EXPLORATORY RESEARCH

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	Included hyperlink and reference for D5.2, which was not publicly available at the last version's submission Included hyperlinks to the project's publications in section 5.2: Project Publications Added subsections 4.2.1 and 4.2.2 in section 4.2, to differentiate technical and non-technical lessons learned Added a video story on the RPAS and AI dissemination event in Table 8

SafeOPS

FROM PREDICTION TO DECISION SUPPORT - STRENGTHENING SAFE AND SCALABLE ATM SERVICES THROUGH AUTOMATED RISK ANALYTICS BASED ON OPERATIONAL DATA FROM AVIATION STAKEHOLDERS

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Abstract

This document concludes the SafeOPS project. It presents an overview of the operational and technical context and the objectives of the project, the work performed, the key results and the contribution towards the SESAR Program and the European ATM Master Plan. Based on the work done and achievements towards the project's objectives, a Maturity Assessment is presented. Finally, conclusions from the overall project are drawn, lessons learned distilled and open points for future research on the concept presented.

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1 Executive Summary

The next generation of Air Traffic Management (ATM) systems are pushed more and more towards digitalization, driven by two goals that are hard to combine. Firstly, the demand for capacity and cost-efficiency of air transport operations increases. Secondly, already high levels of safety and resilience in the ATM system must be maintained and then continuously improved. SafeOPS proposes a solution, in which an AI/ML prediction tool provides real time risk information of potential go-arounds to Tower Controllers, to support them in their decision-making processes, thereby increasing the safety and resilience, when handling arrivals, departures and go-arounds.

To increase safety and resilience in the scope of the proposed go-around handling context, the main objectives of this project were to further investigate the proposed solution by:

1. developing an AI/ML tool for go-around predictions and explore it in terms of achievable performance metrics as well as explainability,
2. enhancing risk assessment methods, such that they can cope with the introduced AI/ML component, and
3. investigating the AI/ML based decision support solution, and evaluate the effects on capacity, safety, and resilience of the ATM operation.

The development of an AI/ML prototype yielded first results on achievable precision and recall values of a data-driven go-around prediction. These metrics were used to discuss the concept with end users in workshops, which performed an initial operational safety assessment for the concept. This assessment indicated the potential benefits of the developed concept, especially in terms of safety and resilience. Based on this risk assessment, a low fidelity, real-time simulation environment was developed and simulation exercises were performed, again in workshops with end users. These exercises supported the findings from the risk framework on safety and resilience benefits, however also showed adverse effects on capacity.

In the context of the ATM Masterplan ambitions to increase capacity by 60% in 2035, compared to 2012, the capacity loss of the SafeOPS concept is however minimal. On the other hand, the concept provides safety benefits, especially in situations of high traffic around the airports, which will increase if the foreseen 60% increase in network throughput should be achieved. The proposed concept might be one building block, tackling the capacity/efficiency vs. resilience/safety trade-off in a more informed way. By providing risk information tailored to each individual approach, the concept can support the decision-making, whether state-of-the-art procedures are adequate or additional safety measures for an approach should be considered.

To mature the concept further, especially work on documenting the data quality for the AI/ML solution is foreseen. Additionally, the low-fidelity simulation can, by design, be enhanced in a Monte Carlo type simulation, exploring the tactics obtained from the simulation exercises in a wider operational context. Finally, a cost benefit evaluation must be performed for the concept. This exercise should include the potential revenue loss, caused by the adverse capacity impact, observed in the simulation exercise. From this exercise we would expect to obtain a hard requirement on the minimum acceptable precision value of the AI/ML solution. This in turn should be fed back to the data science engineers, which will have to prove if the minimum acceptable precision value is achievable with currently available data sets and techniques, which would mark an important milestone for the proposed concept.

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2 Project Overview

2.1 Operational/Technical Context

The next generation of Air Traffic Management (ATM) systems are pushed more and more towards digitalization, driven by two goals that are hard to combine. Firstly, the demand for capacity and cost-efficiency of air transport operations increases. Secondly, already high levels of safety and resilience in the ATM system must be maintained and then continuously improved. As a mid-term solution, we propose integrating a digitalized system with human operational management, introducing quantifiable performance predictions into ATM. This digitalized system will be based on big data technologies, including the fusion of data from different sources. Organizing and making use of the vast number of available sources in aviation will pave the way for Artificial Intelligence (AI) solutions, such as predictive risk estimation and ultimately decision support tools. These solutions will enable safety applications that create a proactive, data-driven approach for safety management, capable of predicting potential safety hazards in real-time.

2.2 Project Scope and Objectives

As one example for a safety-relevant scenario, SafeOPS will base its research on the handling of go-arounds and approaches by ATCOs. Thereby SafeOPS focuses its research on “from prediction to decision”, a common decision-making paradigm in digitalization and predictive analytics. The envisioned decision support concept can be summarized by expanding the current ATM system with an information automation-based decision intelligence. Information automation describes the automated acquisition and processing of operational performance data through big data technologies and AI algorithms, providing new information to the ATM systems. Decision intelligence is an engineering discipline, providing a framework which incorporates (predictive) data science in decision-making processes [1].

