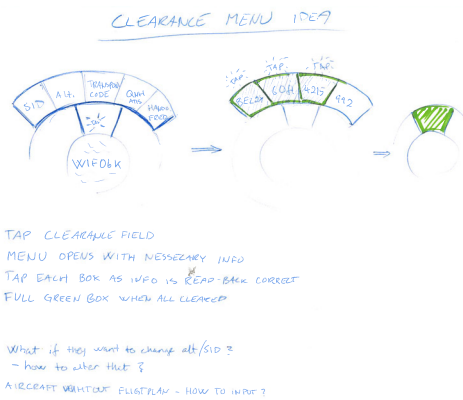
The pending strips occurs in either the departure or arrival pending bays. Here they give information from either GND or Approach to inform the ATCO of upcoming flights. When the aircraft is sent over or ready to be handled on ground they change from a darker shade and light up. Here a simple animation and maybe sound can help to notify the ATCO of a new strip, the same way it is printed out or handed over from the other position.



Clearance menu

From the feedback in iteration 1 there was a suggestion for a clearance menu where information that is given in the delivery clearance could be displayed together. Based on this an idea for the clearance button was developed. The idea is that when an aircraft calls up the tower to get its clearance the ATCO can press the clearance button in the EFS-circle and the menu pops up. This gives the ATCO all the information needed for reading out the instruction, and when getting correct read-back they can tap each item to confirm they have the information.

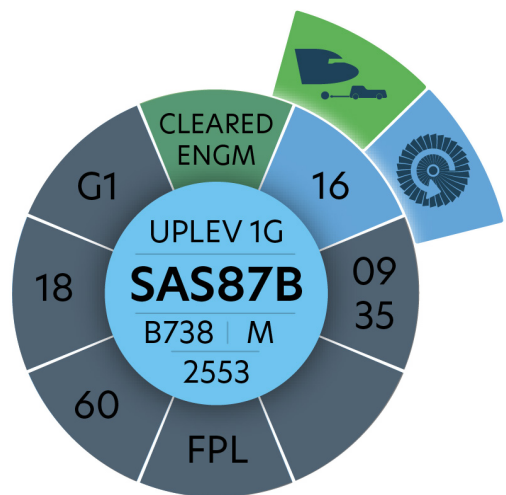
When finished, it turns green to confirm that the aircraft is cleared to its destination. In this example it is “ENGM”, the code for Gardermoen airport.



Push-and-start menu

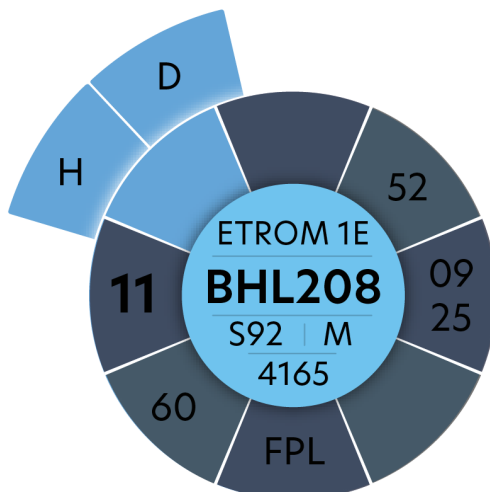
Same as with the clearance menu the pilots call up the ground position to request push-back from the gate and starting up the engines. Here the same feature has been added as in the clearance menu with a verification button for each action. The reason for having one for each is that aircraft sometimes can get a push-back clearance but needs to hold for a while before getting its start-up clearance. Following the guidelines set earlier this was tested with icons to display the meaning of the actions. The icons show a push-back car connected to an aircraft, and the start-up shows a turbine fan with a rotation arrow.

This menu is put outside the stand/parking button. It could have been placed in the clearance button as well, but then the information from delivery would have to go elsewhere. By having this clearance in the Stand-field, all actions can be looked back on with one simple tap.



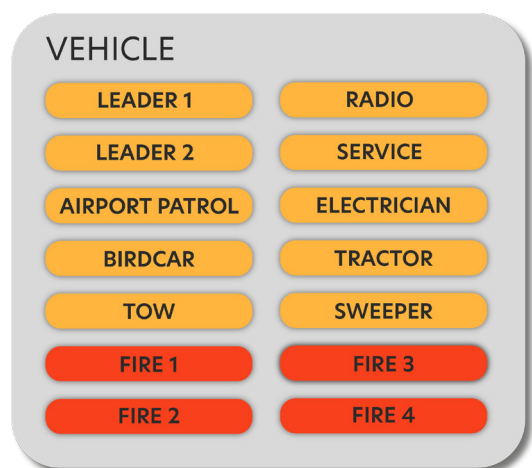
Taxi clearance

Giving taxi clearance works the same way as in iteration 1, where the ATCO inputs the runway intersection when giving the clearance. These are suited to show intersections based on what runway the aircraft is using.



Vehicle strip

This is almost unchanged compared to the first iteration, having a clear separation for the vehicles with an orange centre and a light grey rim. A menu is created to contain the different available vehicles, and either tap or drag the strip on to the panel. In the outer rim, information about intentions can be added.



Create new strip

Push the plus-button down by the menu to open a sub menu. This show upcoming flights that are scheduled but not yet displayed in pending. Below is one button for creating a new strip, a search button and one to close the menu. By clicking the “Create new strip” a new menu is shown to fill out general information about the flight. Typically, a VFR-flight with information to know about the aircraft such as destination, waypoints, cleared altitude, type of flight and a transponder code that is automatically generated. An idea from an ATCO in Bergen was that when a custom strip is created the callsign or aircraft registration will connect to the national aircraft register to automate information about the aircraft type information. Pressing “Create” puts a new strip in the delivery bay.



FILED PLANS

- SAS755 ENVA
- BHL778 ZZZZ
- NAX643 ENGM
- WIF114 ENBR
- SAS254 ENGM

CREATE NEW STRIP

SEARCH

CLOSE

CREATE STRIP

CALLSIGN

DESTINATION

FLIGHT RULES

TYPE OF FLIGHT

WAYPOINT

ALTITUDE

TRANSPONDER

CREATE

CREATE STRIP

CALLSIGN

DESTINATION

FLIGHT RULES

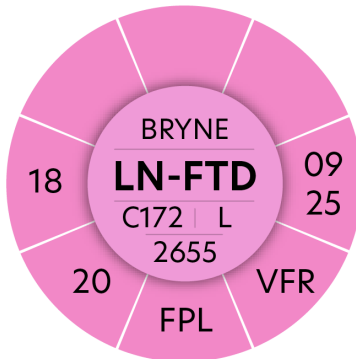
TYPE OF FLIGHT

WAYPOINT

ALTITUDE

TRANSPONDER

CREATE



Single vs. spilt operation

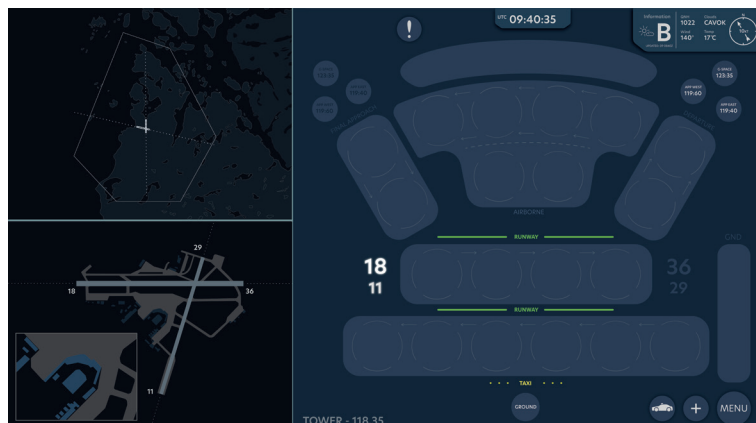
Based on the single operation design the EFS-panel is reshaped to fit better for the individual position's responsibilities, while maintaining shared situational awareness.

Tower

In the tower position the taxi bay is the same size, but put as the lowest bay, as this is the first interaction with departing aircraft.

The runway bay is expanded with four spaces, as the operations are divided. Giving the TWR controller more attention on the runways.

The airborne bay has one difference. In the arc shaped bay, two more spaces for strips are added. At times where they are more ATCOs on duty, the traffic level will also be higher. This can require more available spaces for aircraft inside the tower control zone. The rest of the panel is unchanged compared to single operation.

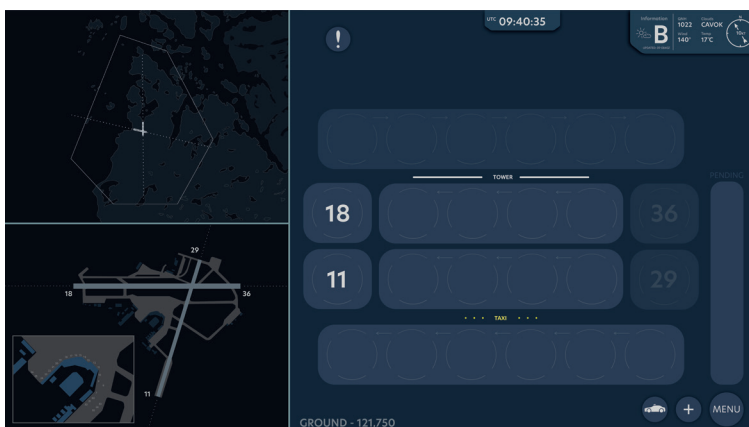


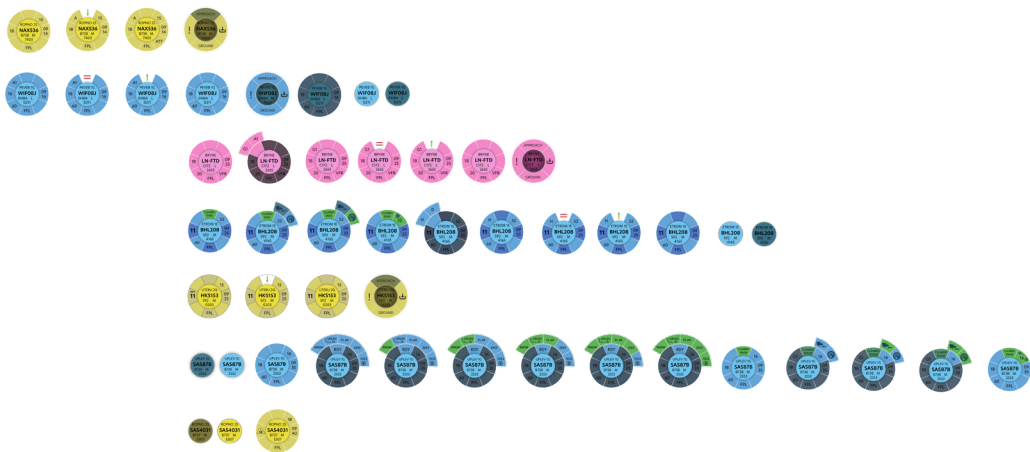
Ground

This position is very different compared to the tower position. The GND controller only controls ground movements, and the airborne bay can be removed. This leaves only horizontal strips and a very different layout, but with the needed presentation. In today's FPS they share the panel, and the GND controller annotates with a "T" for handovers. To handover or send strips between each other in this concept, they have a handover bay where the strip is transferred to the other ATCO. Same as with handovers to Approach, described earlier.

Then a simple animation combined with a sound can help to notify, but it is important that it doesn't take attention away from other activities.

