

RESKILL

PROGRESS REPORT
REV. 2. FOUNDATIONS OF RESKILLING SYSTEMS

TABLE OF CONTENTS

SAMMANFATTNING PÅ SVENSKA	4
INTRODUCTION	5
UPCOMING WORK IN RESKILL 2020-2022, EXECUTIVE SUMMARY.....	5
RESEARCH IN RESKILL 2016-2018: FOUNDATIONS OF RESKILLING SYSTEMS	7
OVERVIEW.....	7
LITERATURE REVIEWS.....	8
INTRODUCTORY FIELDWORK ON INCREASED AUTOMATION AND AUTONOMY IN OPERATIONAL ENVIRONMENTS.....	9
VISUAL BEHAVIOR.....	10
SCENARIO DESIGN FOR RESKILLING IN THE MARITIME AND ATM DOMAINS.....	13
SELF-EXPLAINING AUTOMATION CONCEPT AND DESIGN PROCESS.....	15
INSTRUCTOR SUPPORT CONCEPT.....	22
INITIAL OUTLINE OF REAL-TIME SIMULATIONS 2019-2021.....	26
CAPACITY FOR SIMULATOR STUDIES.....	27
EYE TRACKING CAPABILITY OF RESKILL IN SIMULATOR ENVIRONMENTS.....	29
PROJECT ECONOMY FOLLOW-UP.....	32
COMMUNICATION AND PRESENTATIONS.....	34
PUBLICATIONS BY THE PROJECT MEMBERS.....	34

Jonas Lundberg
Project manager

The RESKILL team
Jimmy Johansson, LIU
Carl Westin, LIU
Aida Nordman, LIU
Billy Josefsson, LFV
Lothar Meyer, LFV
Fredrik Karlsson, Sjöfartsverket
Anders Johannesson, Sjöfartsverket
Jens Gustafsson LFV
Karljohan Palmerius, LIU
Sergey Ignatenko, LIU

SAMMANFATTNING PÅ SVENSKA

Syftet med första delen av RESKILL (september 2016 till 2018) var att skapa grunden för tillämpad forskning i system för reskilling av operatörer inom domänerna sjöfart och flygledning. Vi har etablerat följande grunder:

- Begrepp och operativa scenarier för tillämpning av operatörs- och instruktörsstöd.
- Simulatorlabbmiljöer för tillämpning av koncept, genom en bryggsimulator och en tornsimulator.
- Kapacitet för icke påverkande ögonspåringsstudier (eng. Eye Tracking) i simulatorlaboratorier och för fältstudier.
- Litteraturstudier.
- Initiering av prototyper och test av koncept för operatörs- och instruktörsstöd.

RESKILL har också inspirerat till ett industriellt doktorandprojekt finansierat av VINNOVA, med fokus på reskilling av flygplan/drönarpiloter, vilket startade under 2018.

Huvudmålet i RESKILL är att ta fram grundprinciper för system för 'reskilling' av operatörer och instruktörer, för arbete med automatiserade system. Vi genomför forskning om grundprinciper för visualisering av hur automation fungerar och hur operatörerna arbetar. Med sådana system kommer operatörerna att vara bättre rustade att använda systemet senare, i verkliga operativa miljöer, där principerna för reskilling idag inte används (åtminstone inte i samma omfattning). Dessa koncept är även relevanta för en rad andra domäner, speciellt inom transportsektorn där liknande utmaningar finns.

Det kommande arbetet i RESKILL del två (2020-2022) fokuserar på övergången från att definiera grundkoncept till att utforma och testa olika tillämpningskoncept. Vi kommer att arbeta med prototypdesign, implementering och testning. Forskningsbidragen tar mer grundläggande teorier till tillämpad forskning, som ligger så nära verkliga fall som möjligt.

Vi fokuserar på två olika prototyper, en för sjöfart och en för trafikledning:

- Prototyper för självförklarande automation.
- Prototyper för instruktörsstöd.

Dessa prototyper kommer både att vara del av resultatet (konkretisering av principer) och användas i forskningen, genom att tillhandahålla realistiska data- och applikationsfall. Dessa prototyper kommer också att möjliggöra realistiska övningar, genom implementering i simulatorlabbmiljöer (ursprungligen i vårt laboratorium vid LiU), och tester/demonstrationer med instruktörer och andra intressenter. Övergången från grundläggande forskning till tillämpningar kommer att stödjas genom tillsättandet av en ny referensgrupp under 2019 (från båda domänerna), med representanter från både övning och FOI

INTRODUCTION

The aim of the first half of RESKILL (sept 2016 to 2018) was to establish the foundations for applied research in systems for reskilling of operators in the maritime and air traffic management (ATM) domains. We have established the following foundations:

- Concepts and operative scenarios for applying operator and instructor support.
- Simulator lab environments for application of the concepts, through a ship bridge simulator and a digital (multiple remote) tower simulator.
- Capacity for unobtrusive eye tracking studies in simulator lab environments and for field studies.
- Literature reviews.
- Initiation of prototyping and tests of concepts for operator and instructor support.

RESKILL has also inspired an industrial PhD student project funded by VINNOVA, with a focus on reskilling of aircraft/drone pilots, which started during 2018.

Project aims

The main goal in RESKILL is to uncover core principles for building systems for reskilling for operators and instructors. We conduct research on core principles for visualization of how automation works, and visualization of how operators work – applied to Air Traffic Management and Maritime Piloting. This approach, to use automation to train for automation, is key to maintain performance and quality in the shift toward higher levels of automation. With systems for *reskilling*, operators will be better equipped to use system later, in live operational settings, where the principles for reskilling are not used (at least not to the same extent). This issue is similar for sea and ATM, with applicability in other areas, in particular in the transport sector, facing similar challenges. This addresses societal goals for transportation systems, regarding safety, robustness, and efficiency.

Upcoming work in RESKILL 2020-2022, executive summary

The upcoming work in RESKILL part two focuses on the transition from laying the foundations to designing and testing application concepts. We will work on prototype design, implementation, testing, and refinement. The research contributions are in the move from basic research to applications that are as close to real-world cases as possible. Two prototypes are considered, one for the maritime and ATM domain, respectively:

- Prototypes for self-explanatory automation.
- Prototypes for instructor support.

These prototypes will advance research, by providing realistic data and application cases, challenging the basic algorithms and approaches. These prototypes will also inform practice, by implementation in simulator lab environments (initially, in our lab at LiU), and tests/demonstrations

with practitioners and other stakeholders. This transition from foundations to applications will be supported by the establishment during 2019 of a new reference group from both domains, with representatives from both practice and systems development / research and innovation.

RESEARCH IN RESKILL 2016-2018: FOUNDATIONS OF RESKILLING SYSTEMS

Overview

Work on self-explanatory automation and instructor support has progressed in parallel, increasingly relying on the simulator environment that we have established. While initial efforts were carried out independently of one another, the two RESKILL efforts have utilized a similar research approach and grown closer over time. Although the aim is to cover all aspects of the project from both domains during the full project, initially (to get both parts of the project started) the effort has been unevenly distributed:

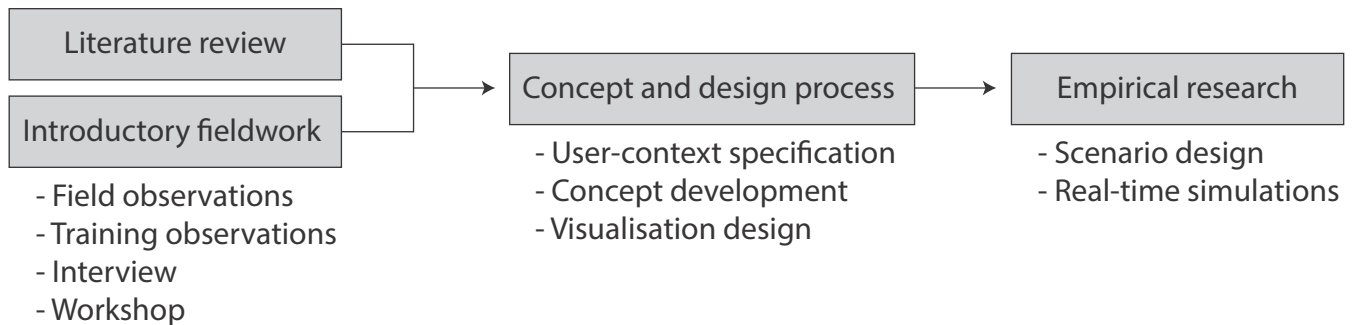
- Instructor support has initially been focused on the ATM domain
- Self-explanatory automation has initially been focused on the Maritime domain.

Considerable efforts have been devoted to the procurement, installation, and training of simulator and eye-tracking equipment. Building know-how and knowledge of how to operate equipment is a time consuming and on-going effort. We have established the use of the following systems in the project:

- SAAB Tower Simulator - Tower air traffic control simulator for multiple remote tower control (system update to fully functional simulator expected around march 2019)
- Transas bridge simulator – Ship bridge simulator for maritime pilots, fully functional.
- Smart Eye – Eye tracking system
 - MAPPS – System used to analyze eye-tracking data, including frame grabbers for capturing video feeds of simulator screens.

The figure below provides an overview of the research activities carried out to address self-explanatory automation:

- Literature review on automation transparency
- Introductory fieldwork
- Automation concept and scenario design for both maritime and ATM domains.
- Implementation of scenario in the maritime bridge simulator
- Initiation of prototype development for the maritime scenario



Research on instructor support has been developing along 5 parallel tracks:

- Literature review on eye gaze pattern analysis
- Initial workshops on training
- Research in interactive visual analysis of sequential data.
- Methods for Automatic Recognition of Areas of Interest (AOI)
- Assessment of eye tracking capability of RESKILL in simulator environments

Literature Reviews

A literature review described previous empirical research on automation transparency. As automation become more complex and autonomous, the requirement for the operator to understand the automation becomes more difficult. Yet understanding is critical if the human is to retain the ability to direct, intervene, and assume responsibility for the automation. Automation transparency is a term frequently encountered in literature from domains of cognitive ergonomics, human-computer interaction, and artificial intelligence. Transparency, it is argued, is an important design guideline of automation, in particular for facilitating trust and understanding. Since characterized as a guideline, one would expect to find literature evaluating the transparency of different systems. The following three aims guided the literature review:

- What characterizes transparent automation?
- How is transparent automation achieved?
- How does automation transparency affect human-automation interaction?