For the selected go-around scenario, an integrated model of risk, incorporating potential uncertainties will be provided. The model allows discussing safety scenarios in a coherent, probabilistic approach. It will include historical aircraft, weather and traffic data, and the outcome of AI algorithms. The computed risk is added information, which flows into the planning and operational management of the overall ATM system. Using this approach, potential risks could be actively managed.

The question addressed by SafeOPS is, how the nature of these information will change the way the system is operated. Beyond “information overflow”, the ATM human agents will have to adapt to more, but also mostly probabilistic information provided by big data analytics. Clever HMI refinements will certainly help to mitigate the potential overflow of information. However, also research on the impact of information automation on the ATM system needs to be conducted. It must show that an increase of capacity and cost-efficiency can be achieved and also the safety and resilience of the system is maintained or further improved.

The work dedicated towards each objective, defined in the Executive Summary, was performed in a dedicated work package of SafeOPS.

The *operational layer* works towards objective 1 and is described in section 2.3.1.

The *risk framework* works towards objective 2 and is described in section 2.3.2.

The *predictive layer* works towards objective 3 and is described in section 2.3.3.

2.3 Work Performed

How big data and artificial intelligence-based decision support systems could impact daily air traffic operations has not been explored yet. Over the course of the project, the SafeOPS team held recurring workshops together with air traffic controllers from two major European hubs and with pilots, to elaborate this question in the context of arrival, departure and go-around handling. The results of these workshops are the foundation of the deliverables of the *operational layer* and the *risk framework*. Based on these workshops, scenarios have been identified in which go-arounds can lead to complex situations in daily operations, in which a time-in-advance forecast of the go-around likelihood of an arriving aircraft can affect the decision making of the tower controller and provide benefits for safety and resilience of the go-around handling. To further investigate this concept, SafeOPS is organized in three layers, an *operational layer*, a *predictive layer* and a *risk framework*, as illustrated in Figure 1.

The *operational layer* was the project's branch, driven by the needs of the stakeholders. It covers the process of defining requirements, as well as proposing and evaluating the SafeOPS solution. A systems engineering approach was used to refine the use cases into user stories and finally requirements to shape an initial design proposal. Also, the simulation exercise to test the impact of the proposed solution on safety, resilience and capacity of the arrival and departure handling was covered by the operational layer. This branch of actions is described in more detail in the WP2 related section 2.3.1.

The *predictive layer* was the project's branch, covering the big-data and machine learning related tasks. It intersects with the operational layer for the data acquisition and developed a machine learning prototype, according to the operational layer's requirements. To investigate the big-data related benefits and challenges, an artificial intelligence-based decision support system poses, SafeOPS set up a big data working infrastructure and collected datasets, to train AI models for the prediction of go-arounds. Data Cleaning and (pre-)processing tasks were performed, and a prototypical machine learning model for go-around predictions was developed. This branch of actions is described in more detail in the WP4 related section 2.3.3 .

One aspect of the incorporation of a predictive technology in the air traffic operating environment is the risk associated with the technology integration, management and use. Therefore, SafeOPS investigates this risk, structured as a *risk framework*. It analyses the impact of the technology and the information presented to the ATCOs. A first process step in the *risk framework* was the development of a risk model. Additionally, the human factor aspects of the SafeOPS solution were investigated. This branch of actions is described in more detail in the WP3 related section 2.3.2.