With split operations, more space is available on the screen. For the GND position the full strip is shown on a toned-down bay. This is so the GND position can see more of what is on the strips before handover.







NAX536



A1 18
WIF08J



LN-FTD

G1 18



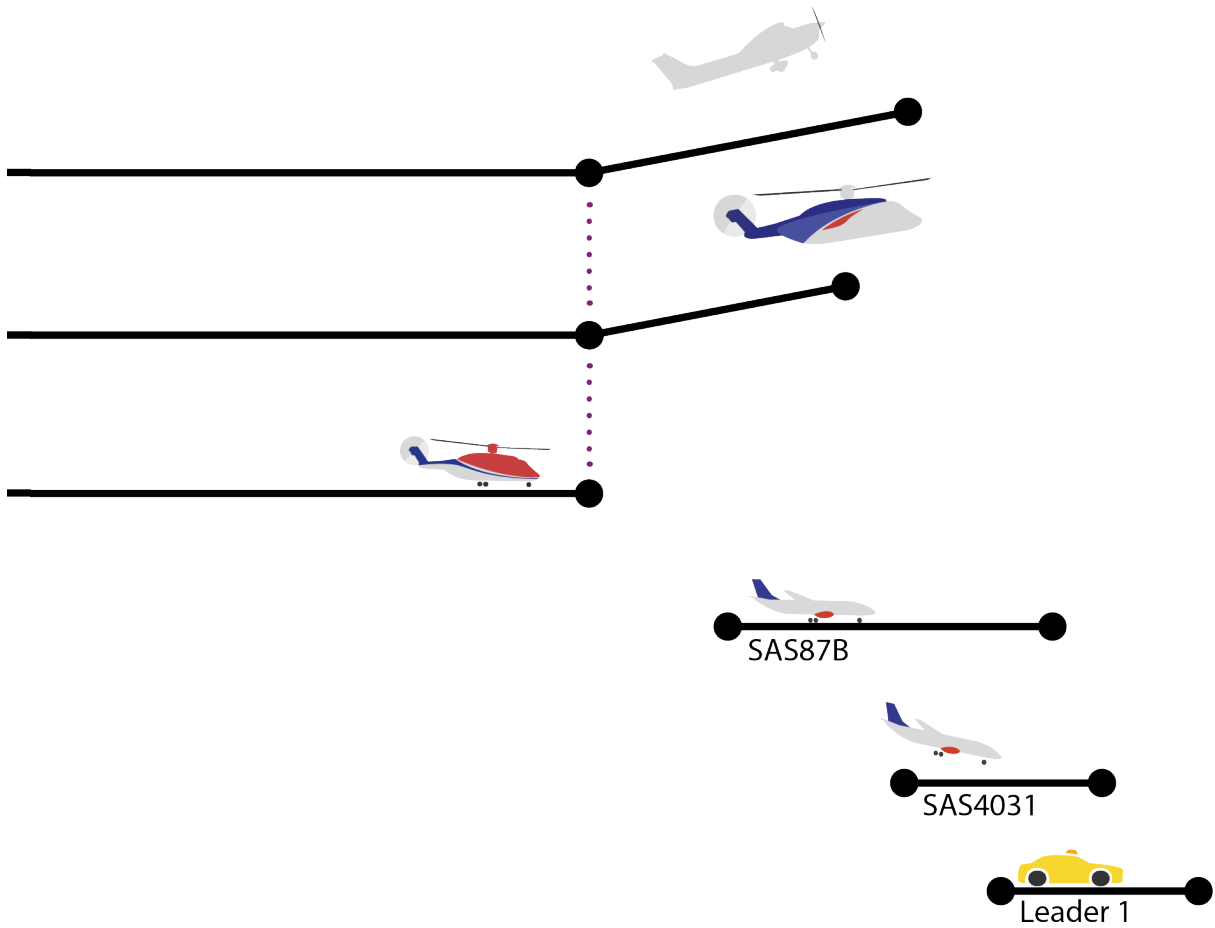
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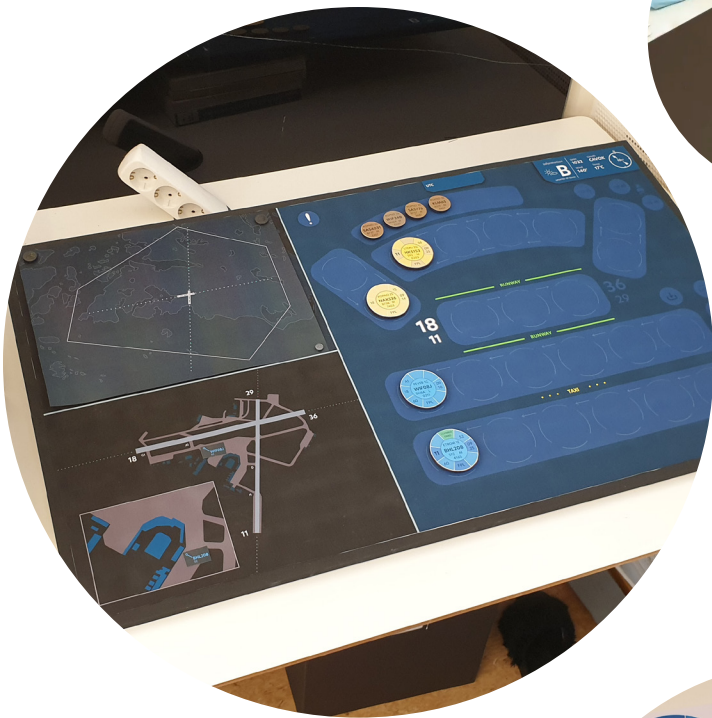
H 11



HKS153

Scenario

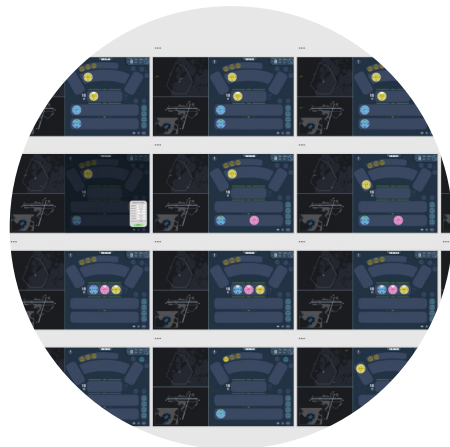




Prototype

To get a simple, functional and full scale prototype a decision was made to create it physically. Cutting out a board in MDF and painting it with magnetic paint gave a surface for the screen. The EFS-concept was printed out with a plotter in the correct 40" size and placed on the magnetic board. With the laser-cutter, circles were made to create the strips. Using magnets on the back of the circles made them stick to the surface and slide with ease.

The advantages with this prototype are that it enables the ATCOs to move strips where ever they want, and the test can be adapted to their actions. Because it is physical it means all changes are done manually, so changes on the strips are different, but the idea is presented. Changes that occur on the screen are more obvious as they need to be changed by the facilitator during the test. In addition, an Adobe XD prototype was created to do testing digitally using Skype.



User testing

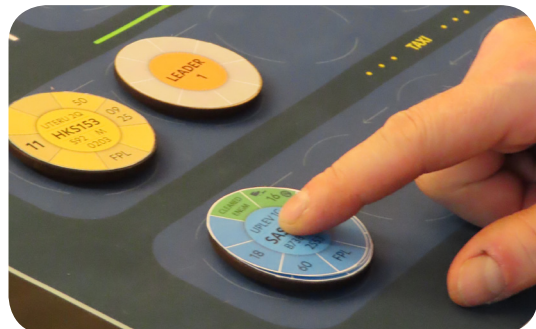
In cooperation with my contacts at Avinor ANS a testing day at Værnes was organized to get user feedback from ATCOs on the prototype. A meeting room in the tower facilities was rigged for testing where the ATCOs came in and sat in front of the prototype.



In total, six user tests were conducted on the physical prototype and two tests via Skype. The test group was either active ATCOs or had a background from working as one. This gave good feedback to the test and it was possible to see how the users interacted with the prototype.

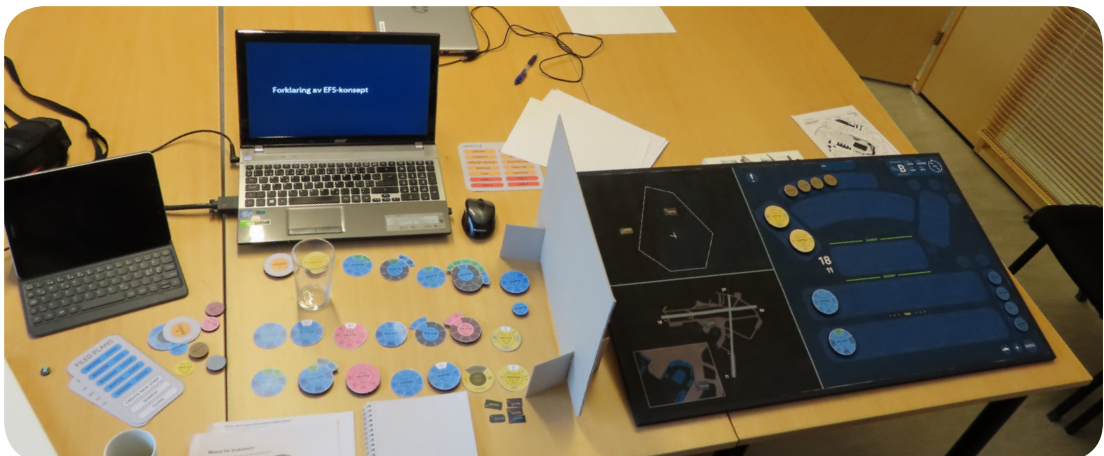
There are still some variables and weaknesses to the tests. The interaction is only with the stripboard and doesn't have the visual cues they also work with in the tower. Dealing with it physically made interactions take longer as buttons had to be expanded by changing the strip. Working alone on testing with the ATCOs also affected the testing since aircraft movements and changes on the "screen" was manually changed by me. Changes were obvious and not possible to see the reaction too, compared to if it popped-up automatically with an animation.

The positive side of having the physical prototype was that the users could move the strips around as they wanted to in the real size, and the test could be adapted to their reactions, unlike in the XD prototype.



The set-up was me sitting as the facilitator beside the user. The user was seated in front of the prototype, like it would be in the tower. On the facilitator side was the strips for the scenario laid out in order. To prevent the user from being distracted by the upcoming strips a cardboard wall was placed to cover this. Before the testing was started, all participants got an introduction to the project and the concept.

As this is intended to be used after training on the system it was logical to inform them about the layout and functions of the prototype. A five-minute introduction isn't much, but at least it made them understand the system before starting the test. A short introduction made them understand the core ideas of the prototype, but as the test progressed it was possible to see how intuitive the concept was.



The test was set to follow the scenario and the first task was to describe how they perceived the situation. Then the test started by moving the labels and asking them to think out loud and react as they would if they were seated in a tower position. As the test progressed they would get “call-ups” from aircraft and react to that. They also gave feedback during the test on their impressions and ideas. After the test was completed, they gave more feedback on the concept. What they liked and what they would like to change.

” *How do you percive the traffic situation based on what you see?*

” *Sola Ground, Scandinavian 87 Bravo, request clearence to Gardermoen*

” *Scandinavian 87 Bravo, cleared to Gardermoen via Uplev one golf departure, climb 6000 feet, sqwack 2553*

Results from testing

First impressions

The general impression from the users was that the concept is exciting and different than what they are used to. When describing how they perceived the situation most of it was described as intended, but there were some confusions as well. Starting from the top. When the HKS153 was placed in the arc, some thought it was passing through instead of arriving. The BHL208 with “Cleared ENXO” was not clear to them, as they questioned if it had a start-up clearance and thought it had that, which it didn't.