The transparency literature showed that there is a lack of empirical research exploring automation transparency. Findings, however, suggest that increased automation transparency benefits human understanding of the automaton (e.g., in terms of why it makes a certain decision or action or why it errs), benefits trust in the automation, improves decision-making, and reduces workload. The review provided a state-of-the-art baseline of automation transparency design principles for developing the concept of self-explaining automation (described under the section Operator Support Concept).

A literature review on eye gaze pattern analysis was also conducted resulting in a state-of-the-art paper. The review was structured around the two main challenges. These are:

- (1) the identification of meaningful areas of interest from the collected eye-tracking data and the extraction of sequences of visits,
- (2) the identification of efficient sequence mining algorithms to be tightly connected with advanced visualization and interaction techniques in order to automatically identify and analyze eye-gaze sequence patterns.

The report investigated current methods dealing with visualization of attributes of eye tracking data AOIs. State-of-the-art techniques (such as space time cube, transition matrices, graphs and trees) are not suitable for analysis of visual clutter, caused by large volumes of eye tracking data. By user-driven exploration it is possible to search for highly visited or less frequented AOI sequence paths. The selective AOI sequences identified by the user can be visualized in, for example, a modified scatterplot by presenting a timeline view and duration information of AOI sequences. Visual clutter is reduced since only the selected scan path sequences based on user interest are displayed. It is hoped that this paper can motivate scientists to deal with visualization methods of temporal AOIs with a more intuitive, data analyst centered visualization approaches.

Introductory fieldwork on increased automation and autonomy in operational environments

A considerable effort was to familiarize and understand the common challenges of increased automation and autonomy for maritime pilots on modern ship bridges, and tower air traffic controllers facing control of multiple aerodromes. To gather an understanding on the unique challenges in each domain, numerous field and training observations, interviews and workshops were carried out.

Maritime piloting

The introductory fieldwork in the maritime domain consisted of two qualitative participatory field studies, a semi-structured interview, and a workshop. Details of these activities can be found in the previous progress report.

The fieldwork activities led to several important outcomes. First, they provided insight and understanding of the automation-related challenges in maritime piloting. Second, they shaped the concept of self-explaining automation and development of a Predictor prototype. Third, they contributed to the development of key scenarios to be simulated. These scenarios will be used to evaluate the self-explaining ability of the Predictor prototype and the instructor support concept.

Multiple remote tower operations

Introductory fieldwork in the ATM domain consisted of two qualitative participatory field observations, a workshop, and two semi-structured interviews. This was reported in the previous progress report.

Findings thereof have led to the development of a self-explaining automation concept aiding tower controllers in controlling two airports simultaneously. In addition, a basic scenario has been developed for empirically evaluating this automation prototype.

Visual behavior

Due to the highly visual nature of the control environments of both domains, a specific research effort was directed towards visual behavior in training. During the workshops and other communication with the LFV training department in Halmstad it became clear that tower controllers' visual behavior is not formally trained. This can to a large extent be explained by the lack of a defined baseline for visual behavior in tower control. It appears that while visual information is the main information source in tower control, as for most activities in general, standard operating procedures detailing visual behavior have not been considered. This does not mean that visual behavior is not important or has not been considered in training of tower controllers. To the contrary, it is very important and there are some clear visual patterns that controllers are being taught. Some visual behaviors have also been noted in training material. However, to a large extent the responsibility to teach visual behavior resides with the instructor. Different instructors have slightly different approaches. Ultimately the student is left with a difficult task to self-identify many patterns and derive a suitable visual behavior that works for that person.

For RESKILL this lack of a standardized visual behavior provided a research challenge in that instructors found it difficult to specify what visual behaviors there are. This in turn makes it difficult to assess visual behaviors. As such, for the development of a support tool for observing students' visual behavior, there is a need to support the identification of visual behaviors (and perhaps for instructors to agree on a baseline). In the short-term, LFV Halmstad were very motivated to determine visual behaviors for different situations that could be integrated as a standard for teaching new tower controllers.

A baseline simulation took place at LFV training facilities in Halmstad on March 19, 2018. During this simulation, two experienced controllers played the RESKILL scenarios (one IFR landing, one VFR landing, one IFR departing, one VFR departing) using portable (Tobii Pro Glasses 2) eye-tracking equipment. In addition to test and evaluate the usefulness of the scenarios, the purpose of the recording was to gather data on both controllers' visual behaviors during these basic traffic movements. Moreover, eye-tracking data can be used to generate a baseline for visual behavior against which empirical data of future RESKILL simulations can be compared and analyzed.

A subsequent workshop was carried out at LFV Halmstad together with three instructors. One of the instructors was also one of the air traffic controllers participating in the baseline simulation and eye-tracking data collection. The goal of the workshop was to:

- Define areas of interest (AOI) for different movements (landing and departing traffic)
- Tie visual behavior to the work analyze of respective movement.
- Determine the accuracy of the eye-tracking data

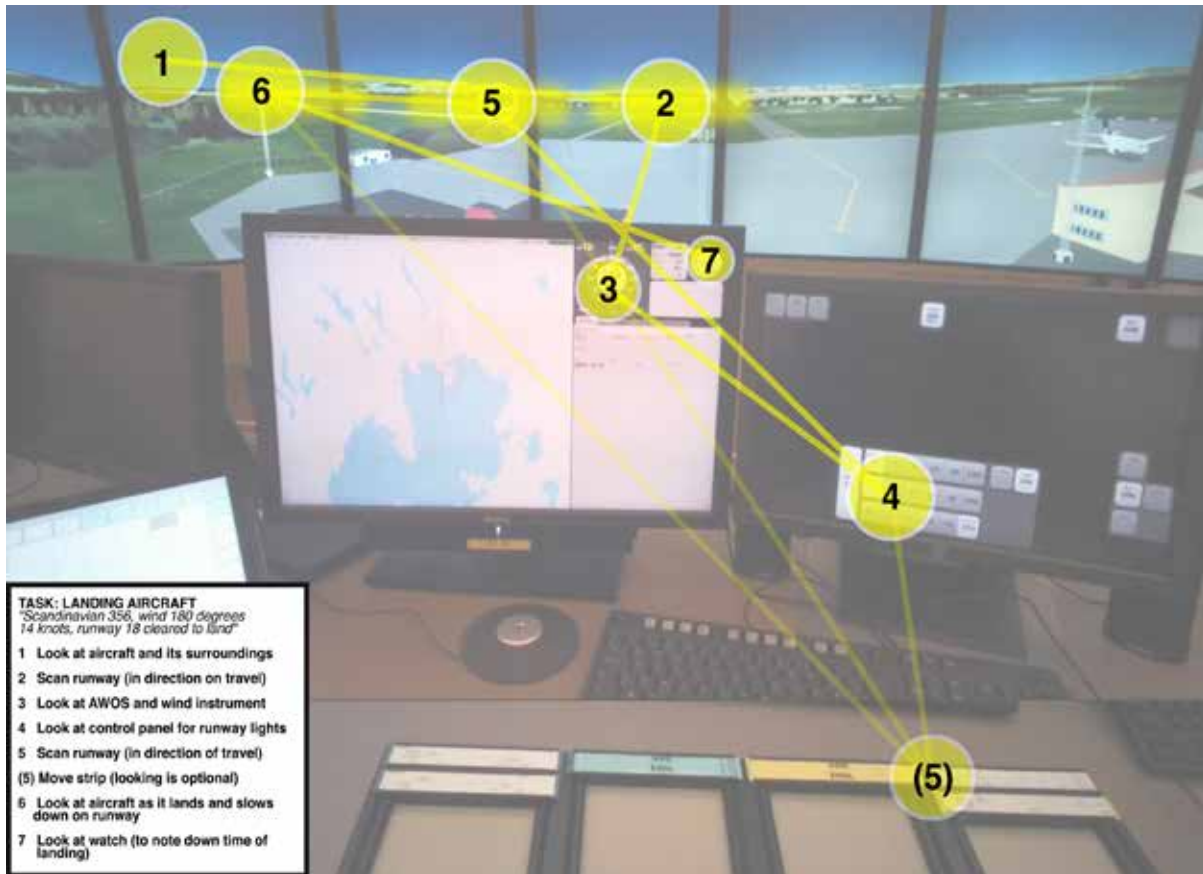
- Determine the possibility of identifying gaze patterns for different activities.
- Discuss the usefulness of eye-tracking in training.
- Validate the preliminary data analysis of gathered eye-tracking data.

As a preparation for the workshop, videos of each controller's eye-tracking data were analyzed and transcribed in a hierarchical chronological order. This resulted in a task analysis with visual behavior for each traffic movement (the two landing and two departing aircraft).

The main results are as follows:

- Standard for visual behavior patterns during task of providing clearance to land and clearance to takeoff.
- Realized benefits of eye-tracking in training among instructors.
- Identification of suitable Areas of Interest during landings and takeoffs.
- General visual patterns identified (the "time glass" and "wagon-wheel").
- Desire for creating a training video consisting of a video replay with correct visual behavior for different scenarios and tasks (e.g., when instructing cleared to land).

The figure below illustrated the agreed visual behavior that controllers should use when clearing an instrument flight rules (IFR) aircraft to land during visual meteorological conditions.