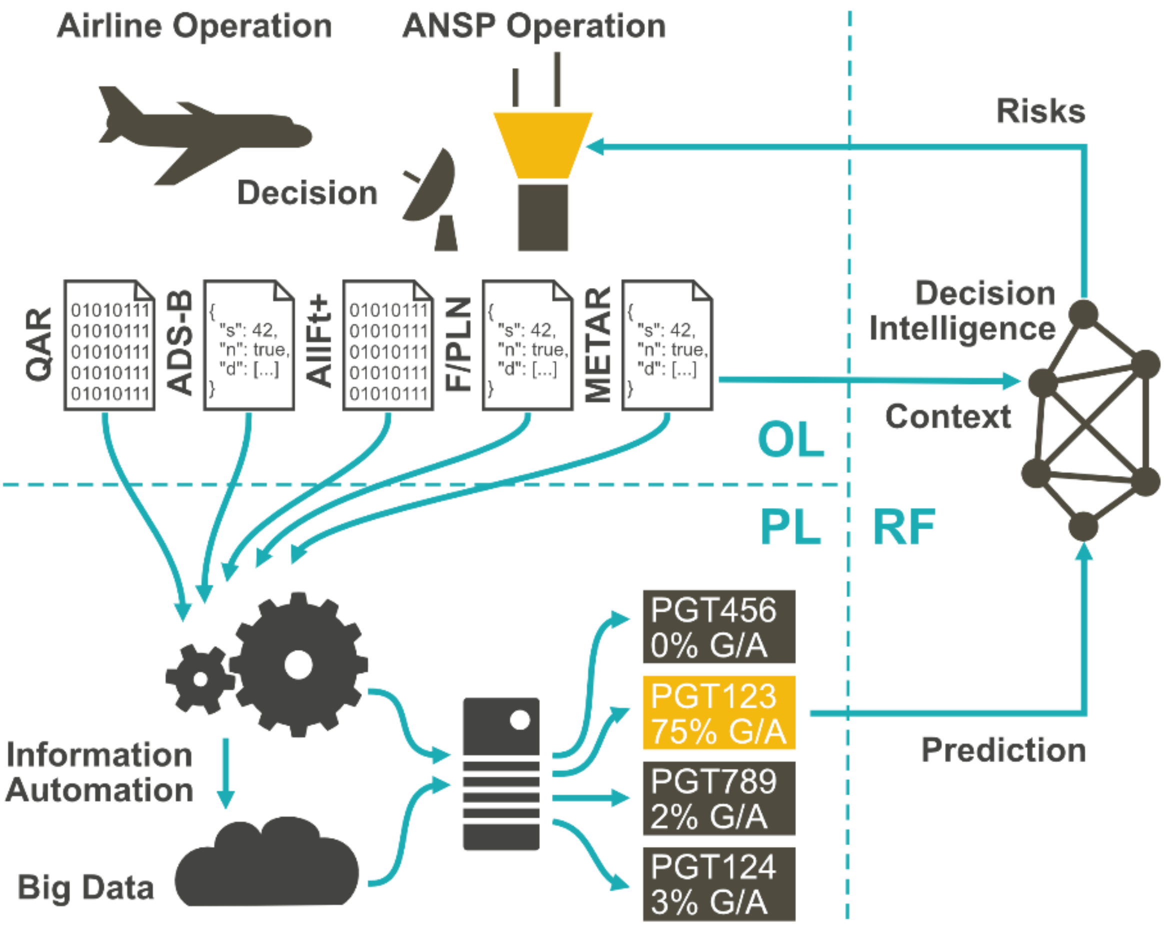

Figure 1: SafeOPS Work package Structure, divided by the operational, big-data and risk related tasks to evaluate the SafeOPS solution.

2.3.1 Operational Layer – WP2

The operational layer initially defines the solution, SafeOPS investigates through workshops with ATCOs and pilots. Based on these workshops, that ensure a user-oriented project, scenarios and requirements have been defined. The requirements are passed on, to the work packages 3 and 4, which orient their technical work and developments along these requirements. The scenarios were used in the impact evaluation, after the work packages 3 and 4 delivered their results, to validate the SafeOPS solution. Accordingly, WP2 is divided into the following three tasks:

- 2.1 - Requirements development and data acquisition
- 2.2 - Impact evaluation of developed decision support tools
- 2.3 - Generalized guidelines on decision intelligence for Air Traffic Management

each attached with a contractual deliverable.

Task 2.1 – Requirements development and data acquisition

The objective of this task was to generate a set of requirements for the developmental phase of the project. The basis of all actions in WP2 are workshops with operational personal, mainly ATCOs but

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also pilots, together with researchers, to guarantee a user-oriented approach of SafeOPS. Initially, a common understanding of ATCO's go-around handling strategies was established with the researchers. Based thereon and in discussions with ATCOs different scenarios were elaborated in which a decision support tool could benefit the safety and resilience of the ATCOs go-around handling strategies. From these scenarios, several use cases and requirements have been derived, to guide the developmental work of the work packages 3 and 4. Based on the data related requirements, also the targeted data sources were deployed.

Task 2.2 – Impact Evaluation of developed decision support tool for ATM

The objective of this task is the evaluation of the research question posed by SafeOPS: **How a data-driven decision-support tool influences safety and resilience of the ATM system in the context of go-around handling?**

Based on the results of work packages 3 and 4, work package 2 evaluated the impact on safety and resilience of the proposed solution in the described go-around context. Therefore, an experimental plan was produced and executed in task 2.2. Therein, the solution as well as the experimental planning and setup is described and expectations are documented. Consequently, the results of these experiments were worked out and compared with the expectations

For the impact evaluation, a complementary action was proposed to measure the change of the defined safety, resilience, and capacity metrics. Based on the results of the risk framework, a low fidelity, real-time simulation exercise was designed, which was performed in workshops with air traffic controllers. The simulation environment is described in detail in D2.2 Appendix B and includes a visualization tool to mimic the radar screen, as well as Simulink based aircraft models for departures and arrivals. The operational experience of DFS, Iberia and Pegasus contributed to the development of the models, especially for designing realistic performances in the simulation.