First action

In the first part of the test there was some differences in what the first action was. Some decided to give the NAX536 “cleared to land” and some gave WIF08J “Cleared for take-off” first.

Because they were uncertain on how far out the NAX536 on final was, there was some differences where both actions were accepted even though the scenario was set up with the NAX536 landing first.



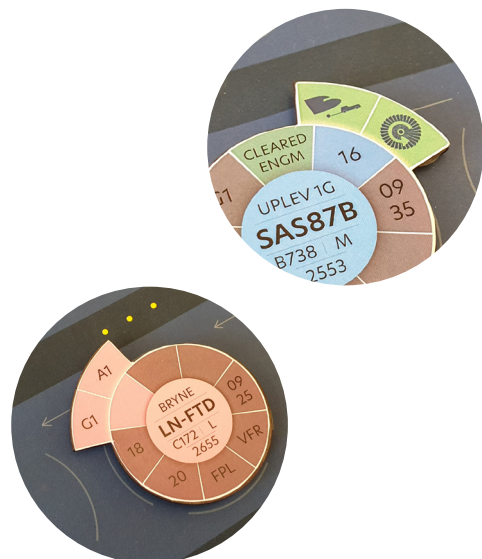
Create new strip

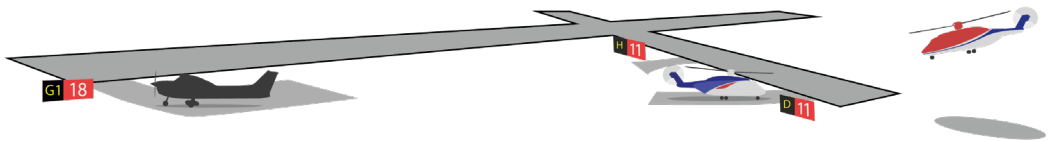
They quickly went to the corner and the menu buttons, talking about both the menu button or the plus. Some would go in the menu, and others would press the plus. After pressing the plus everyone looked at the sub-menu and pressed “Create new strip”. In the “New strip”-menu it was too much information. Flight rules and type of flight is information that should be implicit for this action. The only things needed to enter is the callsign and get a transponder code. Then the rest can be put in the strip later if necessary. Regular local aircraft could also be added to a list for quicker input.



Start-up and taxi clearances

When getting clearance, the users would say it and didn't react with the prototype as intended. This can also be because of the short introduction, but those that did press the buttons and use it thought the idea was good.





Multiple aircraft in the runway bay

For some ATCOs it was against their principles to have more than one strip in the runway bay at the time. For others this was more natural, and it gave three ways of solving the situation:

1: As in the scenario

- 1) HKS - Cleared to land
- 2) LN-FTD - Line-up and wait
- 3) *HKS passing Delta* - BHL, line-up and wait
- 4) *HKS touch-down* - LN-FTD, Cleared for take-off
- 5) *LN-FTD passing runway 11/29* - BHL, cleared for take-off

2: Prioritizing the helicopters

- 1) HKS - Cleared to land
- 2) *HKS passing Delta* - BHL line up LN-FTD line up
- 3) *HKS on taxiway* - BHL, Cleared for take-off
- 4) *BHL out*, LN-FTD cleared for take-off

3: One at the time

- 1) HKS landing
- 2) Line-up and take-off, BHL
- 3) Line-up and take-off, LN-FTD



” Contact Approach 119.4

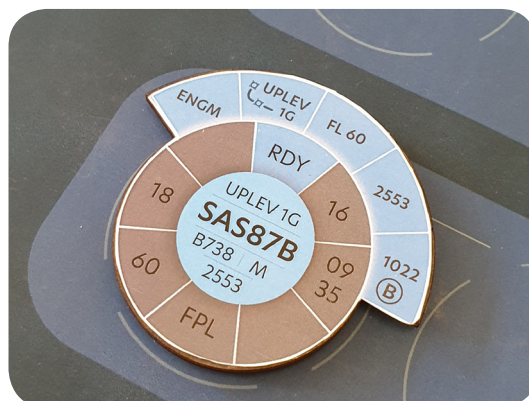
Hand-over and archiving

Some used the archive bay, others wanted to drag them out of the bay and screen to make them go away. For some it took long before they reacted to them and they were placed on the board for a long time. A suggestion was also that the strips should disappear automatically when they arrive at the gate.



Giving delivery clearance

They thought the idea was good, but they would like to mark everything in one click. Some commented that they don't put a check-mark at each point in the strip. This is something that has been observed done by several ATCOs during tower visits, so this might be differences for some ATCOs. Some comments were that this should be done before it is placed in this bay, so the clearance is done while the strip is placed in pending. The ATCOs from Sola informed that start-up is included as well for helicopters.



General feedback

Have the time displayed beside each other to prevent it being interpreted as runways when being on top of each other.

What if not all clearance boxes are marked, what colour is it then, blue or?

Pending bay should be much bigger to display more aircraft.

Give the delivery clearance in this bay. Use the delivery bay only for aircraft that are ready to start and soon taxi.

Dynamic interface where the number of spaces in the bays can expand if needed.

Change the STAR information in the inner circle and have the approach type instead. (ILS, R-NAV, VISUAL)

Depending on how many sectors that are open, it can be 5-6 “exit-points” to handover aircraft on.

Can give different clearances to aircraft as they depart or approach the airport. Clearances that stop at 2000 feet or other types of limits to the clearance that need to be accounted for.

In the airborne bay Sola can have as many as 7-9 VFR aircraft at the same time under their control.

To have a clearer separation on aircraft on final it could be two inbound bays, one for each runway.

The layout at Sola today isn't good for differencing aircraft on the crossing runways, but at the same time they are intersecting and depending on each other.

Looking only at the EFS-panel it is hard to interpret what aircraft is what runway, and in what sequence they can be cleared.

Using one bay works, but it isn't an optimal solution.

The ground bays could have a different colour compared the airborne, to separate them.

Analysis of results

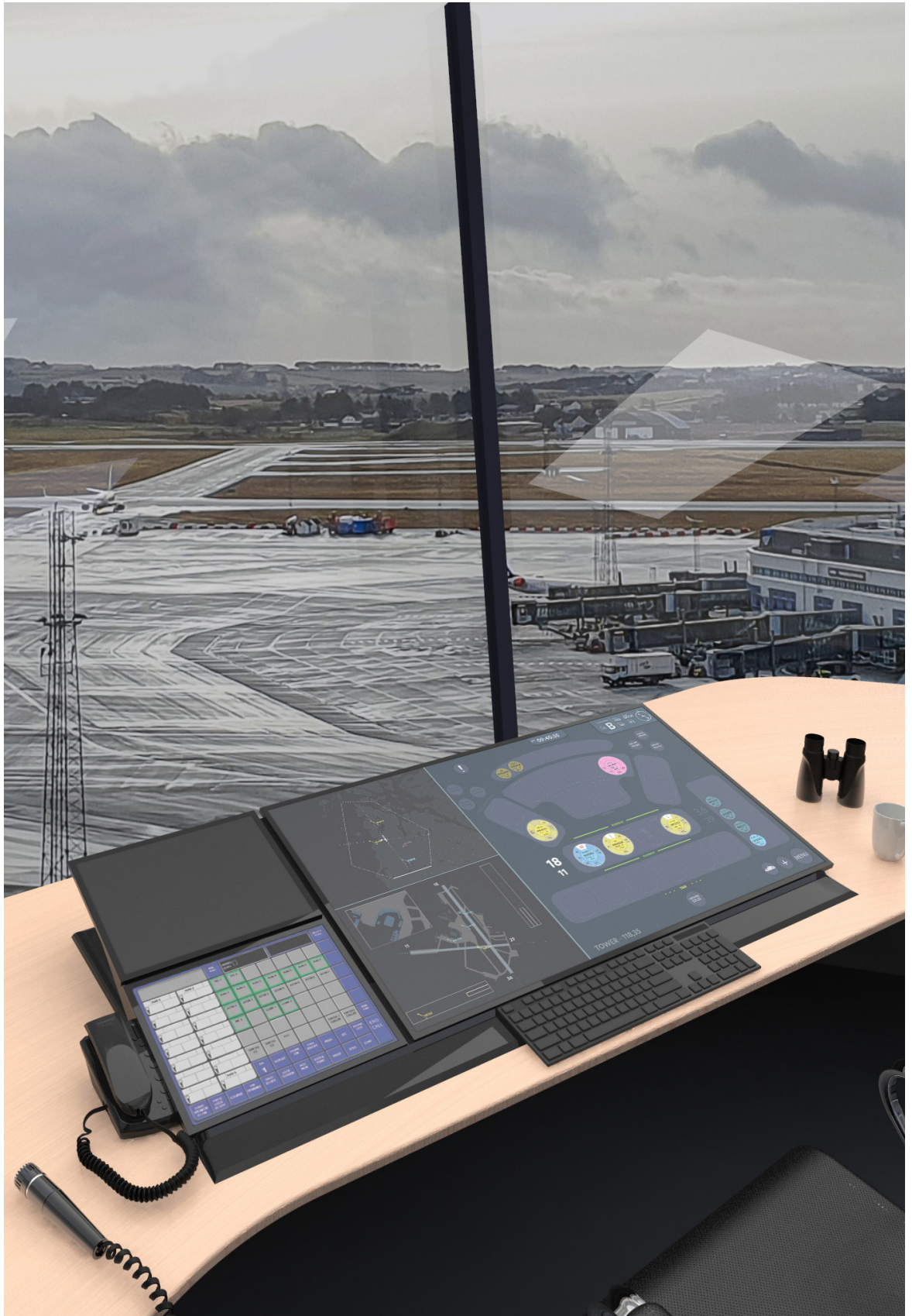
The comments are from ATCOs with experience from working in tower. Some are or have been operative at Stavanger and could give feedback based on experiences from working at the airport. Others were not experienced with crossing runways and had some different views on the design.

Looking at how the ATCOs interacted with the prototype, they got the concept of moving the strips according to how they directed the traffic. The information on the strips seem to give the necessary information in a logical way, regarding the short introduction to the project. What happens when not all the clearance buttons are pressed, is not defined, and one idea is that the field could turn yellow to mark that it is unfinished. For the clearance menu everything could be marked by clicking the same button that is used to open the menu.

The placement in the bays are important and to define when an aircraft goes from pending to active is something that needs to be defined. During testing there was some confusion when the HKS153 was placed in the arc, that it meant it was passing through or at least not landing.

One of the comments that were repeated from multiple ATCOs was that the pending needs to be bigger. Something to look at more is how to expand this field and maybe move the delivery clearance to this bay.

It was interesting to hear the feedback from the ATCOs at Stavanger, that the system today works, but they aren't satisfied with how it works. But they don't know in what way it could be improved and shows that this is challenging to solve.