The next figure illustrates the AOI derived from the workshop with the instructors. Using these derived AOIs, it is possible to in the data “see” the visual pattern illustrated in above figure. Moreover, the definition of AOIs and identification of a standardized visual gaze pattern for landings and takeoffs will aid analysis of forthcoming experiments investigating the self-explaining automation concepts and instructor support.



Scenario design for RESKILLING in the maritime and ATM domains

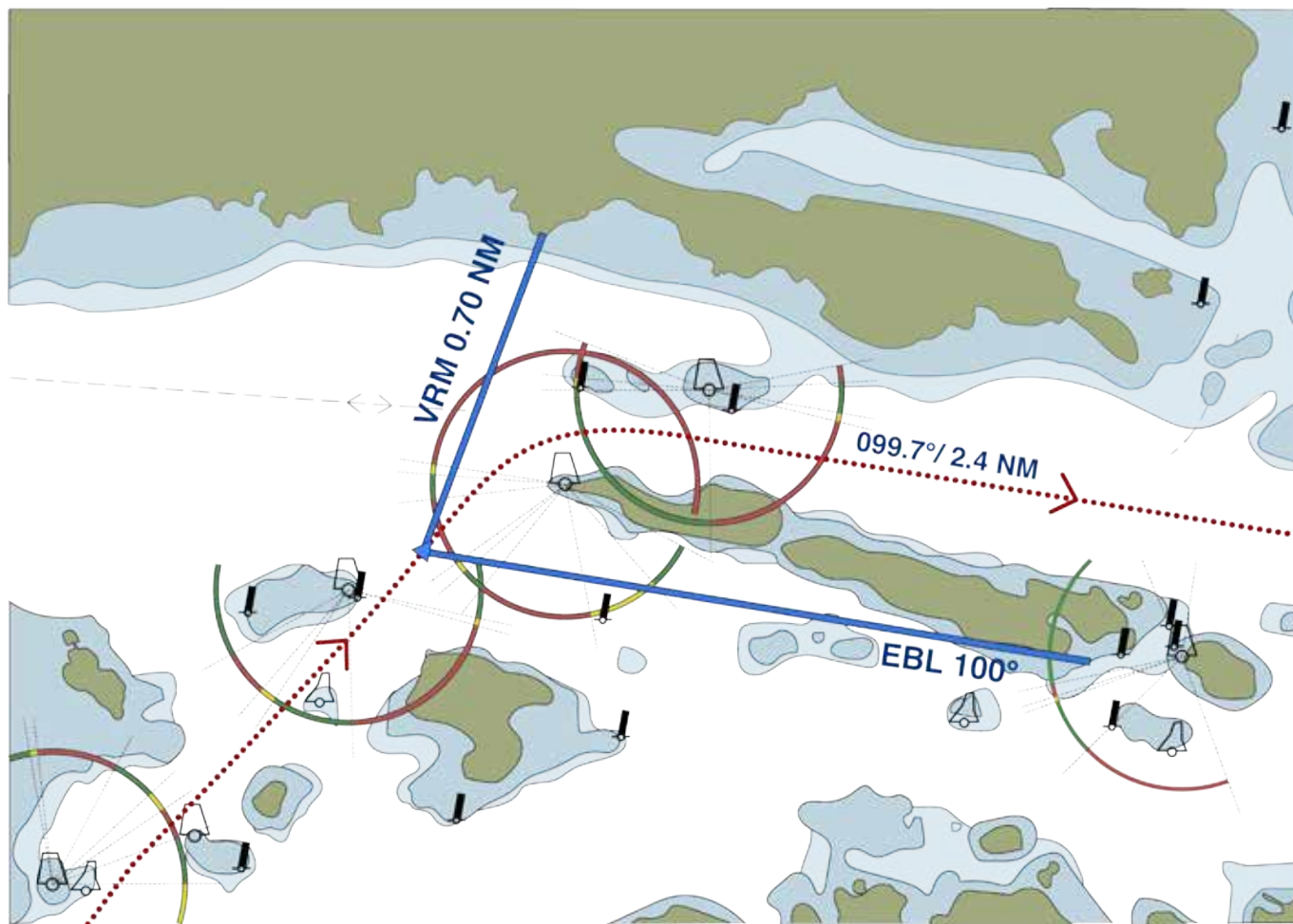
Key scenarios have been developed for each domain. These respective scenarios will be used to empirically explore the respective automation concepts and instructor support concepts in each domain.

Maritime piloting scenarios

Use of the Predictor is particularly critical during turns. Therefore, the scenario chosen for the maritime domain consists of different challenging turns. The baseline scenario has been defined as the “Granholmen turn.” Granholmen is an island in Stockholm Archipelago around which pilots have to turn, representing one of the most critical passages inbound to and outbound from Stockholm harbour. The scenario is scripted so that the Pilot will have to rely primarily on the Predictor. This is primarily achieved by reducing the visibility from the ship's bridge. With limited ability to verify the Predictor's prediction, the Pilot's understanding of the Predictor become increasingly important for the success of the turn.

The figure below illustrates the Granholmen turn. The red dotted track shows the intended track of the ship sailing outbound from Stockholm harbour. The ship must make a sharp turn to the right around Granholmen. It is a tight turn with little margins for error. The blue lines (VRM 0.70 NM

and EBL 100) illustrate cues that the Pilot uses to judge when to start the turn. Among other things, the complexity of the turn is tied to the size and characteristics of the ship. For purposes of using a challenging scenario, a large sized Container ship has been chosen. The container ship is 177,5 meters long, 30,5 meters in breadth, with a draft of 9,5 meters, and max speed of 18,8 knots. The ships displacement is roughly 30 000 tons.



Multiple remote tower operations scenarios

For ATM, the *Twin Airport* scenario focuses on future automation (that we will build a mock-up of) for management of simultaneous operations on the two airports. It is relevant, since the operator can become a bottleneck for multiple remote operations. In particular, if operations at one airport (e.g. a take-off) must wait for the completion of operations (e.g. a landing) at another airport. The level of automation is higher, since the support (the mock-up) will be in the form of a cognitive companion, that presents the plan of the whole maneuver (i.e. the whole landing) to the ATCO, and also monitors it for deviations, as directed by the ATCO.

The specific aerodromes have not yet been defined for the scenario because of delays with the simulator and uncertainties in terms of aerodromes included in the database. However, the aerodromes chosen will be small to medium sized aerodromes, representative of the business case for remote tower aerodromes. Aerodromes specifics are, however, of less importance since the traffic scenario is generic in nature and can be applied to any aerodrome couple. The scenario consists of a sequence of two landing aircraft and two departing aircraft, with movements occurring simultaneously at both aerodromes. Note that this capability of simultaneous operations goes beyond current operational concepts of multiple remote tower operations.

One landing aircraft consist of a commercially flown Boeing 737 jet under instrument flight rules (IFR). The other landing aircraft consist of a privately flown Cessna 172 under visual flight rules (VFR). These two variants were chosen as they make up the majority of traffic to the type of aerodromes considered susceptible for remote tower operations.

Self-explaining automation concept and design process

Results from the fieldwork conducted in the two domains, together with literature on automation transparency, drove the development of the self-explaining automation concept. Both domains are expected to increasingly utilize automation. Not only will there likely be more automation, but also more advanced and complex automation. The fieldwork indicated that operators already experience challenges with understanding and using current automation in both domains. Moreover, the fieldwork showed that there are concerns in both domains that these challenges will exacerbate with the introduction of more automation. The literature review on automation transparency shows that these concerns are widespread across domains and not unique to the maritime and ATM work environments considered here. Research on automation transparency argues that human understanding, trust, and use of automation can benefit if the automation can explain its behavior. As a way forward, operators should be able to question the automation's decision-making, actions, and judgments. The concept of self-explaining automation expands on this notion as an essential automation functionality capturing the automation's ability to communicate its behavior and intentions.