Task 2.3 – Development of generalized guidelines on decision intelligence for automation

This task concludes the overall work done in SafeOPS and was performed towards the project end. Based on the gained experience from the project developments and based on a review of similar SESAR Projects and literature on other high reliability organizations and their achievements in decision support and automation, guideline material was produced.

For this task, SafeOPS looked into the 'efficiency vs resilience' trade-off, on which a general discussion emerged especially after the Covid-19 pandemic. This topic is discussed in areas like supply-chain management, computer science, energy infrastructure (especially fuelled by the Russian invasion in Ukraine and the emerging sanctions on Russia), or health care. This 'efficiency vs. resilience' trade-off is also important for ATM, since the ATM Master Plan [2] aims at an increase of capacity/efficiency as well as an increase of safety/resilience, which are goals that are challenging to combine.

Additionally, this deliverable compares the workflow and work done in SafeOPS against the new EASA guidance on AI/ML applications in aviation [3], thereby identifying open tasks for further research on the SafeOPS concept and adding additional guidelines beyond the EASA material, where deemed necessary.

2.3.2 Risk Framework – WP3

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One aspect of the incorporation of a predictive technology in the air traffic operating environment, is the risk associated with the technology insertion, management and use. Therefore, it is critical to assess and manage this risk. Work Package 3 of the SafeOPS project was assigned to the investigation of this risk, structured as a 'Risk Framework'. The Risk Framework developed in this project was aimed at analysing the impact of the technology on the current safety levels being achieved in ATM today.

For this aim, WP3 took a two-tiered approach to the development of the Risk Framework, in addition to a third task of deepening analysis of a key aspect of safety and technology insertion, namely the Human Factors Integration (HFI) component of the process.

Task 3.1 Benchmarking of existing risk models

The first part of the Risk Framework involved the methodical analysis of existing risk models, in order to ascertain their suitability for the assessment of risk on the SafeOPS project, specifically assessing the risk associated with the integration of a machine learning, decision support tool. After filtering and reviewing a number of risk models, the most appropriate risk model was selected by analysing the models through the lens of a number of acceptance criteria developed in the context of this project. Although none of the models had elements aimed at assessing ML or AI technologies, one important criterion, that ultimately drove the final selection, was that of being able to assess change in an extant system. As such the work recommend the Accident Incident Model (AIM) framework, a model which has been extensively validated, capable of showing the change in risk with the addition/change of a technological tool, assesses safety impact qualitatively and quantitatively, and one which allows an extensive coverage of Human Factors aspects.

Task 3.2 Integrated Risk Framework

The second part of the Risk Framework was to pick up the recommended risk model and use it for the articulation of risk associated with the integration of the SafeOPS tool into the ATC system. This was achieved through three activities; firstly, by identifying the operations, decisions and actions which were impacted by the presence of the SafeOPS tool, secondly by describing and integrating these components into the AIM risk model, and thirdly by describing how the individual elements of the model change after introducing the SafeOPS tool. In this exercise it was possible to effectively identify the base events that were impacted by the introduction of the SafeOPS predictive tool, which in many cases involved the lack of sufficient time to timely assess, and react to, the evolving situation. The analysis revealed that there were several improvements to the safety of the system, from the introduction of the SafeOPS tool.

Task 3.3 Human Factors Assessment of Risk

The final part of WP3 involved analysis of the Human Factors associated with the design and integration of the SafeOPS technology. Therefore, a visualization prototype was developed based on the requirements from D2.1. These requirements define, how the prediction shall be presented to the controller. While also vague at this stage, they condense on what the operating personnel could agree at the earliest stage of the project, regarding how the computed information shall be provided to the controllers. It became consensual that visual indications in the radar screen are the preferred option. To avoid information overflow and nuisance warnings, a customizable visualization and a threshold for the predicted go-around probability to trigger visual information was requested.

2.3.3 Predictive Layer – WP4

The SafeOPS solution, as defined in work package 2, includes a big—data driven, machine learning prediction of go-arounds. The work package 4 activities were set up to develop the necessary big-data pipeline and the machine learning models for the go-around prediction solution. The tasks of work package 4 thus included the development of:

- An automated data preparation pipeline. This encompasses a number of tasks ranging from selecting and obtaining the necessary data sources and cleaning and preparing the data for the investigated AI/ML tools.
- The AI/ML model for the predictive analytics. Therefore, different possible AI/ML constituents for the proposed solution were evaluated and, through a benchmark, the most promising candidate was chosen.
- Human interpretability functionality of the chosen AI/ML candidate.

Task 4.1 – Data Pipeline and AI/ML solution for the selected scenarios

SafeOPS developed an automated processing pipeline for the deployed data sources. The processing includes structuring, fusing, and labelling of the data. Furthermore, a feature engineering process, inferring new variables with meaningful information for the operational scenario was added to the automated pipeline.