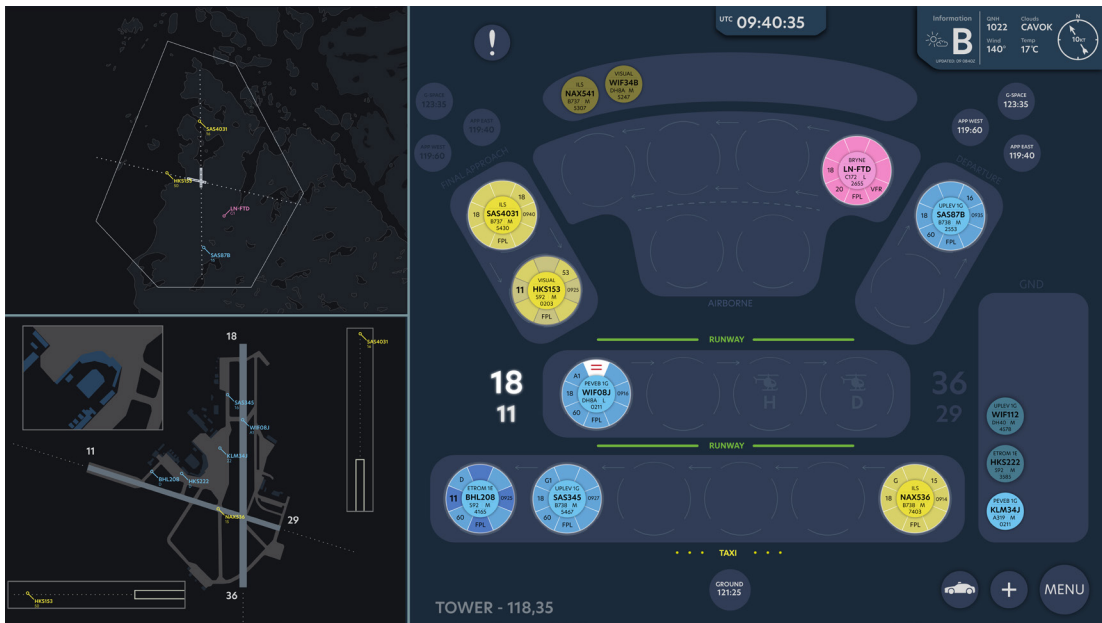
Final concept for Stavanger

Going through the experiences and feedback from the user tests some changes are made to the concept. This time the focus has been to implement the feedback into the split operation panels because this shows more how it would work on a daily basis.

The renderings show how it could look in the tower.

In addition to the EFS screen the ATCOs have some other tools available, such as radiofrequencies, audio control and lights. To cover this, two smaller screens are added to have this information available. They have the microphone for communication on the radio, and a phone for quick contact with other ATC stations. The idea is to have a keyboard to make written input easier and quicker.





Tower

The TWR panel is decided to remain almost unchanged. To make the runway bay more specified for Stavanger two of the spaces are marked with a helicopter icon and the two runway intersections. Placed on the right side to have the same orientation as where the ATCO would look out to see the helicopters when landing on either “D” or “H” on runway 11/29. The handover to ground is centred in the middle below the taxi bay to make a short way for sending strips to the GND controller. The ground radar is oriented pointing north to correspond with the CTR radar. A final-approach radar for both runways is also added to show aircraft coming in for landing. The pending bay is expanded to fit some more pending strips, but not as many as in the ground position.

UTC 09:40:35

Information **B** 1022 CAVOK
Wind 140°
Temp 17°C

! 11 15 36 29

TOWER

11 TAXI

GROUND - 121,750

+

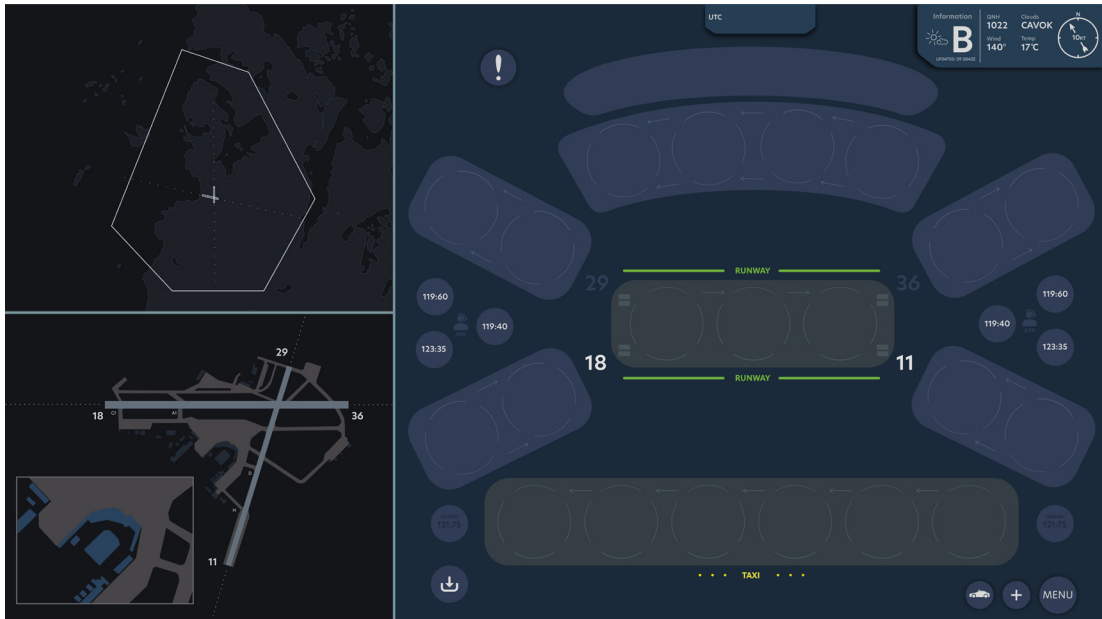
MENU

Ground

The radar displays are moved to the right side of the panel with the ground radar on top as this is more important for the GND position.

The airborne radar display is made smaller to give more space for three additional pending bays. If necessary, they can also be expanded by removing the airborne bay at very busy times. Having them on the right side of the screen makes the EFS panels on both screens closer to the other ATCO. This makes it easier for an ATCO to glimpse over at the other screen to get an overview of the status on their table.

The single space bays with runway numbers are handover bays where the strip is put to be handed over to tower, same as they put a “T” on the strip on FPS. Based on the feedback from testing it can also be possible to have the delivery clearance in the pending bay and turn the whole pending strip green. The decision is to make it as in the user test with giving the initial clearance in the delivery bay, but in high traffic periods it can be possible to give the clearance in pending as well.



Alternative TWR layout

Looking back at the iterations, another way that could have been interesting to look at, is the design that is displayed on the previous, with one bay for each runway. This is also based on feedback from one of the user tests where an idea was to have the individual approaches to each runway separate. This could be another way to show what direction aircrafts are coming from, but at the same time it takes up much space for other bays and other information. Testing different concepts with challenging scenarios in an ATC environment will help to better identify what would be the best way to solve it.

In the next chapter the focus will change to first look at the observations from visiting the tower in Bergen and suiting the design to their needs.



Bergen Airport

Single runway and complex traffic

ENBR

TWR

FPS OPERATION

GND



*PRINT

DEP PENDING

"Request clearance to..."



*READBACK CORRECT

MOVE TO GND OUT BELOW START

"Req' push & start"

TAXI - MOVE ABOVE START

ARCHING

AT GATE

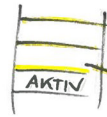
"GND INB"

"TAXI TO STAND via..."

"CONTACT GND..."



SEND FPS TO TWR



*PRINT



STAND

CLR LND

LND TIME

*HELI TAXI Y LND

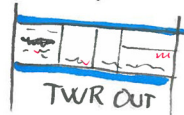


RWY INTERSECTION

APP



*CLR TAKE-OFF



Bergen Airport, Flesland

This report has been focused mainly on Stavanger, but the observations in February gave a lot of insights to the operations at Bergen as well. This chapter will show an idea of how the new concept can be well suited for a single runway airport, with considerations to the challenges at Bergen.

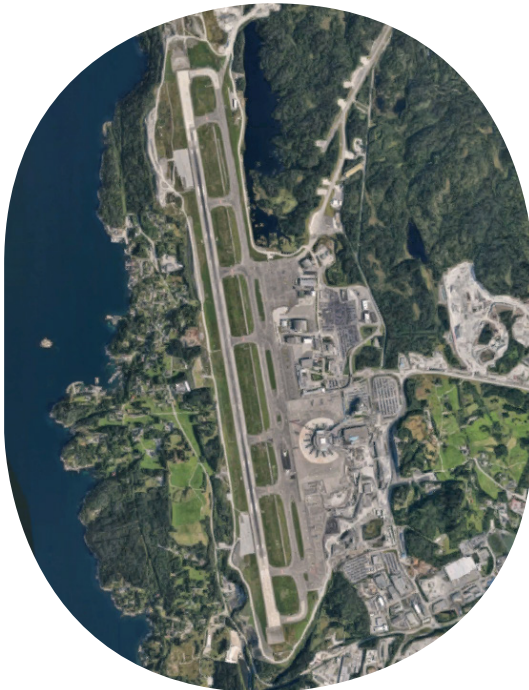


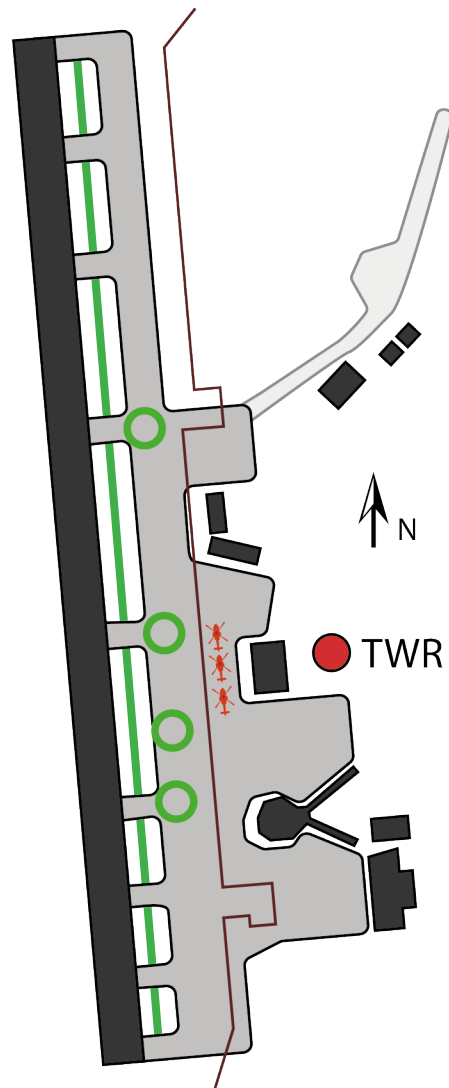
Photo: Google Maps

Bergen Airport Flesland is a single runway airport with much of the same traffic as Stavanger. Their challenge is combining all the traffic on one runway.

Their operation is also split into TWR and GND position. They sit in line, beside each other with a good overview of the airport surface. The FPS-panel is divided in inbound and outbound fields for both GND and TWR. When a strip moves from GND to TWR or opposite, they take the strip out of the bay and sends it across the table to the other ATCO. The observations at Bergen gave a lot of insights, more than included here, but to limit the amount of details for this thesis, a few important factors are mentioned.

”YANKEE”

To have less helicopters occupying the runway Bergen has landing areas for helicopters on the taxiway, that can be illuminated when in use. This makes the runway free faster than if the helicopter needs to taxi off the runway. This operation requires awareness at both the TWR and GND because it requires TWR operations on the taxiways. Therefore they both put a “YANKEE” strip in the taxi bay as a reminder. They have four landing spots, “B”, “C”, “D” or “E”. The strip is marked with an arrow down, Y and the landing spot: ↓YC



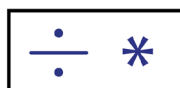
Middelvei

Between the taxiway and the runway there is a road for cars that is called “Middelvei”. This is used to keep vehicles off the runway and taxiways if they need to go far up or down on the airport. When a vehicle is on this road a “Middelvei”-strip is placed in the Taxi-bay. The road is shown as the green line in the illustration on the previous page.