Maritime piloting: The self-explaining Predictor

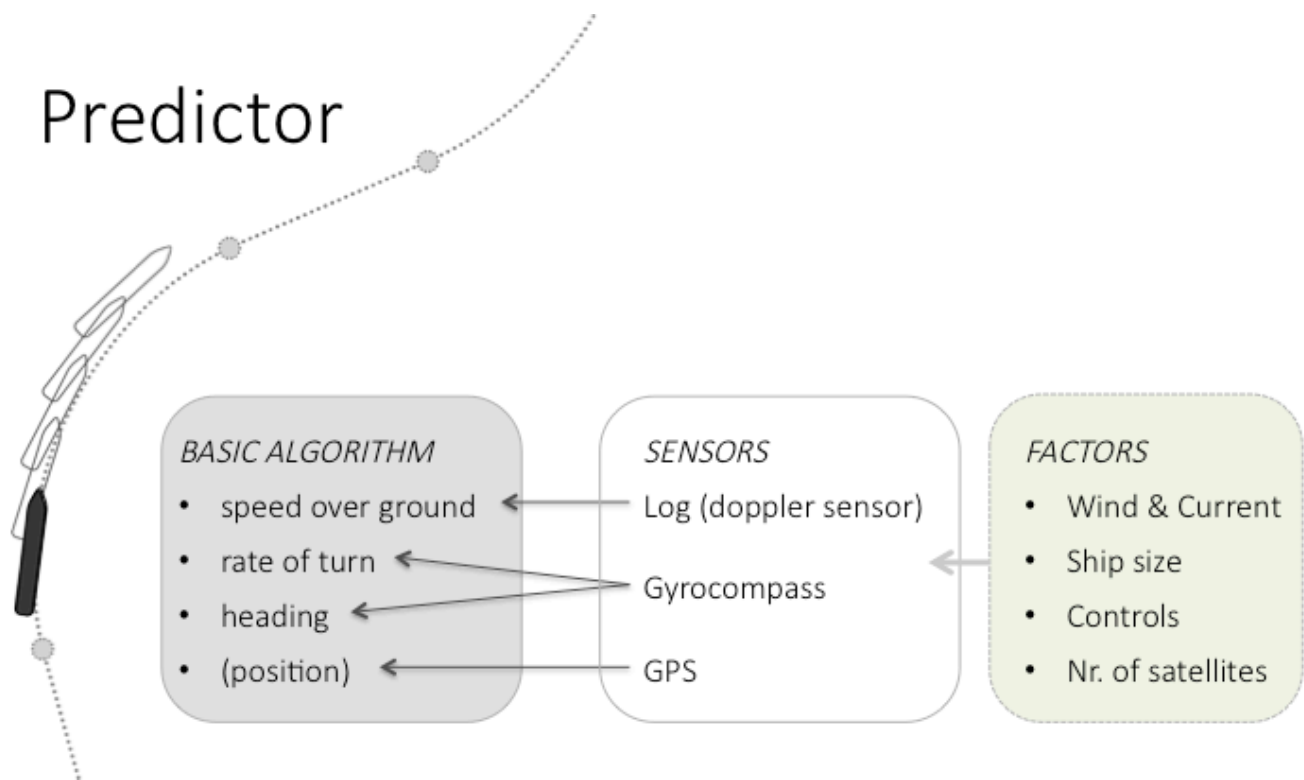
The currently used Predictor is a navigation aid that visualizes the vessels historical position and predicted position. The Predictor is visualized on the electronic chart display and information system (ECDIS), the Radar, and on pilots' own portable pilot units (PPU). The positions are based on an algorithm incorporating different information and the application of user-defined settings. The Predictor provides an 'absolute' prediction of the ships predicted position over time, usually in the range 0-6 minutes. It is absolute in that it shows a single position prediction without any uncertainty. While the prediction provides a 'best guess' of the ship's future position, there can be considerable uncertainty. Current Predictors do not provide information on the uncertainty associated with a prediction. Instead, this has to be estimated by the user of the Predictor.

The Predictor function was considered particularly interesting for RESKILL as it constitutes an existing decision aid on board modern ship bridges that can be difficult to understand. The

Predictor is also representative for the type of automation that is likely to become more common on ship bridges. Maritime pilots will increasingly interact with advanced automation, such as the Predictor, which necessitates a good understanding of how it works.

A review of maritime incidents and accidents involving the use of the Predictor indicate that current day Predictors are not transparent and fail to facilitate an adequate understanding of how they work, why a certain prediction is derived, what the uncertainties is to the prediction, and how different errors (e.g., to critical input sensors such as the GPS) affect the prediction.

A basic Predictor algorithm consists of three information sources: the speed over ground (SOG), the rate of turn (ROT), and the heading (H). For navigational purposes this information must be related to the position of the ship. The information is derived from two or three sensors: the log which provides SOG, the gyrocompass which provides ROT and H, and the GPS which provides position. Note that the GPS also can provide the other measures. The sensors are, in turn, affected by many different factors including environmental factors (notably wind and current), ship size, its control, and its hydrodynamic characteristics, number of satellites (for GPS accuracy) etc.

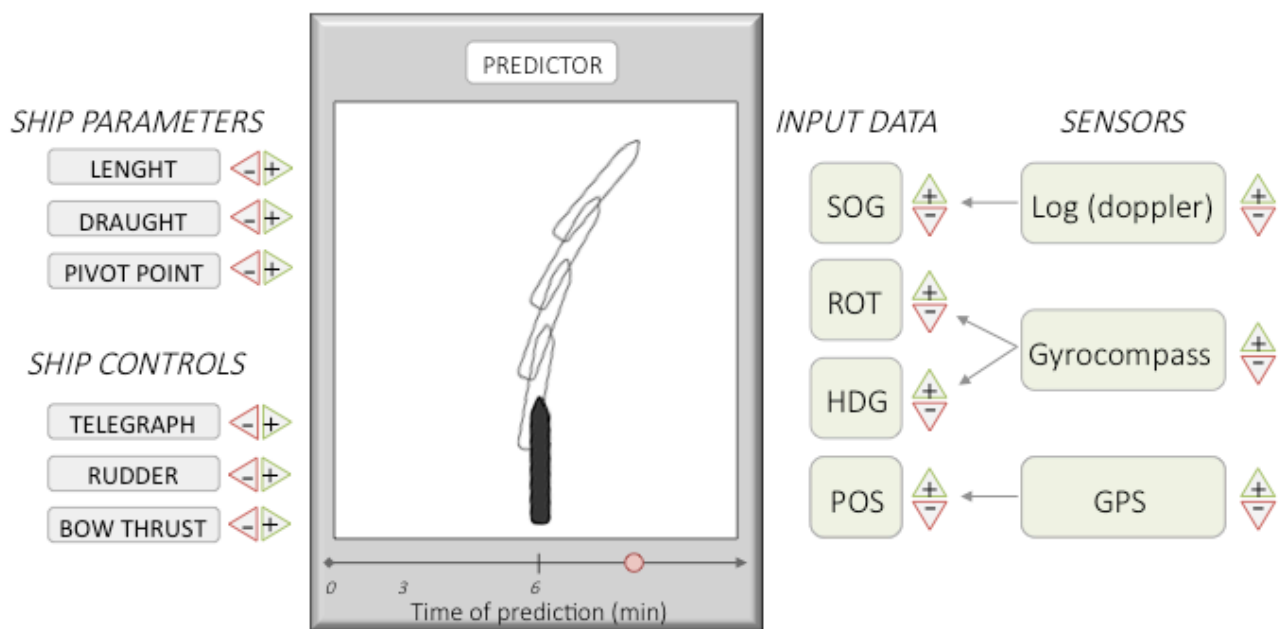


The RESKILL team is currently underway with developing a self-explaining automation prototype of the Predictor. To increase pilots' understanding of the Predictor, it should be able to address the following questions:

- How does the Predictor work (algorithm)?
- Which sensors does the Predictor use?
- How does different input errors affect the Predictor?
- How certain is the prediction?
- Which limitations does the Predictor have?

The Predictor prototype (see an initial sketch, below) should allow operators to play around with the algorithm, the sensors, and factors affecting them. A better understanding thereof is believed to result in a better understanding of how the predictor works, when it can be trusted, and when it should not be trusted. How to utilize the Predictor prototype in order to gain the most effective reskilling must be evaluated. While real-time integration with the simulator has been set as a goal, there is a risk that the operator is overloaded with information. An alternative approach would be to have the operator work with the Predictor prototype as a standalone application, strictly for the purpose of improving the operator's understanding of the Predictor. This would allow the operator to play around with the Predictor free of time pressure and stress, which would not be possible in many real-world situations.

The self-explaining Predictor



Multiple Remote Tower Control: The self-explaining Controller Assistant

Digital tower technology has opened up possibilities for one controller to simultaneously control more than one aerodrome. Although multiple remote tower control has not yet been implemented, it is considered an important next step for increasing the efficiency of air traffic services. Research on multiple remote tower control, however, indicate that there is a considerable risk that the

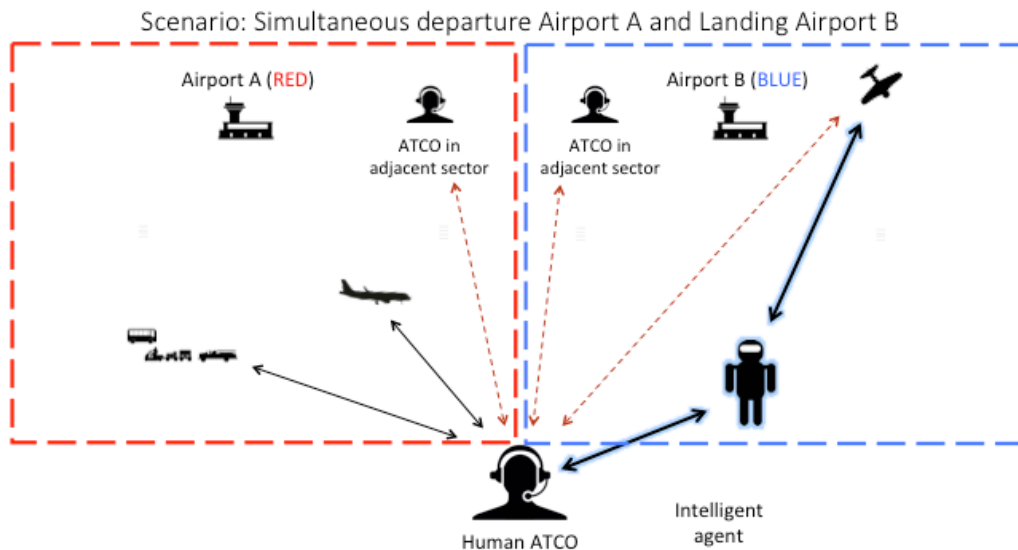
controller becomes overloaded if there are simultaneous movements at both aerodromes that require the controller's attention. As a solution it has been suggested that traffic flows should be controlled so that critical movements do not occur simultaneously at both aerodromes (e.g., avoid landing at airport 1 occurring simultaneously as a takeoff occur at airport 2). Unfortunately, this approach greatly restricts the potential benefits to efficiency of multiple remote tower operations.

As a way forward, increased automation support could alleviate the controller to allow for multiple remote tower operations. Inspiration for this approach was found in previous research by Hexmoor and Heng around year 2000¹, who explored artificial intelligent agents aiding tower controllers in monitoring traffic, identifying conflicts, and process landings. In their study only one aerodrome was considered. In context of multiple aerodromes, the controller could delegate functions on one aerodrome to an intelligent agent. This agent, or *controller assistant*, could support handling of traffic at the less demanding aerodrome, allowing the controller to attend to more demanding tasks at the other aerodrome.