Based on the generated data set, a training of the different AI models was performed in an automated fashion, which allows a comprehensive investigation of these algorithms, comparing their accuracy and confidence levels. Based on the results, a benchmarking of different ML solutions was performed and the most promising candidate for the SafeOPS solution was chosen.

Task 4.2 - Human interpretability framework for the selected user stories

An important aspect for SafeOPS is the realization of suitable interpretations of the probabilistic AI prediction for the selected case studies. Therefore, task 4.2 conducted research on model interpretation strategies and accuracy vs interpretability trade-off. The study focuses on model interpretation strategies, as well as human interpretability, where also the results of other SESAR projects are considered. A special focus was laid on general and local feature importance techniques. Whereas general feature importance techniques are relevant to define the overall behaviour of an ML solution, which targets more the training of users with the methodology, local feature importance techniques explain for each prediction, the relevant features responsible for the models result. This is especially important since users asked for the possibility to indicate the contributing factors for a prediction in real time in the radar screen upon request.

2.4 Key Project Results

The key project results, progressing the SafeOPS concept are summarised in the following.

2.4.1 Concept of Operation

The SafeOPS solution concept is visualized in Figure 2 and defined in more detail in D2.2. The idea is to use available performance (ADS-B) and weather (METAR) data and train an AI constituent to predict the likelihood of an arriving aircraft to perform a go-around in the landing phase. The real time risk information, computed through the AI/ML constituent for each arriving aircraft is presented to the Air Traffic Controller via the radar screen. The ATCOs can use this information in their preplanning on the arrival, departure and go-around handling. D2.1 defines several real-world operational scenarios, considering environmental conditions and procedures at two major European airports, for which the SafeOPS solution is relevant. To generalize the projects results, a generalized scenario has been defined, laid out in the following.

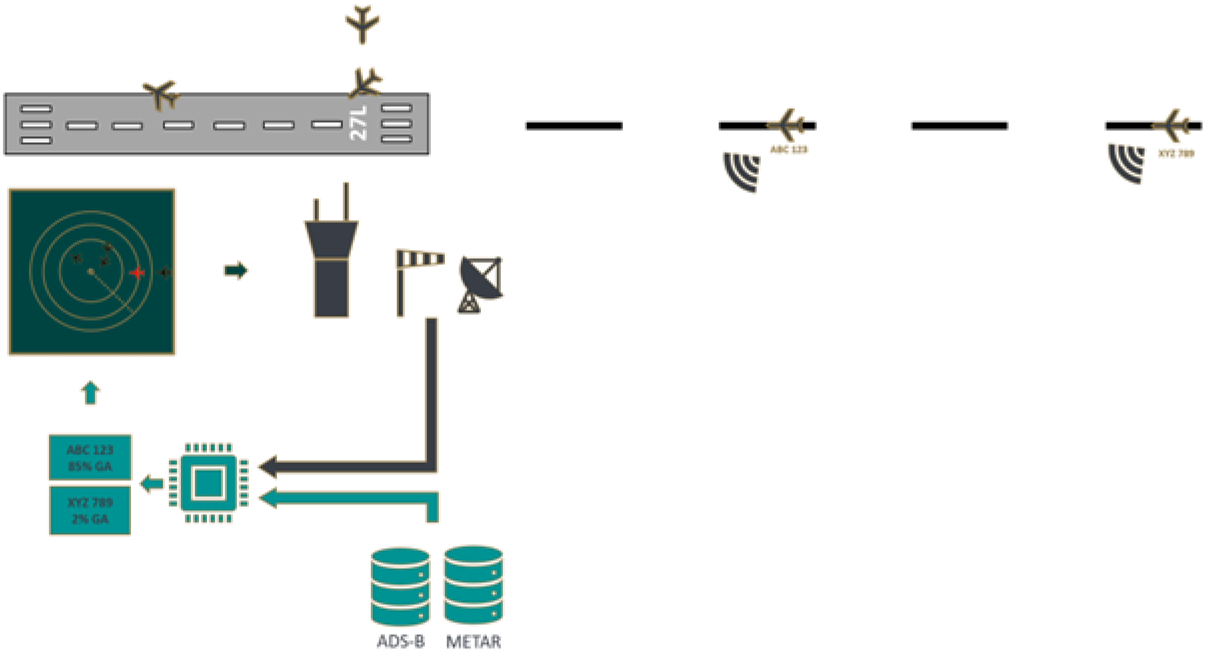

Figure 2: SafeOPS concept visualization

Generalized Mixed Mode Runway Scenario

For the impact evaluation and the reasons stated above, we describe a generalized, mixed mode operated runway scenario for the SafeOPS solution. A mixed mode operated runway is a runway from which departures and arrivals are managed. In the investigated scenario, we assume dense inbound traffic, such that gaps in the inbound traffic can be used for only one departure per gap.