De-icing

In winter conditions, aircraft collect snow and ice on the wings that needs to be removed for safe operations. On the airport they have designated spaces for de-icing the aircrafts. When de-icing is needed the ATCO insert a new strip in the panel to create a De-ice bay. If there are many aircraft that needs de-icing, another strip is put on the panel to sequence a de-ice que. They also have annotations on the strips. If an aircraft doesn't need de-icing, the strip is marked with a division symbol (\div), and if an aircraft wants de-icing it is marked with a star symbol (*).





Iteration 4 - Bergen

Single runway and complex traffic

Single runway operation

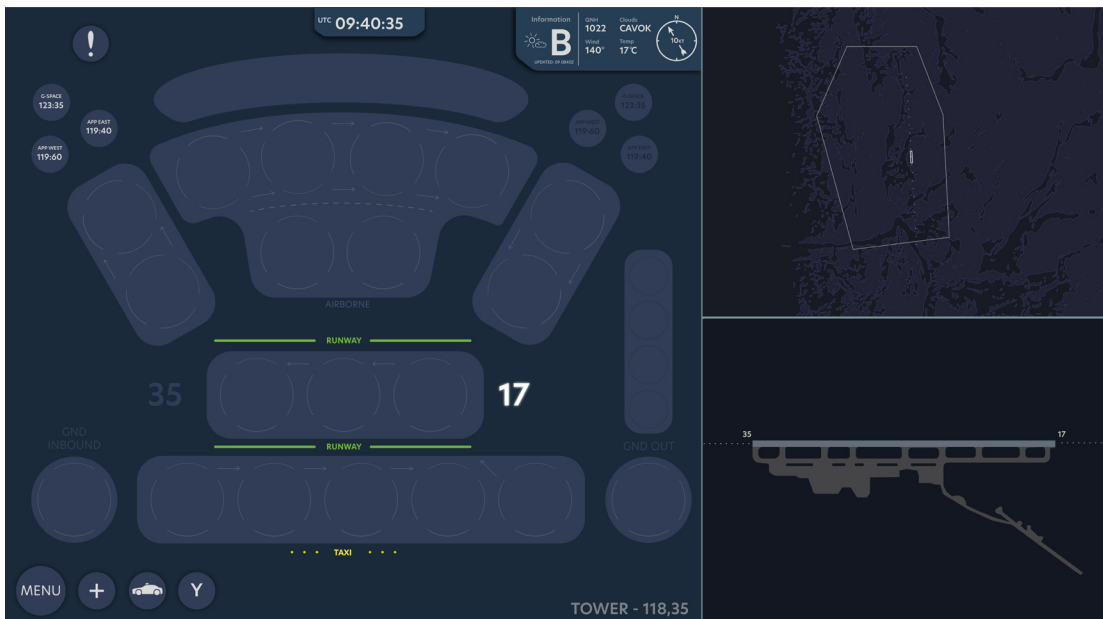
The design should fit even better for a single runway airport as the flow is simpler and more logical. There is only one main taxi way and one runway to have control over, making the system fit very nicely to the airport. The layout should give an even better overview of traffic when comparing the EFS-panel with the radar displays and the view when looking out.



Tower

For tower the design is very similar to the crossing runways design. The airborne field is unchanged to have room for traffic around the airport. Because operations are on one runway the number of spaces is reduced to 3 in the runway bay. The TWR position has a smaller pending bay because they take over traffic after they start taxiing, meaning a lot fewer than the pending departures at the gates.

When the strip is handed over from GND to TWR the idea is that it moves down to the bigger bay below, with an animation and possibly a sound notification. Handover from TWR to GND works the same way where the ATCO moves the strip to the bay on the opposite side.



Yankee-strip

When the Yankee-taxiway is used it is important for both GND and TWR. When used, oral coordination between the ATCOs will occur first and they will put a notice on the panel. Both should have the option, and it is added as a button by the menus for quick access.

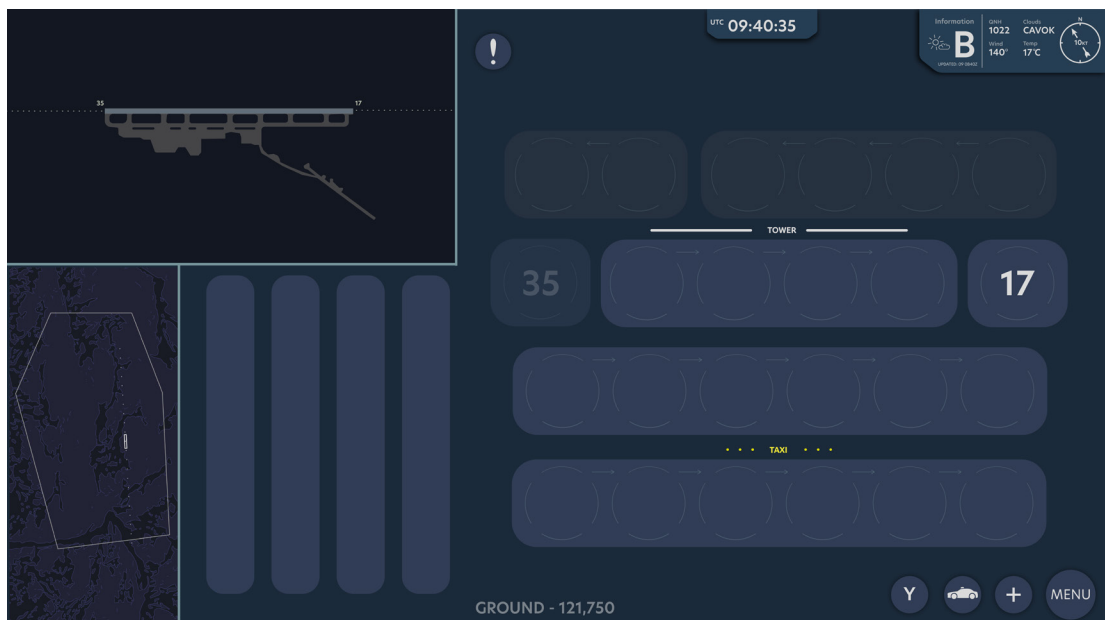
There can be many ways to visualize this in the panel, but for this thesis it is done in the same way as in their operations. Putting a circle onto the taxi bay at both TWR and GND to remind, with a red outer circle and a white inner circle. This is to distinct it from traffic as this is a reminder combined with information on the strip. When putting the strip in the bay it should also be possible to enter the landing spot.



Ground

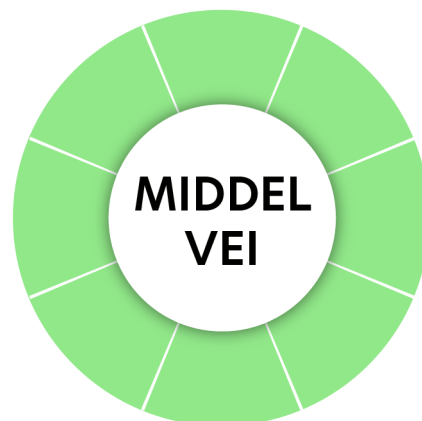
Compared to the GND configuration for Stavanger, the one for Bergen is built up the same way. The pending bays are moved to the other side to correspond with where the gates are in Bergen. The ground radar is also moved to that side.

In Stavanger they wanted the ground radar to be oriented north-up, but in observations in Bergen they operate with the radar parallel to the head-up view, looking out of the tower. This works better because of just one runway. The CTR radar is also included to give better SA. It has the same handover system, but for one runway, giving another taxi bay below.



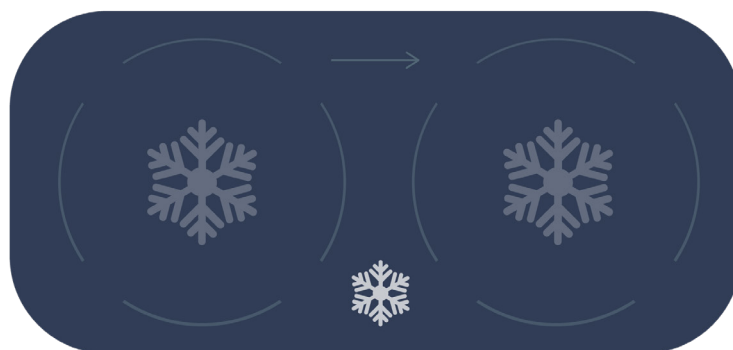
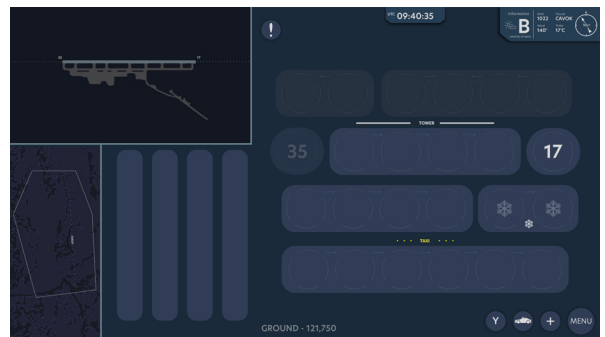
“Middelvei”

To show a vehicle going along the car road a strip can be placed in the bay. Using the same colours as the strips in Bergen, makes it recognizable and additional information can be put in the outer circle as with vehicle strips. This has the same design as the Yankee strip, but with a green outer circle to make it recognizable. More information describing the vehicle can be put in the outer circle.



De-icing

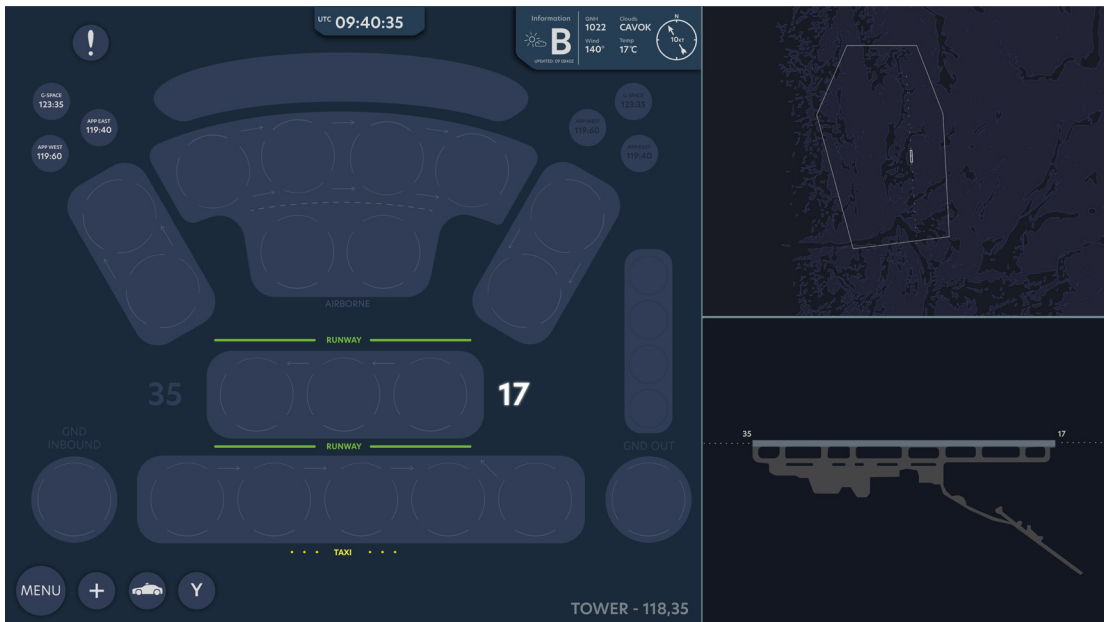
In the ground position the taxi bay can be split up to get spaces for aircraft that need de-icing. This bay will then be separated from the rest and have an ice crystal on each bay to symbolize this. Here it has two slots, but if needed it can adapt for more aircraft that are de-icing. For the de-ice que, this can either be marked on the following strips with an ice crystal and a number, or as a separate pop-up window, showing the que in a list.