The automation concept is illustrated in the figure below. There are two aerodromes: the red and blue. In the following scenario, the human controller delegates the monitoring of an approaching aircraft for landing at the blue aerodrome to the intelligent agent. The intelligent agent only controls airborne movements, while the controller remains in control of all ground movements at the blue aerodrome. Note that this is a scenario-specific limitation for the purpose of forthcoming RESKILL simulations. Conceptually, it would be practical if the intelligent agent could handle both ground and air movements.

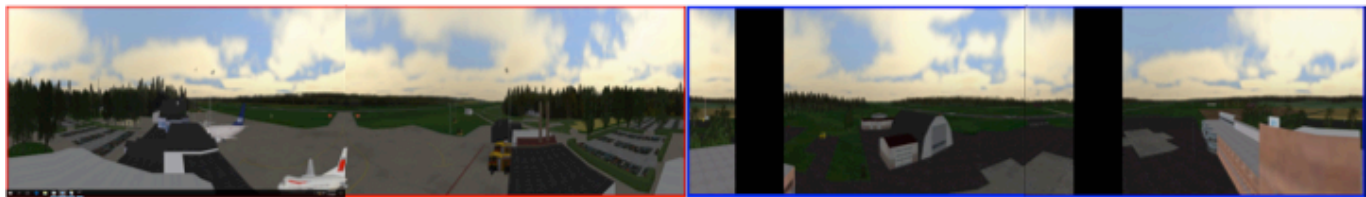
At the same time, the controller is handling traffic at the red aerodrome, where an aircraft is expected to depart simultaneously as the aircraft is landing at the blue aerodrome.

¹ Hexmoor, H. and T. Heng. *Air Traffic Control Agents: Landing and collision avoidance. Proceedings of the International Conference in Artificial Intelligence (IC-AI)*. 2000. Las Vegas: CSREA Press.



The figure below depicts the controller's working position in the SAAB tower simulator. There is an out-the-window view (OTW) for both the red and blue aerodrome (each displayed on two large screens). On a table in front of the controller there are three screens. The voice communication system (VCS) provide the means for communication with actors at both aerodromes. The electronic strip (e-strip) is a physical representation of the controller's mental model of traffic movements at an aerodrome. It allows the controller to track and anticipate movements, while assuring safe separation. In the SAAB tower simulator, one electronic strip is provided for each aerodrome, together with and runway configuration information such as runway and taxiways lights and activated navigation aids. Finally, the radar screen provides a geographical overview of traffic at both aerodromes and their vicinity. In addition, the radar screen provides the controller with weather information on the automatic weather observation system (AWOS). The radar screen provides important information about traffic at an in the vicinity of the aerodrome that is beyond the visual view on the OTW. For controlling traffic in immediate proximity to the aerodrome, the controller relies on the OTW as long as there is adequate visibility. As such, during low visibility conditions, information provided by the radar becomes increasingly important. Results from the fieldwork made clear that the OTW and radar are susceptible to increased integration with automation.

Out-the-window view



Airport A

Airport B

Technical equipment



VCS

E-strip

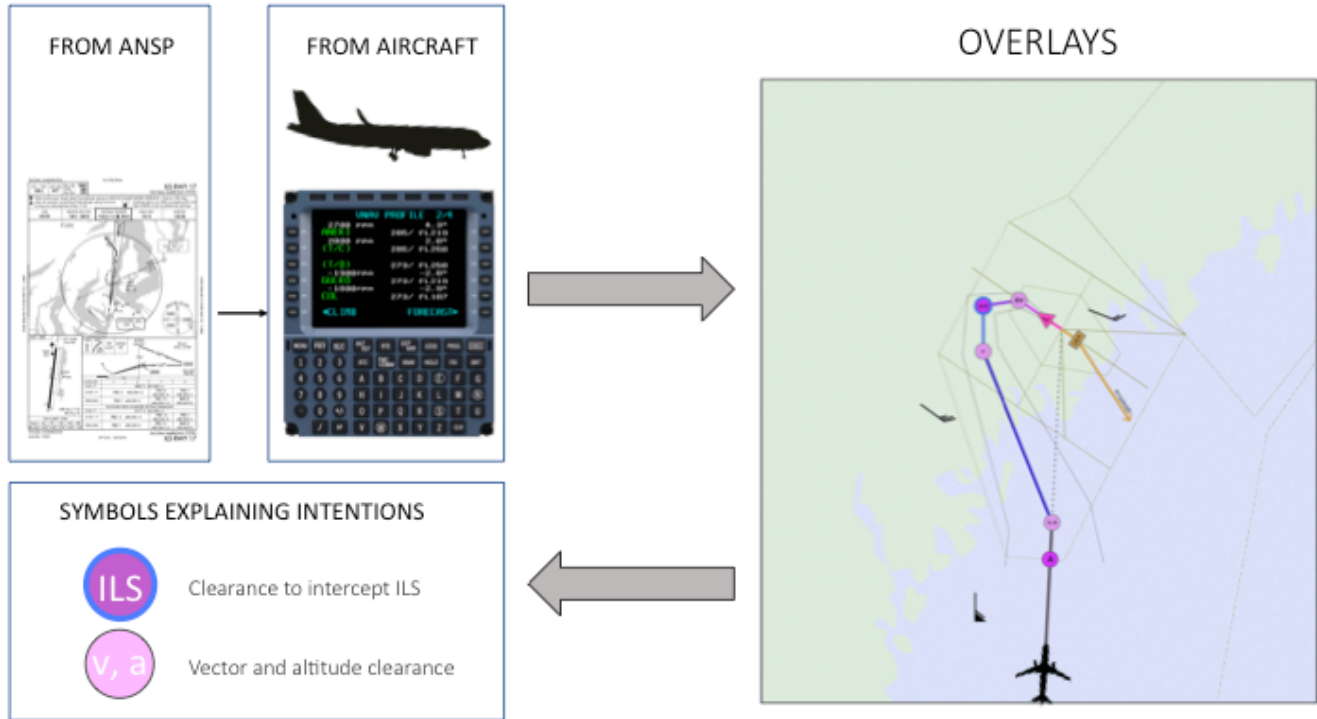
Radar



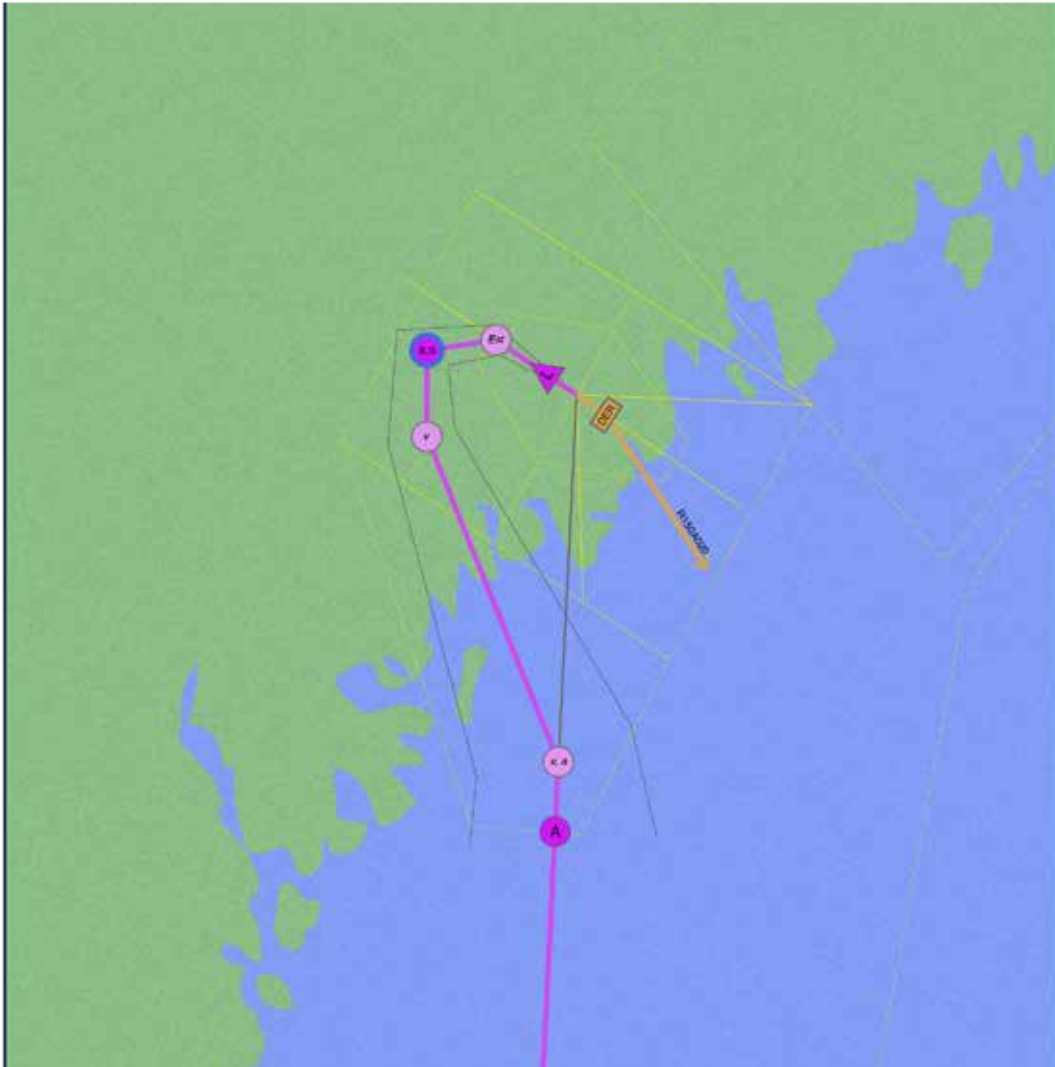
Human ATCO

The self-explaining controller assistant prototype will explore visual overlays on the OTW and radar. The figure below illustrates how the controller assistant will work in a scenario involving an approaching aircraft for landing. Air navigation service providers (ANSP) participate in determining standardized routes in and out of the aerodromes terminal area. Inbound routes are referred to as standard terminal arrival routes (STAR). These are connected to runway-specific approach routes, such as ILS, VOR, or RNAV approaches. Tower controllers make use of these routes to manage and separate inbound and outbound traffic to aerodromes. Inbound routes are primarily chosen depending on the current weather conditions and from where aircraft are arriving. Controllers instruct pilots which STAR and approach they should use. Pilots program their aircraft's flight management computers (FMC) with these routes. The aircraft's computer system then computes target speeds and altitude levels along the route.