For the prediction of go-arounds, a binary classification algorithm is used. The details of predictions are covered in D4.1 and D4.2. The relevant details are summarized in section 2.4.2. The prediction tool provides the Tower Controller with an indication of the go-around likelihood for the arriving aircraft, when the arrival passes the 6NM, 4NM and 2NM mark from runway threshold. Based on this indication, the Tower Controller can incorporate the risk indication in his decision making on how to handle the departure and arrival aircraft. Since a classification tool, as used for the go-around prediction, can produce true or false predictions, both must be considered in the evaluation of the solution. For both cases, true and false predictions, Table 1 and Table 2, describe possible strategies of the Tower Controller, to handle go-arounds, depending on the point where a prediction is available.

Table 1: Strategies for the true positive prediction

Time/Point of Prediction	Options

after take-off clearance for preceding departure	In this case, the departure is rolling and will take off. The ATCO can thus use the time to brief the arriving aircraft for an alternative missed approach procedure which reduces wake/separation risks.
after line-up clearance and before take-off clearance for preceding departure	In this case, the ATCO can decide whether to give a take-off clearance or not. In case he does not give a take-off clearance, the ATCO has to command a go-around for the arriving aircraft, since the runway is blocked. The aircraft, which is predicted to perform a go-around thus would initiate the go-around based on the ATCOs instructions, without the departing aircraft in the sector. No wake/separation problems occur, however the departing aircraft's take-off will be delayed until the aircraft performing the missed approach, which is flying on runway track, is vectored or has finished the standard missed approach procedure.
before line-up clearance of preceding departure	In this case, the ATCO can decide whether to give a line-up clearance or not. In case he does not give a line-up clearance, the arriving aircraft could continue the approach. In case the predicted go-around is performed, no knock-on effects of wake/separation encounters will occur.

Table 2: Possible Strategies and expected impacts in case of false positive predictions

Time/Point of Prediction	Options
after take-off clearance for preceding departure	In this case, the departure is rolling and will take off. The ATCO can thus use the time to brief the arriving aircraft for an alternative missed approach procedure which would reduce wake/separation risks. In case the prediction is wrong however, the arriving aircraft could perform the landing, since the runway is free.
after line-up clearance and before take-off clearance for preceding departure	In case the ATCO does not give a take-off clearance, the ATCO has to command a go-around for the arriving aircraft, since the runway is blocked. In case the prediction is wrong, and the arriving aircraft would have landed, a landing slot will not be used, resulting in a loss of capacity.
before line-up clearance of preceding departure	In case the ATCO does not give a line-up clearance, the arriving aircraft continues the approach. In case the prediction is wrong, the arriving aircraft can perform the landing. The downside of this option is that one gap will be lost for a departure, reducing the airports capacity.

2.4.2 AI/ML Prototype

An important milestone and key result was the development of an AI/ML prototype for go-around predictions. This was achieved in task 4.1 and the results allowed concrete discussions with the users in workshops, beyond the definition of scenarios and requirements at the beginning of SafeOPS, which contributed especially in the work of D3.2.

Based on the problem definition in D2.1, a data set for model training was generated. For the predictive layer development, nearly two years (646 days) of ADS-B data at two major European airports, containing both approaches and departures as well as the relevant METAR reports have been captured and stored in a data lake. Table 3 provides an overview on the number of approaches and go-arounds, found in the final dataset used. For each of these approaches and go-arounds, a set of over 200 features was computed, containing information on general flight information, weather data, approach performance, and airport performance for the previous 60 minutes before the approach under investigation.

Table 3: Size of data set, used in the predictive layer

Airport	Number of approaches in data	Number of go-arounds in data	Go-arounds per 1000 approaches
Airport 2	227044	646	2.85
Airport 1	377712	1237	3.27

Based on the generated data set, a binary classifier was trained to predict go-around likelihoods of arriving aircraft when the aircraft passes an 6NM, 4NM and 2NM mark from the runway threshold, based on its approach performance and weather information. The performance results of the ML prototypes are specified in Table 20 and Table 21. A full discussion on the results is described in D4.1.

2.4.3 Risk Framework Result

The risk framework identifies the operations, decisions and actions which are impacted by the presence of the SafeOPS tool. Based thereon, new risk models based on existing AIM are developed by integrating these. By describing how the individual elements of the model change after introducing the SafeOPS tool, a comparison of the state-of-the-art procedures with the envisioned procedures, introduced with the SafeOPS concept is performed. The first step of this analysis identified at a high level the safety functions fulfilled by the ATCOs before and during the go-around manoeuvre:

- **Runway management**
- **Traffic separation**
- **Monitoring of the wake category**
- **Trajectory management**

Through this exercise, it was further possible to effectively identify the base events that were impacted by the introduction of the SafeOPS predictive tool, which in many cases involved the lack of sufficient time to timely assess, and react to, the evolving situation. The analysis revealed that there were several improvements to the safety of the system, from the introduction of the SafeOPS tool. These improvements included **increased situational awareness** in the ATCOs, more time to get an accurate and complete picture of the traffic, and **more time in which to perform their tasks.** These improvements have a **smoothing effect on operators' workload** and thus results in a lower probability of human errors, an increased chance that a potential conflict is identified and a higher likelihood that effective plans are made to anticipate or resolve potentially hazardous situations. Although considered highly unlikely, **the analysis also found a small number of drawbacks.** These include the eliciting of unsafe behaviours, such as **issuing clearances based on a disproportionate level of confidence** that an inbound aircraft will definitely go-around or land; and also, the act of cancelling a take-off clearance resulting in an increased risk of runway excursion.