GROUND



TOWER





Reflections

Evaluating the project

Evaluating the results

The observations at Bergen and Stavanger gave a lot of interesting insights and challenges that needed to fit into the EFS concept. Looking back at all the ideas and visions for making the design, it was necessary to limit the amount of work and features to add to this prototype. Compared to the result in Design 9, this is a more complete HMI where both the sequence of operations and presented information is better. The flow and functions of the strips is more defined and suited to the needs based on aircraft operations.

The results have been developed following the insights and guidelines to serve the core functions of both ATC and FPS. The testing in this project has confirmed that the circular strip presents flight information in a way that gives the ATCO an overall perception and mental picture of the traffic. With the added functionality the concept supports the ATCO with administration of instructions and handover of flights between ATCOs.

Working with both a single operation design and a split design has given more thoroughly prepared system. It was important to make both because the single operation gives the possibility to test the complete system and flow with one user. This will be the case under some circumstance where one ATCO is in control over everything, as well as smaller airports that operates with only one ATCO for both GND and TWR.

Having the split configurations was also important to make, as this is the basis for daily operations at the largest airports. Using the shared SA requirements with the insights from iteration 2 and 3 made it easier to split the requirements and design for each position.

During the project I wanted to explore ways of developing a digital prototype that was possible to interact with and move the strips around more than the constraints of the Adobe XD prototype. That was when the idea to create a physical prototype came. This allowed testing in the correct scale and at the same time give the ATCOs the freedom to move strips anywhere they wanted.

In terms of colour the design it still has the six colours with a unique meaning with some exceptions.

EFS "strips"

- Light blue - Departure
- Yellow - Arrival
- Pink - VFR
- Orange/light grey - Vehicle
- Green - Clear
- Red - Not clear

Display

- 2 variations of dark blue - EFS panel
- Grey - Radar display

The label for departing aircraft is a light blue text to connect it with the strips. The guidelines say not to use pure blue for text. The colour should be light enough to give sufficient contrast compared to a pure blue colour.



Crossing Runways

Crossing runways was a big challenge. Especially designing the system for operation on two runways, where they intersect and affect each other. Because they are linked, the result was focused on having one runway bay, so an aircraft on any runway is an aircraft on the runway. Then the goal was to find ways to separate them via the design of the strip but using colour and other effects was challenging. By using the information as it is presented on the strips, combined with additional information with both a CTR radar and a ground radar presents flight information in a way where the ATCO has control over the different runways. The division in operations with aircraft on the main runway and helicopters on the other also helps to give a separation. Something to test further is if that perception changes if there is an aircraft and not a helicopter that is landing on the opposite runway (11/29).

Single runway

The focus in the thesis has been working with a solution for Stavanger and crossing runways, but also to make an HMI where the sequencing is natural for general ATC operations. Because of that the design can fit an airport like Bergen with minor changes and tweaks to fit their needs and it works even better than for Stavanger. When the ATCOs have the flow of traffic parallel to how they look outside, the system should give good representation and help maintaining a mental picture. The handover bays in the tower is an idea that needs testing to see if it is a solution that works.



Future work

The development in this thesis has ended up in a more complete design of an EFS concept for ATC. Still a lot of work is required to have a system that can be implemented in an ATC tower. It is important that any system that is implemented in a safety critical environment like ATC is tested thoroughly. That is why a lot more testing is needed for something like this to be finished. Specially putting the system in a simulator where it can be tested in a real environment. Before that, more testing with a bigger team of people in Avinor ANS should be included to finalize the concept. It should also be put into testing with complex scenarios and challenging operations.

More design is also needed in designing for emergency situations. This is a problem I chose not to focus on in this thesis.

For Bergen I got more information during the observations that could have been included in prototyping, but these are details and features that can be added without affecting the design. One of these details is called wake turbulence where different size aircraft needs different time separations to take-off because of vortexes created by larger aircraft. An idea for the circle is to use the outer circle to display a loading animation that shows when it is clear to give a lighter aircraft take-off clearance.

One challenge with using a screen in the tower is the reflection from sunlight that might make the screen more difficult to see. It is important to have enough contrast and create day and night modes.

It is important that the touch functions are good so that the strips are easy to move and when moving an item or pressing a button the ATCOs will get immediate response to their actions.

Learning outcome

It has been interesting to continue developing an HMI for ATC Towers. Dealing with complex scenarios and trying to create a solution that covers the needs and tasks of the users. Developing the concept further has allowed me to go more into detail within an environment I'm familiar with and gain a lot of insights. I have gotten more experience of going out on observations and dealing with a very specified user group. Listening and trying to understand how they work has been a big part of the thesis, and when beginning with the development of solutions I learned that I can get even better at gathering information by noting and taking more pictures to remember what I had observed.

The testing also gave many experiences to how challenging it is to do live testing without having a team to work with. To be the one that informs, facilitates, does the "magic" on the board and to observe and note the observations and comments was a challenge. One more person to divide the work with during testing would have made it flow better and it would have given more information during the test.

I have become more comfortable with the software Adobe Illustrator and other tools in creating material for the prototypes and how to use functions to get the aesthetics I wanted in the concept.

Conclusion

The thesis has been an existing journey and I'm very pleased with how the end results turned out. Looking back at the first iteration from Design 9 and comparing it with the result in this thesis, the design is now more complete and represents traffic in a much better way. Sequencing and visualizing aircraft are easier with having one line with the arrows, but for airborne traffic there are still challenges. With all the available tools they have in the tower, such as radar displays and visually looking out the window, the EFS concept supports the ATCO in operation with more possible input than in the FPS they use today.

I hope this can work as an inspiration in development of new EFS systems. Showing that there are other ways than copying the FPS when visualizing and interacting with the information when moving to a digital interface.

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Appendix

Appendix

Appendix 1 - Literature review

Appendix 2 - Iteration 1, details

Appendix 3 - Iteration 2, User testing
Results and example sheet

Appendix 4 - Iteration 3, Guide for user testing

Appendix 1

Literature review

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 cues. 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 seem to be adaptations 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 mental 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 were 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 (Druso 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).

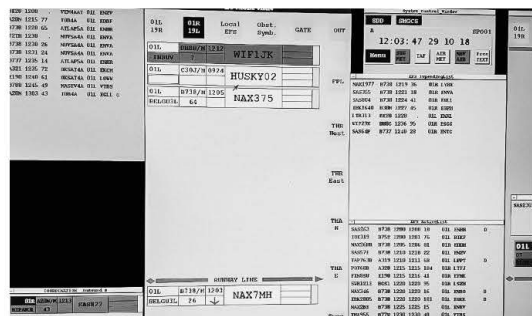


Figure 2 – EFS at Gardermoen

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).

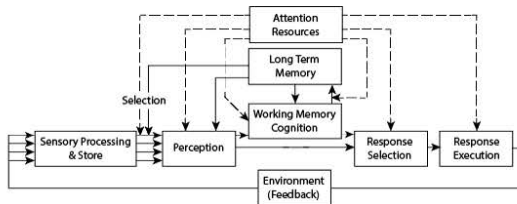


Figure 3 – A model of human information processing stages.

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).

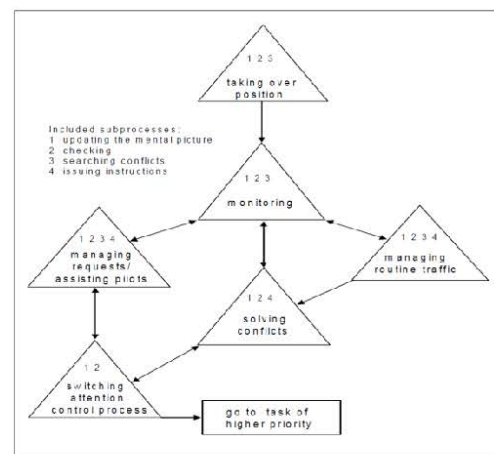


Figure 4 – Basic cognitive processes in ATC.

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 lighting 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 crooked 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 than 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.

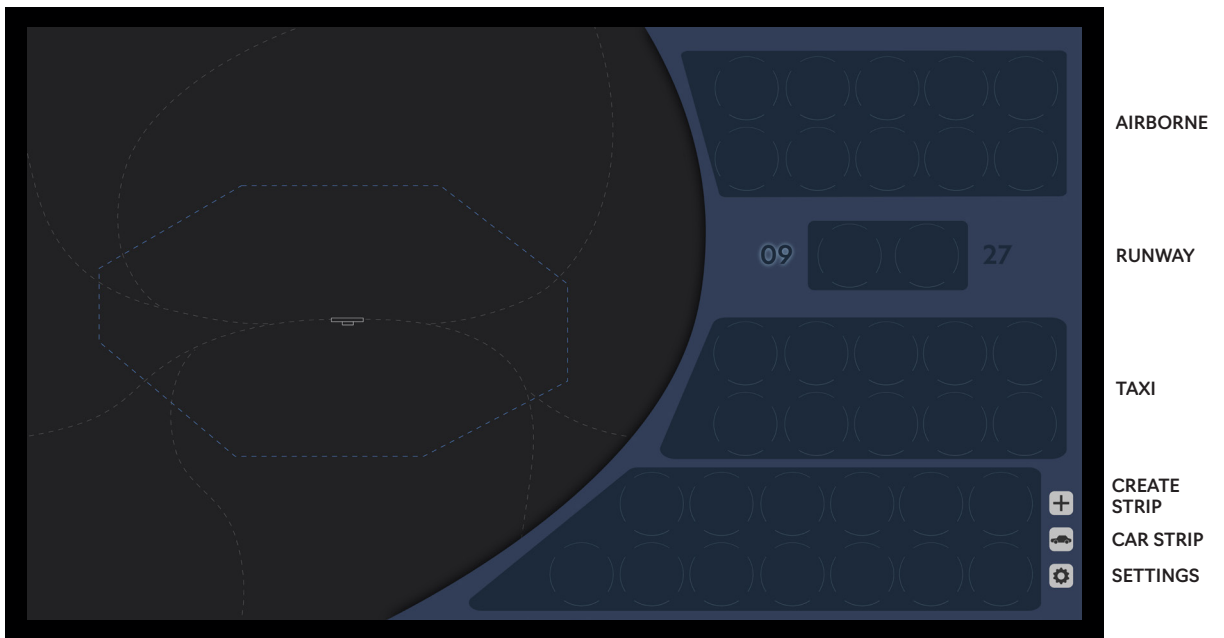
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Appendix 2