Our automation concept assumes that the controller assistant can retrieve the route as planned in the aircraft's FMC. Note that this capability of aircraft avionics currently is being used to a limited extent and will continue to expand. With detailed information about the aircraft's calculated route, the controller assistant will be able to provide a more accurate 4D trajectory for the aircraft, predicting where the aircraft will be at what time. The controller assistant can visually present this information on the radar screen and the OTW. Coloring and symbols can be used to communicate the intentions of the aircraft and the controller assistant to the controller. For instance, circles can be used to illustrate positions along the route where the controller assistant intends to provide vector and altitude clearances, or a clearance to intercept the ILS approach for a specific runway.



Critical for the successful teamwork between controller and automation, is that the controller understands the automation and its behavior. Thereto, the automation must be able to explain why it is doing something, how it intends to do it, and when. The intentions of the controller assistant for the landing aircraft can be seen in more detail in the figure below. By providing these symbols and coloring cues, the controller assistant is able to explain how it intends to manage the arriving aircraft. The controller assistant could brief the human controller on its intentions already before the aircraft arrives. The human controller should be able to question the controller assistant and modify the plan if needed, before approving it. Subsequently, the visual overlay could be shown during the approach to allow for comparison between intention and actual outcome, improving detection of deviations.



Instructor support concept

Since the operator environments in both domains are highly visual in nature, visual attention is an important aspect of operator work (and operator training). Eye movements can be captured by the use of eye tracking equipment.

Eye tracking equipment records eye movements, summarized as fixations (usually, several fixations per second). The result of recording e.g. 40-minute training scenario in a simulator is an enormous amount of information about eye movements, and a sizeable data set about what happened in the scenario itself. The challenge is to convert this dataset to meaningful information about visual attention and uncover problem solving strategies used in operator training scenarios,

to support instructors. Current (off-the shelf) approaches are limited and can only provide meaningful information after considerable manual analysis. These approaches are typically based on heat maps and gaze plots. When dealing with long duration experiments, as in the case of operator training scenarios, heat maps and gaze plots lead to visual clutter making it nearly impossible to analyze operator's behavior.

The main motivation of this work is, therefore, to develop techniques that support the instructors in the exploration of the tasks performed by operators in very long duration eye-tracking experiments.

Challenges and approaches

Currently, we address two challenges, to form the basis of innovative tools. The first challenge regards sequences. The instructor needs to know to what extent the operator has looked at the "right" regions in the display and outside the display, in the right order, versus the temporal sequence of what goes on. Since the knowledge of what is right lies with the instructor, this tool must be interactive. To address this challenge, we propose a system using interactive visual sequence mining which allows instructors to explore the strategies used by operators to solve the problems encountered during training scenarios (e.g. an aircraft landing).

The second challenge regards AOIs, in particular to be able to identify (from the data) what areas (and objects) were actually of interest to the operator. A common alternative is to base this step on manual marking of AOIs, relying on assumptions on what should/could be of interest. That approach has two main drawbacks. First, it can miss what operators actually found interesting and, second, it does not account for the temporal characteristics of the AOIs and the changes they may display during the course of an instruction scenario. Again, the instructor must be able to compare actual AOIs to the areas that (in their view) are/were critical to attend to. To address this challenge, we are working on a technique that allows automatic detection of areas of interest from the datasets collected during training scenarios.

Interactive Visual Analysis of Sequential Data

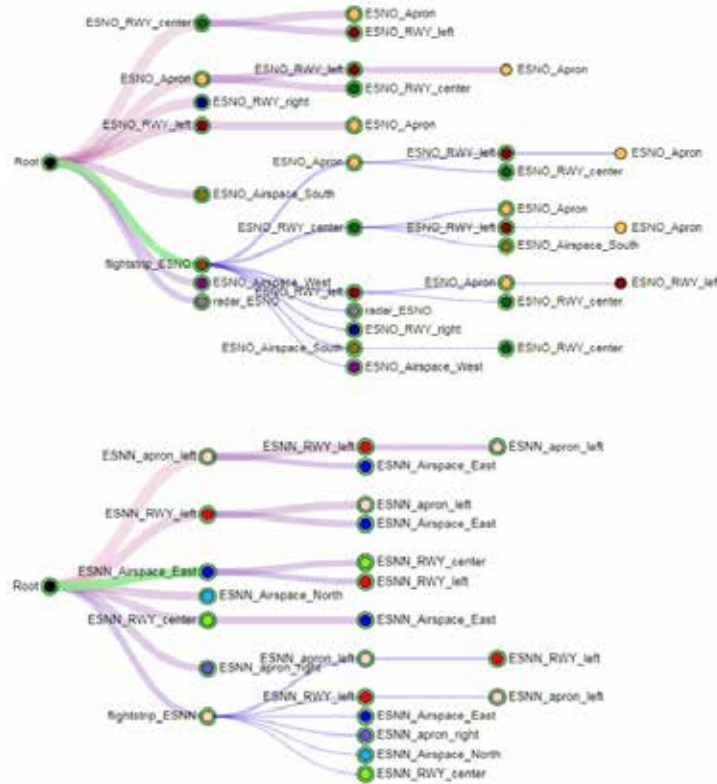
This part of the project is concerned with the research and development of effective interactive visual sequence mining approaches for the identification and analysis of eye-gaze patterns of trainees (operators) using a simulator. In this way, it is possible to support instructors in finding patterns of operator's attention and analyze operator's behavior during training scenarios.

As a first step in this direction, a novel approach to interactive visual sequence mining has been proposed that allows the user to guide the execution of a pattern-growth algorithm at suitable points through a powerful visual interface. The proposed approach (1) introduces the possibility of using local constraints during the mining process, (2) allows stepwise visualization of patterns being mined, and (3) enables the user to steer the mining algorithm towards directions of interest. The use of local constraints significantly improves users' capability to progressively refine the search space without the need to restart computations. The approach has been implemented within a prototype system named ELOQUENCE (for ExpLOratory seQUENCE mining). This

research was accepted for publication in the peer reviewed IEEE journal “Transaction on Visualization and Computer Graphics” (TVCG), in June 2018.

The system supports the mining of patterns in datasets composed of sequences of ordered events and of temporal event sequences, where each event has a timestamp associated with it. Data collected during eye-tracking experiments consists of temporal event sequences, where events correspond to areas of interest (AOI). For instance, an AOI can be “runway” (in figure below, named as “RWY”) or “flightstrip”. ELOQUENCE has been extended with a specific algorithm to mine long event sequences, since datasets obtained from ATC training sessions consists often of a small number of very long sequences.

Two main views compose the system. A pattern view in which patterns are visualized stepwise as they are grown by the mining algorithm and, consequently, allow the instructor to gain a gradual understanding about the dataset (i.e. the behavior of the operator during the training session). For instance, by inspecting the figure below, we can see that looking at the apron, followed by looking at the runway, and then looking back at the apron section is a common scanning behaviour used by the operator for both airports. For both airports, after looking at the flightstrip, the operator often looks at the apron or runway.



The pattern view can be complemented by the sequence view which displays a scarf plot showing both the sequence of events over time and the events' duration. For instance, the pattern view in

the figure below shows a pattern that involves shift of attention between both remote airports through the flightstrips, i.e. the operator tends to look at the flight strip for one airport and then (soon after) looks at the flightstrip of the other airport, too. The scarf plot (on the sequence view) shows a specific instance of this occurrence (on the right side). In addition, it is possible to click on a specific event in the sequence view and launch the video widget supporting frame navigation synchronized with events. The three views (pattern view, sequence view, and video view) allows the instructor to explore the behavior of the operators, from training sessions.



During 2018, the ELOQUENCE system has been improved in the following ways.

- Added a video widget with frame navigation synchronized with selected events.
- Improved scrolling in the sequence view.
- Added visual cues in the sequence view for ease of event navigation.
- Implemented an algorithm to mine patterns within long duration event sequences.

We have also converted two groups of datasets to the appropriate format for input into the system and are currently analyzing them.

- One dataset was obtained during a training session involving multiple remote control tower with one operator.

- The second group of datasets was obtained during a training session consisting of four scenarios, two aircraft landings and two takeoffs, each performed by two participants. One of the goals in analyzing these datasets is to discover baseline eye tracking patterns.

Automatic AOI recognition

In order to be able to explore eye-tracking data and extract eye-gaze patterns using sequence mining approaches, the data need to be converted into an appropriate format. From continuous measurements of eye-gaze positions, the data need to be translated into movements between discrete areas of interest, i.e. sequences of AOIs. This operation could be performed manually by pre-defining a fixed number of AOIs and registering the order in which these are visited by the continuous eye-tracking data. Using such a manual approach, however, often ignores the temporal characteristics of the data and can miss how different AOIs may be appearing or disappearing or changing importance and shape over a period of time in response to altering workload, emergencies or other variables.