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2.4.4 Validation of the Concept of Operation and Solution Scenarios

For the described scenario in section 2.4.1, SafeOPS developed a low-fidelity simulation environment. The complete simulation environment is described in D2.2 Appendix B and consists of a visualization tool as well as departure and arrival aircraft models in Simulink. The visualization tool mimics a radar screen and can easily modify the information as well as colour schemes, to transport the new information of the AI/ML constituent to the ATCO. In this LinkedIn video, the simulation setup is visualized. Regarding the relevant Key Performance Areas (KPAs) Safety, Resilience and Capacity, identified in the Experimental Plan in Appendix B, several objectives including metrics and success conditions are defined, to evaluate state-of-the-art reference as well as solution scenarios.

The detailed results, including the simulation configuration, sequence diagrams, visualizations and metric evaluations are presented in D2.2 Appendix A2.2, and the analyses per objective is detailed in D2.2 section 4.2 and the respective subsections. Overall, we can summarize that for the investigated scenarios, a benefit in safety and resilience can be observed. As trade-off comes a loss in capacity.

While for the safety metrics, in case of true positive exercises, the metrics either stay equal or improve, they remain constant throughout all false negative exercises. For the investigated scenario, we conclude that the true positive predictions of SafeOPS concept can provide information to Tower Controllers (PL) that allows them to adapt their strategies, resulting in a safety benefit. This safety benefit arises, since the adapted strategies prevent conflicts that cannot be avoided in procedure designs of the Standard Instrument Departures (SIDs) and Standard Arrival Routes (STARs). The true negative predictions on the other side show no negative impact on the investigated safety metrics.

Regarding resilience, we can observe benefits in case of true positive exercises, but also negative impacts in case of false positive exercises. In case of true positive predictions especially at 4NM and 6NM, the overall workload, as well as the peak workload of the Tower Controllers can be reduced. The reduced workload arises from coordinative actions which can either be performed earlier, in phases of less workload, or are not necessary. Therefore, more cognitive capacity of the Tower Controller is available to react to unforeseen events. For the false positive predictions, we observe an increase of coordinative tasks, which in contrast increase the workload. Weighted by the precision of the predictions, obtained from WP4, the average shows an improvement of the resilience, according to the defined metrics.

Regarding capacity, we must observe negative impacts in the 6NM true positive and false positive prediction exercises, and the 4NM false positive prediction exercise. The remaining solution scenarios show similar capacity metrics as the reference scenarios.

True positive predictions have a ratio of around 87%-90%, based on all positive predictions. This means that in the resilience case, in around 7 out of 8 cases, a benefit can be expected compared to 1 out of 8 cases, in which the solution results in a negative impact. Regarding capacity, around 3 out of 10.000 approaches would be impacted negatively, meaning either a gap for a departure is not used or a go-around would be performed which would, without the solution in place, have performed a landing. This must be weighed against the 7 go-arounds, for which a safety benefit can be demonstrated.

Finally, it has to be concluded that the 2NM predictions show no difference in all metrics, in the true positive and false positive solution scenarios, when compared to the reference scenarios. From the quantitative metrics, the prediction at 2NM can therefore be concluded to be "too late", as the take-off clearance has been given to the departure and no change in strategy is possible anymore. However, it should be emphasized that according to D3.2, covering also questions regarding situational awareness, ATCOs stated that still for the 2NM predictions, an increase in situational awareness can be expected, as discussed in section 2.4.3.

2.5 Project Deliverables

All publicly available deliverables of SafeOPS can be downloaded from either CORDIS or the SafeOPS website. Table 4: Project Deliverables provides an overview and short descriptions for *all* project deliverables, as well as the hyperlinks to download public deliverables, directly from CORDIS.