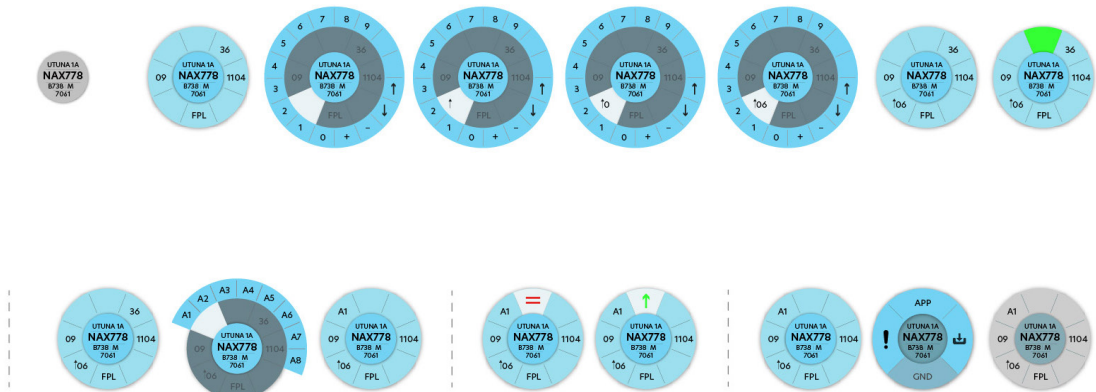
Iteration 1 - details

40" Display

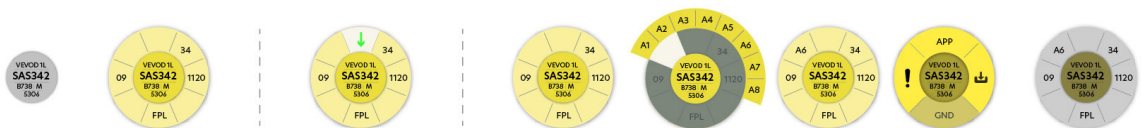


Steps in scenario in Iteration 1

NAX778 - Departing



SAS342 - Arriving



LN-ABC - VFR Touch and go



Flight plan

In the paper prototype I only tested the display and movements of strips, and for the new prototype the "flight plan" is added as a sub-menu. To understand what information to include I looked at the information they had at Værnes and Gardermoen. Sketching variations using the design guidelines as a foundation. This menu will be a pop-up window when pressing the FPL button on the strip. It takes more space and includes more information about the aircraft and its flight.



Flight plan-menu

NAX778					BOEING 737-800	M
STAND:	ATIS:	TRANSPONDER:	ADEP:	DEST:		
34	H	7061	ENVA	ENGM		
EDEP:	CTOT:	ETA:	SPEED:	CFL:		
1105	1115	1205	NØ461	FL300		
Dep RWY:	SID:	STAR:	Arr RWY:			
09	UTUNA 1A					
ROUTE:						
UTUNA	M609	TUTBI	DCT	BELGU		
EQUIPMENT:	WAYPOINT:	PASSTIME:				
R-NAV						
REMARKS:						

Appendix 3

Iteration 2, User testing
Results and example sheet

Hei,

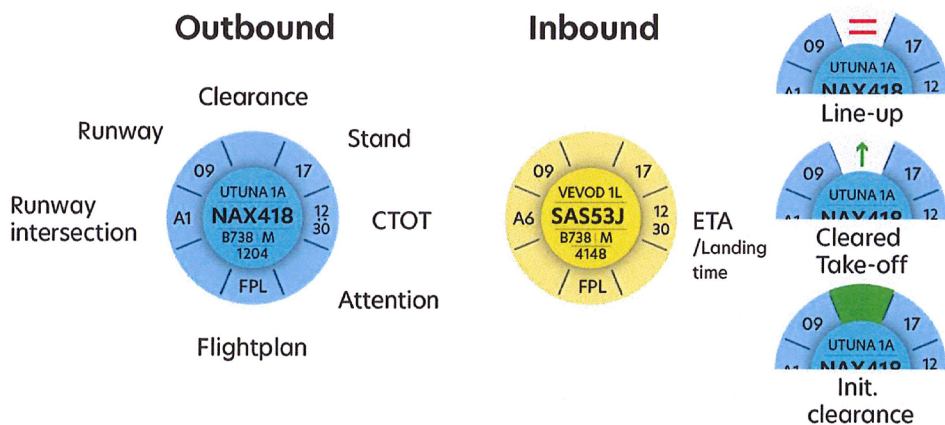
Mitt navn er Mats Ruste Holen og jeg jobber nå med min masteroppgave ved Industriell design på NTNU i Trondheim, i samarbeid med Avinor Flysikring. I forbindelse med oppgaven ønsker jeg at du gjennomfører denne testen som tar rundt 15-30 min å gjennomføre. Du kan ta hele testen i en gang eller ta den i flere omganger etter som hva som passer for deg. Jeg setter veldig stor pris på om du kan bruke litt av tiden din til å gi meg dine tilbakemeldinger. Dette er kun for min masteroppgave hvor jeg utforsker hvordan designet mitt fungerer og dersom noe er vanskelig å forstå er det mitt design som er problemet.

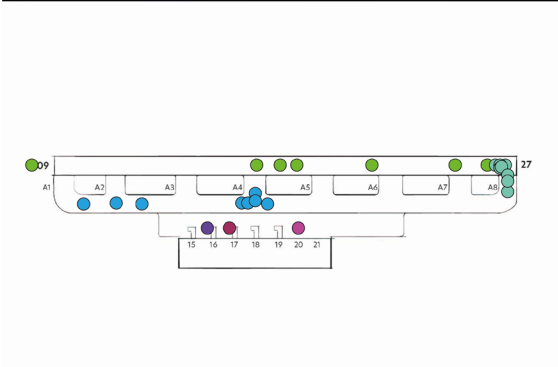
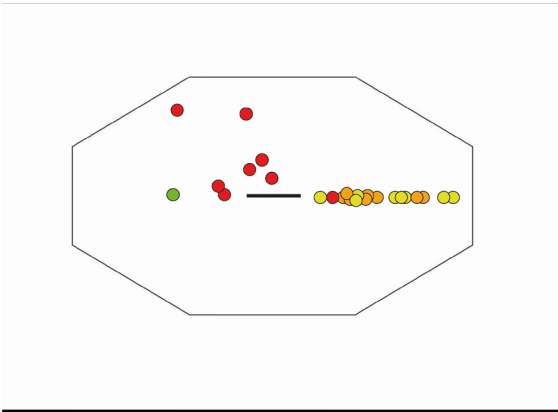
Opggaven er et videre arbeid på prosjektoppgave forrige høst, med å lage et nytt konsept for «Electronic flight strips». Målet var å bruke min designkompetanse innen interaksjonsdesign til å lage et system som løser oppgaven til strips på en ny måte enn det har blitt gjort så langt. Gjennom studie av litteratur, besøk på flyplasser og utvikling av idéer endte jeg med et konsept jeg videreutvikler.

Konseptet

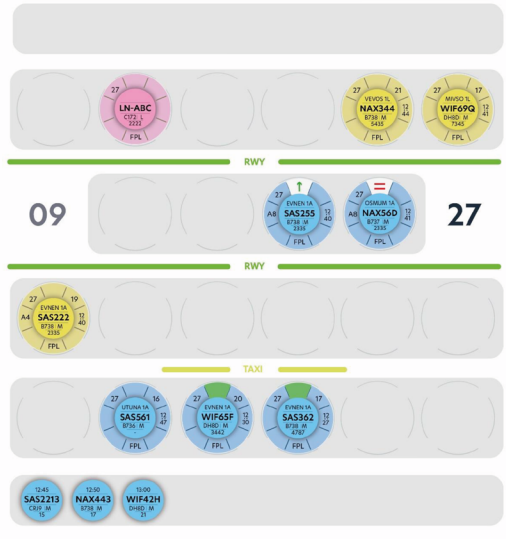
Konseptet baserer seg på sirkulære «strips» hvor den indre sirkelen inneholder informasjon som ikke/sjelden vil endre seg for en flight. Ytre sirkel har informasjon som kan variere lignende det å notere med en penn. Systemet baserer seg på touch, hvor den indre sirkelen er fast og trykkes og holdes for å flytte en strip. Den ytre har knapper som gjør at man kan endre informasjon med enkle tastetrykk. Se beskrivelsen i figuren for forklaring av en «strip». For testen er størrelsen en del mindre enn det tenkte konseptet som vil være på en skjerm lignende det som brukes i Remote Tower, tekst vil derfor være større og enklere å lese enn den er i eksemplene. Detaljene er ikke viktige å studere i denne testen.

Strippene er plassert i ulike paneler og det jeg ønsker å vite med denne testen er hvordan panelene kan utformes for å gi en så god situasjonsforståelse som mulig. Hvilken retning bør panelene være og hvilken retning/rekkefølge skal strippene ligge for å gi en god forståelse av trafikken?

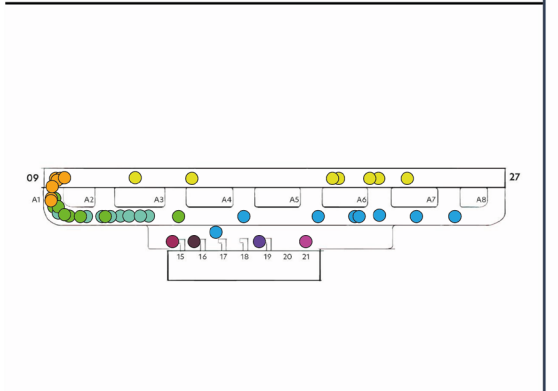
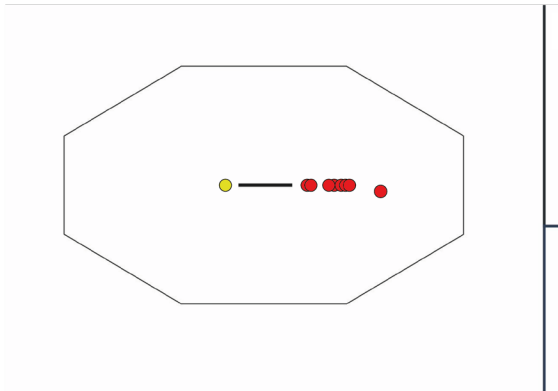




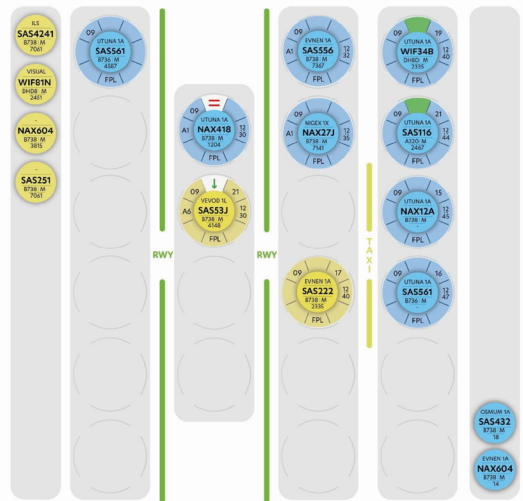
- LN-ABC
- NAX344
- WIF69Q
- SAS255
- NAX56D
- SAS222
- SAS561
- WIF65F
- SAS362



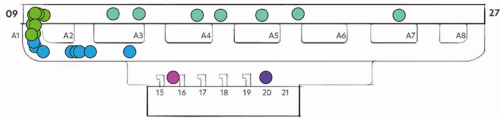
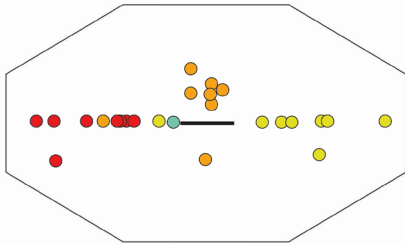
Testsheet 1 - results