To this end, we have been researching and implementing a method to automatically identify dynamic AOIs through a combination of clustering and cluster merging in the temporal domain. Through an interactive interface, the analyst is able to control this merging to explore user behavior and identify changes in response to changing conditions. Using this proposed method, it is possible to import the raw data collected using stationary eye-tracking devices (such as the Tobii Eye Tracker or the Smart Eye Pro tracker) and automatically extract a set of dynamic AOIs. Following this, the AOIs can be labelled appropriately and the order in which they are visited by the continuous eye-tracking data can be registered in order to extract sequences of AOIs that can be further analyzed with the researched interactive visual sequence mining approaches mentioned above. The initial parts of this research (the automatic AOI identification) have been presented in a paper accepted to the 20th Eurographics Conference on Visualization. The latter part of the research, namely the translation to sequences of AOIs for further analysis is currently ongoing.

Currently, we are evaluating the application of this approach with relevant datasets for RESKILL, collected by LFV. We will then evaluate how it can be used as part of our instructor support tool concept.

Initial outline of real-time simulations 2019-2021

One overall experimental design has been drafted. This design will be specified in detail for each domain. The use of a single overall design is necessary in order to facilitate comparison between the two domains. The underlying research question is: How does the visualization of the automation's algorithm affect operators' performance and understanding of the automation's behavior? The design consists of a within-participants design with three conditions of automation support

- No automation (control condition)

- Basic automation
- Self-explaining automation prototype

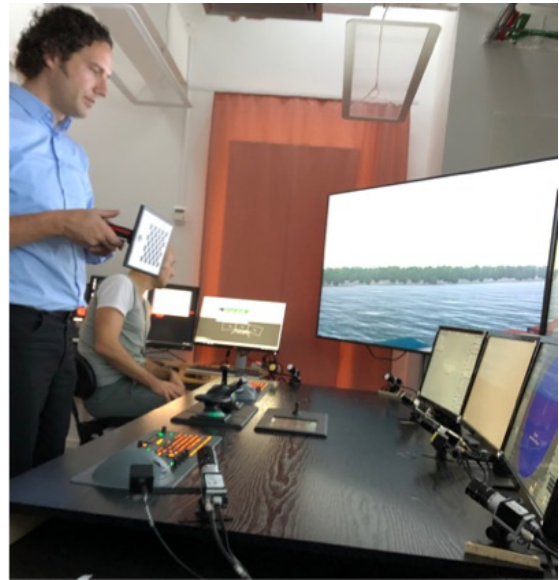
Currently, there are two independent variables: self-explaining capability (on or off) and automation uncertainty/accuracy (high or low). Uncertainty could be introduced by, for example, introducing errors to different sensors. Several dependent measures are being considered, including understanding, trust, performance, and workload. Understanding, trust, and workload can be measured through subjective questionnaires. The simulator allows for measuring any interaction with the simulator, such as inputs to controls, keyboards, toggle switches, and the trackballs. All choices and settings on displays and instruments are also recorded. The entire simulation session is saved and can be replayed at a later moment. This allows for investigating different performance related measures. In addition, eye-tracking equipment will be used to measure the operators' visual behavior.

It is hypothesized that understanding, trust and performance will benefit from using the self-explaining automation prototypes, especially in light of high uncertainty. Performance, for instance, can be measured by cross track deviation from optimal route. Conversely, workload is expected to decrease with self-explaining automation.

Capacity for simulator studies

We have built a lab environment to be able to prototype and test the RESKILL concepts. During 2018, LiU has built two new simulator rooms for the project, connected by a large window. This allows a traditional setup with test leaders in one room, and test participants in the other room. Our installation also has a dedicated server room next to the simulators, with a local network that is fully separated from the university network.





For the ATM domain, we use a multiple remote tower simulator provided by SAAB, currently (predicted for march 2019) being upgraded to the latest version. We are also changing the screens to 55" and will re-purpose the four current screens for simulator pilot and training leader positions.

For the maritime domain, we use a ship bridge simulator (procured from Transas). The installation is complete for usage of the simulator, and simulator training has been performed.

In addition to the core simulators, we have also built up positions for two additional simulator pilots for the ATC simulator, and one additional instructor position for the Maritime simulator (one in each room). A high capacity backup solution for saving data and backing up the simulator software has also been procured and installed in our server room.

We have procured two eye tracking systems. For field studies and situations when a short setup-time is required, we have procured two Tobii Glasses 2 systems, one at LiU, one at Sjöfartsverket. For studies where more setup-time is available, and where a shorter time for analysis is a priority, we have procured the Smart Eye Pro system. To use with the SmartEye system, we have also procured a synchronized recording and playback of up to nine video sources together with audio, which is currently sufficient for both simulators in the RESKILL project.

Considerable effort has been devoted to learning and working with the SAAB tower simulator, the Transas ship bridge simulator, and eye-tracking systems (Tobii Pro Glasses Two and Smart Eye). Training sessions have been conducted on the SAAB tower simulator, the Transas Ship Bridge simulator, and the SmartEye Pro system.

Tobii Pro Glasses Two were used in field observations and workshops in both domains (ATC and maritime piloting) for purpose of acquiring the knowledge and skills needed to empirically work with the eye-tracking equipment. Results thereof were used to familiarize the research team with the quality and accuracy of eye-tracking data and evaluate possibilities for data analysis. For RESKILL, the Tobii glasses appear to be most suitable for field studies. Several test runs have also been conducted with the Smart Eye system. For purposes of RESKILL, the Smart Eye system appears to be the most suitable equipment for future simulations. Identified shortcomings are being addressed in order to secure an acceptable level of functionality and quality required for simulations.

Eye tracking capability of RESKILL in simulator environments

This section reports on the eye tracking capability of the RESKILL project in simulator environments, through the SmartEye system. The test was conducted at the LFV facilities in Sturup. In this test, we used a simulator with more screens placed in a wider area than we will use for the simulators at LiU in Norrköping.

The system in use consisted of the 6 IR-cameras, the frame grabbers and 5 computers for processing and managing. The experimental setup had a tower controller position, including six times 4k-displays for the out-the-window view, radar, e-flightstrip and the com system (see figure below).



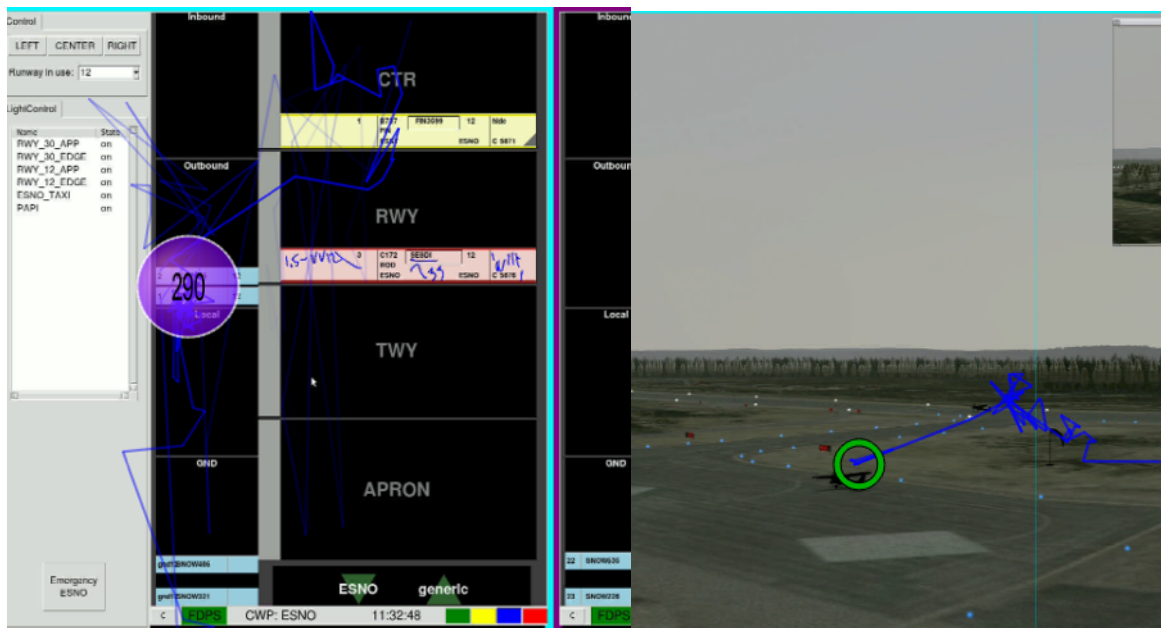
Accuracy

The accuracy depends on the distance from the test person to the focused display. Once the system begins to track the eyes, the accuracy is high for identifying which strip is fixated (see figure below) or functional elements are used (runway in use). For the OTW displays, the accuracy is lower due to tolerances that are amplified by the longer distance (see figure below, right). The spreading increased significantly during the scan pattern between the fixations. This “jumping” behavior results from inaccuracies in the angle calculations during fast eye movements.

AOI-Analysis

Times that the test person’s attention spends on the airspace and runway can be clearly determined by using the “Regions of Interests”-functionality in the MAPPs software. Time of

entering and the dwell time are the output. In comparison, dynamic area of interest analysis (e.g. aircraft movements) is not supported. The object of interest must be located manually by using the grabbed video material. The alternative option to map the objects position to the video based on the position logs of the simulator is theoretically possible and in progress. A dedicated self-programmed coordinate transformation is needed for a successful mapping. (Note that the MAPPs software does not identify sequences, and does not identify the actual areas of attention by the controller, but relies on the analyst specifying areas of interest).



Camera Setup

The camera setup is a crucial factor for the accuracy. The positioning of the cameras on the table next to the instruments provided a full coverage for all nine displays of the experimental setup. In general, the cameras should be positioned as close as possible to the test persons. This is because the captured resolution of the retina is a major factor for the accuracy of the eye tracking. There are some points to consider that concern the test persons pose. Test persons are used to lean forward and backward as well as move on the office chair slightly during the trial. This depends on the situation and attitude. This affects the aperture and focus of the camera setup that are usually optimized for a certain distance of the test person's face. The camera setup should consider all variants of poses:

- Leaning forward: E-flightstrip, Radar and com system
- Leaning back: mostly OTW displays

In addition, it was noticed that the right arm (right handed test persons) used for the pen display (managing the flightstrip and radar) hide the right sided cameras.