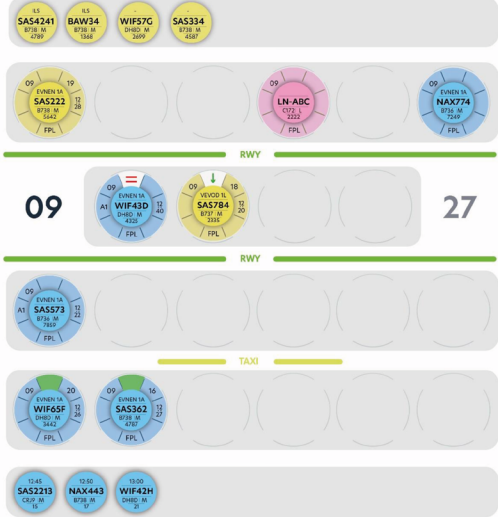
- SAS561
- NAX418
- SAS53J
- SAS556
- NAX27J
- SAS222
- WIF34B
- SAS116
- NAX12A
- SAS561



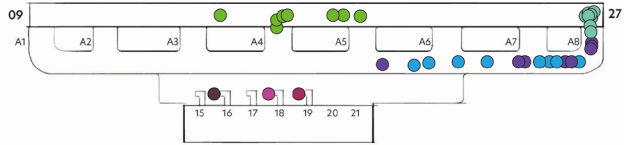
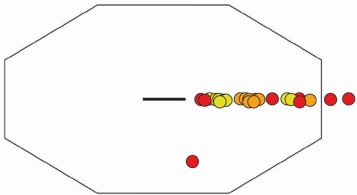
Testsheet 2 - results



- SAS222
- LN-ABC
- NAX774
- WIF43D
- SAS784
- SAS573
- WIF65F
- SAS362



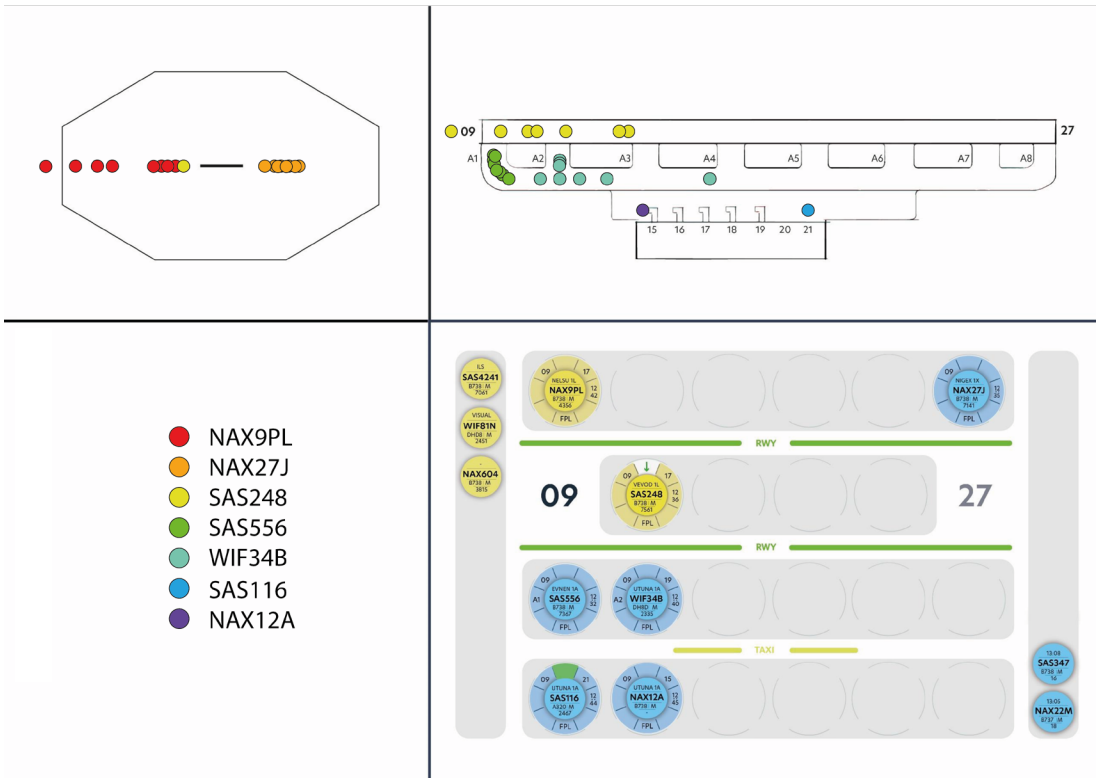
Testsheet 3 - results



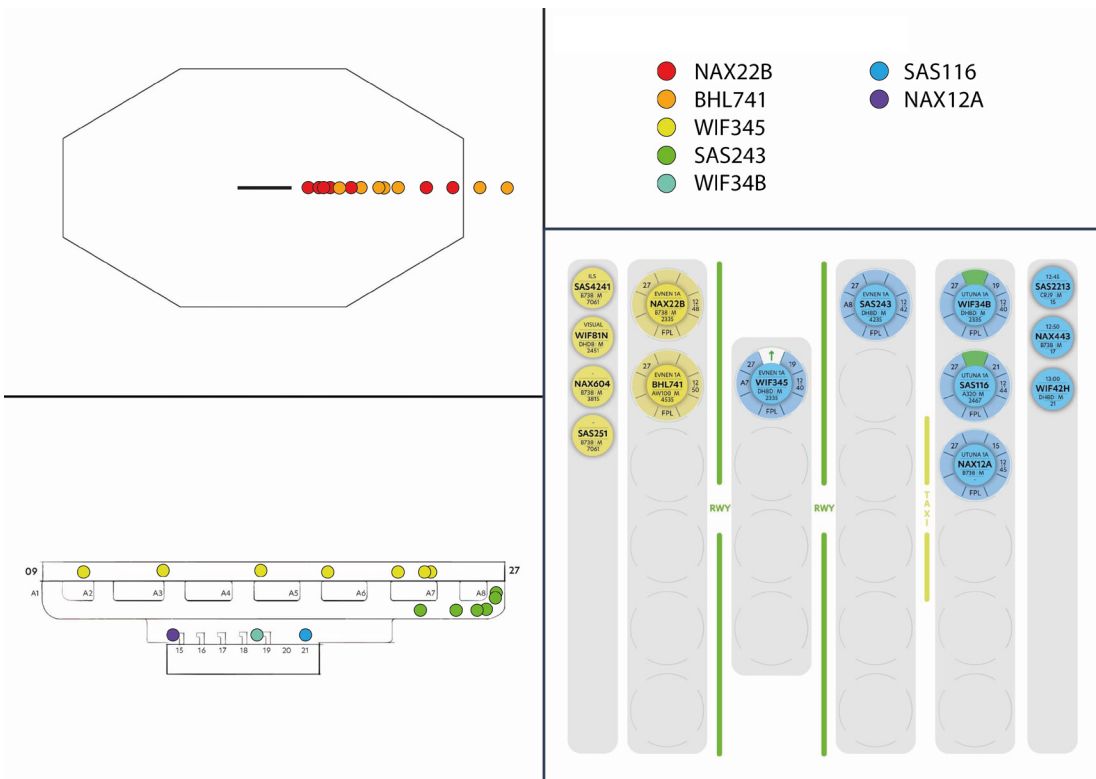
- NAX4142
- NAX344
- WIF69Q
- SAS222
- NAX774
- BAW26K
- NAX566
- WIF5YJ
- NAX73A
- SAS257



Testsheet 4 - results

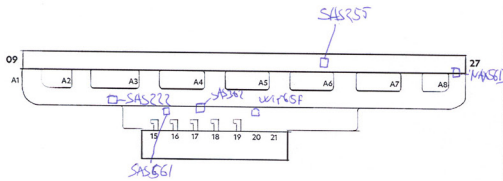
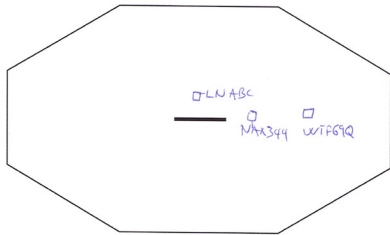


Testsheet 5 - results



Testsheet 6 - results

EKS 1



+ Rwy är övervakad på 09 i Sverige. - Inga indikatorer på start up/pushback. A vanskälic A vite huok local trafikered ev. (LN-ABC)

Example of filled out testsheet from a participant

Appendix 4

Iteration 3, Guide for user testing

Script for user testing:

Can you describe how you perceive the traffic situation?
What is the first thing you would do?

ATC: NAX536 Cleared to land

*move strip down to RUNWAY

4 klikk* - radar movements

*Move NAX563 to the middle spot

ATC: WIF08J, Line-up and wait rwy 18

*Move WIF08J to RUNWAY

ATC: WIF08J, winds 140 deg, 10 knts, cleared for take-off rwy 18

*Press the line-up icon

*Move NAX536 to taxi.

*Move WIF08J to airborne

ATC: WIF08J, contact Approach on 119:60, so long.

*Move WIF08J to handover, 119:60

*NAX536 at gate, archive strip

LN-FTD: "LN-FTD request VFR-clearance to Kjevik via Bryne"

*Press pluss, create new strip, fill form

Do you think this is the relevant information to put in for a new strip.

*Create strip.

ATC: LN-FTD, cleared to Kjevik via Bryne, climb straight out to 20 ft. and continue in G aerospace

*Move Helibuss 153 to final app.

BHL208: "Bristow 208 request start-up"

ATC: "Start-up approved"

LN-FTD: "LN-FTD request taxi"

ATC: "LTD taxi to holding point G1"

*Move LN-FTD to taxi bay.

ATC: "Helibuss 153 winds..., cleared to land, runway 11"

*Move HKS153 to runway bay.

BHL208: "Bristow 208 request taxi"

ATC: "Bristow 208 taxi to holding point H, hold short and wait for landing helicopter."

*Move BHL208 to taxi bay.

*Move HKS153 on rwy bay.

*Move LN-FTD to runway bay.

*Move BHL208 to runway bay.

ATC: LN-FTD, winds, cleared for take-off, runway 18.

*Move HKS153 to taxi

ATC: Bristow 208, winds ..., cleared for take-off, runway 11.

*Press clearance on read-back.

*Move LN-FTD to airborne.

HKS153 at gate Move to archive.

*Move BHL208 to airborne.

ATC: LTD continue VFR, so long.

*Move LN-FTD to 123:50 bay.

Activate SAS87B

ATC: "Bristow 208, contact approach, 119,6, good bye."

BHL208: "Contact approach, 119,6, Bristow 208, bye."

Move BHL208 to hand-over, APP

SAS87B: "Sola, Scandinavia 87 Bravo, request clearance to Gardermoen."

*Press clearance field in strip.

ATC: Scandinavian 87 bravo, cleared to Gardermoen, via UPLEV 1 Golf departure, climb 6000 feet, squawk 2553, QNH 1022.

SAS87B: Cleared Gardermoen, via UPLEV 1 Golf departure, 6000 feet, squawk 2553 and QNH 1002, Scandinavian 87B."

*Activate, SAS4031

SAS87B: "Sola, Scandinavian 87 bravo, request push and start".

ATC: SAS87B, push and start approved.

*Press stand field and then push and start for SAS4031

Adobe XD

Wind direction changes

*Change runway by pressing the number "29" by the runway bay.

"Leader 1, request to pass taxiway Golf from parking."

*Press vehicle button, press Leader 1, put it in taxi