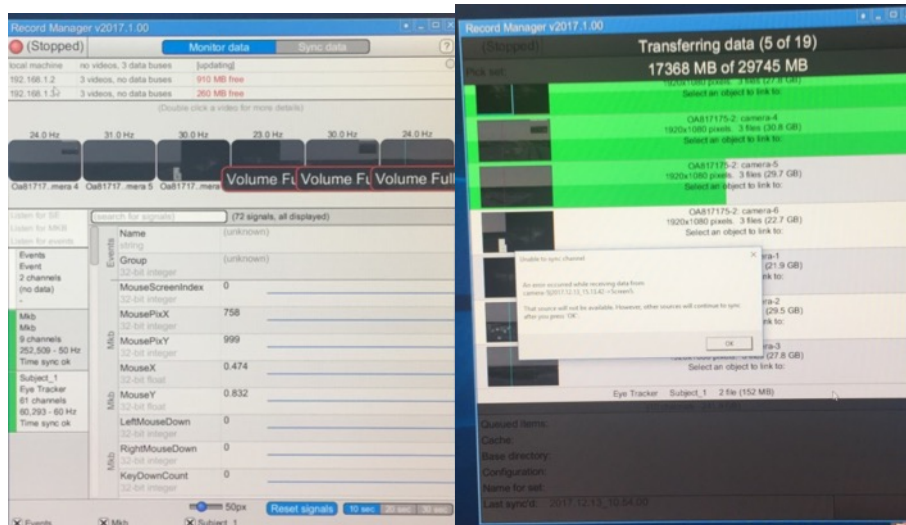
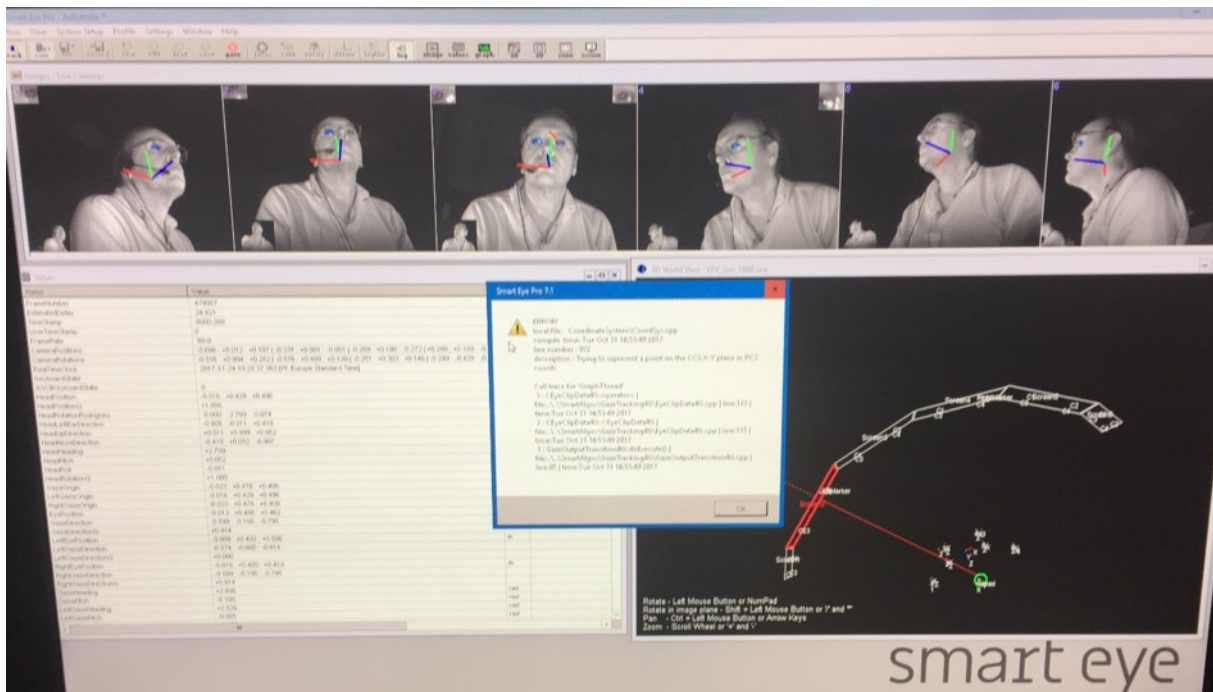
Test persons characteristics

Test persons wearing glasses could in practice not be tracked reliably due to multi reflections of the IR-signal in the glasses. Still, there is no method available to mitigate this effect. Another source of distortion was test persons wearing long hair. Hair strands that fall into parts of the face during the recording cannot be compensated by the head-tracking of the Smart Eye system. A reason might be the mismatch with the training set data in which the face had different distinctive features.

Usability of the Software

The practical handling of the software is the major downside of the whole system. The successful measurement and merging of frame grabbing and eye tracking was severely impacted by the low usability and little intuitive guidance by the software GUIs of both the Smart Eye tracking software as well as the record manager and related streaming clients. Technical a-priori knowledge is needed for accomplishing the setup and the recording process.

- Setup of the system. More specifically the cabling, buildup of the World Coordinate System by the laser measuring instrument and the synchronization of all system clocks using NTP
- Error handling. Error messages appeared during the calibration of the camera positions, the recording of the eye tracking (see figures below) as well as during the fusion of the video with the eye tracking the software offers no help at this point.



Project economy follow-up

Total project costs are within the original budget for the project for 2016-2017. For 2016, the procurement of the eyetracking systems (Smart Eye pro, Tobii glasses 2) and hardware for the Air Traffic Management simulator was the main priority. This resulted in the following costs:

2016	Plan	Outcome
Salaries (including indirect costs)	126 000	32 000
Procured services	0	0

Equipment	1 641 000	1 785 000
Travel expenses	0	0
Other expenses	50 000	0
<i>Sum</i>		<i>1 817 000</i>

For 2017, we adjusted the budget for higher hardware costs than expected, by re-allocating costs from salaries at LFV, Sjöfartsverket and LIU to hardware. The higher costs were due to higher costs for simulators than expected. Delivery delays (mainly for the maritime bridge simulator) however resulted in lower costs for 2017 than expected at the end of the year, costs that instead must be covered 2018. We also had slightly lower travel costs, and slightly lower costs for procured services (LFV costs) than expected.

2017	Plan	Outcome
Salaries	1 778 000	1 311 000
Procured services	950 000	650 000
Travel	92 000	33 000
Equipment (maritime bridge simulator)	90 000	473 000
Other expenses	1 004 000	1 185 617
<i>Sum</i>	<i>3 914 000</i>	<i>3 651 000</i>

For 2018, we have made an adjustment of funds between LFV and LiU. We use a simulator engineer at about 40% from the LFV (to work on simulators for both domains), instead of an engineer at LiU. Corresponding funds for salary have been transferred from the LiU (salaries) budget to the LFV budget (to procured services). Costs that are a consequence of the simulators are also added (service and upgrade costs) to procured services, as well as costs that transfer over from 2017 (hardware delivery delays). Further, the movement to two simulator rooms and one server room also resulted in hardware costs, to set the rooms up correctly. Some costs that were expected during 2018 are now instead expected during 2019 (some, early 2019), partly due to delays in delivery of the simulators, and partly to a shortage of air traffic controllers for participation in studies in the ATM domain during 2018 (indicated by the difference in the plan versus expected outcome). This is also reflected in the extended duration of the second half of the project (one year extension, no changes to the funding amount). The necessary adjustments described above means that RESKILL is positioned for testing, measured trials and demonstration starting with the maritime applications.

2018	Plan	Expected Outcome
Salaries	1 840 000	1 248 000
Procured services	1 150 000	1 133 000
Travel	120 000	57 000
Equipment	0	404 000
Other costs	1 004 000	501 000
<i>Sum</i>	<i>4 126 000</i>	<i>3 530 000</i>

Communication and Presentations

Presentations in the project aim at two communities, to the scientific community (see the next section, publications) and to stakeholders in the maritime and aviation domains – as well as the transportation domain in Sweden (presented below).

- Presentations
 - 7 feb 2018 – presentation at Transportstyrelsens sjöfartsseminarium.
 - 1 june 2018 – presentation at Sjöfartens forsknings- och innovationsdag.
 - 23 mar 2017, Trafikverkets foi-dag (part of larger presentation)
 - Jan 2017, Transportforum (part of larger presentation)
 - Jan 2018, Transportforum
 - 6 dec, 2017, 16 may 2018, Presentation for the Human Factors Network (between research and practitioners).
- Media:
 - SVT, 13 feb 2017: <https://www.svt.se/nyheter/lokalt/ost/sakerheten-hotas-om-robotarna-tar-over>
 - Ny Teknik, 7 sept 2017: <https://www.nyteknik.se/digitalisering/manniskan-i-centrum-av-automatiska-trafiksystem-6868505>

Publications by the Project Members

- Vrotsou K. and Nordman A. (2018). Exploratory Visual Sequence Mining Based on Pattern-Growth. Submitted to IEEE Transactions on Visualization and Computer Graphics.
- Muthumanickam P., Vrotsou K., Nordman A., Johansson J., Cooper M. (2018). Identification of Dynamic Areas of Interest in Long Duration Eye Tracking Data Sets. In. Submitted to Eurographics Conference on Visualization (EuroVis) 2018.
- Westin C, Lundberg Johansson J, Vrotsou1, Nordman A, Eklund R, Osvalder A-L, Josefsson B. Reskilling challenges of air traffic controllers for remote tower operations 7th SESAR Innovation days (SID). Belgrade, Serbia. 28-30 November 2017.