Table 4: Project Deliverables

Reference	Title	Delivery Date[1]	Dissemination Level[2]
Description			
D1.1	**Project Management Plan**	**11/03/21**	**CO**
This deliverable defines the management procedures, which include a Documentation Plan, Quality Management Plan, Management Information System and Risk Management Plan for the SafeOPS project. It formalizes the project's management structure and ensures all participating parties are aware of these. Furthermore, good practices for documentation of communication of the project's findings are defined, and a quality plan is elaborated to ensure timely submission of all deliverables while ensuring a high-quality standard. In order to reduce the impact of potential risks, also a risk mitigation plan is provided in this document.			
D1.2	**Final Project Results Report**	**16/12/22**	**PU**
This deliverable (which is this document) summarizes the project. It contains an overview over the operational context, the project's scope and objectives, the work performed and the key results. Additionally, this document contains the assessment of the project solution's achieved maturity as evaluated by the SJU in the Maturity Gate Meeting, and provides conclusions, lessons learned and suggestions for further R&D tasks for the proposed solution.			
D2.1 [4]	**User, functional and data requirements**	**30/06/2021**	**PU**
This deliverable defines the Systems Engineering Process and the influential methodologies from resilience engineering and agile methodologies used in SafeOPS. Based on the described methodologies, the deliverable documents reference and solution scenarios for the proposed concept, user stories and requirements. Finally a technical problem statement for the envisioned AI/ML predictive tool is documented.			
D2.2 [5]	**Impact Evaluation of the Developed Decision Support Concept**	**05/10/2022**	**PU**
This deliverable describes a low fidelity simulation environment, developed to validate the solution scenarios from D2.1. The focus of this deliverable is to investigate the various tactics, ATCOs could apply with the AI decision support in place. It focuses on the impact of the AI solution on the safety, resilience, and capacity in the described scenarios, by comparing ATCOs actions in reference and solution scenarios. As basis for the safety and resilience considerations serve the results from D3.2. Also important, to evaluate the impacts of true as well as false predictions are the results of D4.1 and D4.2, which provide initial estimates of possibly			

[1] Delivery data of latest edition

[2] Public (PU) or Confidential (CO)

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achievable precision values for go-around predictions. Concluding, D2.2 finds that the concept has a benefit on safety and resilience but might reduce capacity.

D2.3 [6]	**Guidelines on Decision Intelligence for Air Traffic Management**	**31/10/2022**	**PU**

This deliverable summarizes the methods, applied in the different work packages towards achieving their objectives and distils the lessons learned. Additionally, the SafeOPS workflows are compared measured against the EASA Guidance on AI Applications [3], and additional guidelines, where deemed necessary are proposed.

D3.1 [7]	**Risk framework: scope and SoA**	**24/12/2021**	**PU**

This deliverable addresses the initial phase of the process in the compilation of the Risk Framework, namely a systematic review of current risk models available for application in an aviation context. The review aims to provide a critical assessment of existing risk models and their suitability for use in the SafeOPS Risk Framework. In conclusion, the performed review identified the Accident - Incident Model (AIM) as the most appropriate model for further use in the SafeOPS project. AIM meets all acceptance criteria. It is well established and widely used for modelling ATM operations, it already covers all relevant aspects and hazards involved in go arounds, and it enables to consider Human Factors aspects and to capture the impact of variations to the current standard of operations in a relatively straightforward manner.

D3.2 [8]	**Integrated risk framework**	**15/07/2022**	**PU**

The deliverable concludes the activities on the risk framework. It assess the benefits and hazards, which result from the introduction of predictive analytics in the specific context of go - around operations. The proposed risk framework is based on Eurocontrol's Accident - Incident Model (AIM). The AIM templates were subsequently expanded to meet the scope of SafeOPS. The results of the analysis show that the go - around predictions of SafeOPS generally support the functions of the air traffic controllers, by heighten their situational awareness and increasing the available time to monitor the airborne and ground traffic situation, determine the consequences of an eventual missed - approach procedure, make a plan for resolving the situation, and maintain a set of alternative plans to react to every foreseeable development of the events. The potential unwanted effects of the go - around predictions are considered highly unlikely and much smaller than the expected benefits.

D3.3 [9]	**Human Factors assessment of risk**	**27/05/2022**	**PU**

This deliverable investigates Human Factors aspects of SafeOPS concept. Focus is laid on the Human Computer Interaction aspect. The analysis performed in this study is aimed at determining how the provision of probabilistic information changes the tasks the ATCO s perform and how the display of such information influences their decision making and subsequent actions. The key part of the study was to conduct a design evaluation of the SafeOPS concept's display interface, to identify design issues that had the potential to result in safety and usability problems. This was done by assessing the design against a series of design requirements and design heuristics, with the users at a number of workshops. Finally, according to the experience and feedback from the users in the SafeOPS workshops and in alignment with current Human Factors knowledge and research, guidelines on how best to present SafeOPS tool to the user were detailed

D4.1 [10]	**Complete Data Pipeline and ML Solution**	**18/05/2022**	**PU**

This deliverable describes the it infrastructure used for SafeOPS, Furthermore, the deliverable documents the complete data pipeline, developed for the development of the AI/ML constituent in the SafeOPS concept. Therefore, it describes data deployment, data cleaning, data pre-processing, data exploration, feature engineering, data labelling, model selection and model training actions, performed for this task. Finally, it presents a benchmark study on various ML models and their performance in predicting go-arounds. Therefore, it uses precision and recall as performance metrics, as tribute to the highly imbalanced classification at hand. Also the receiver operating characteristic (ROC) and Precision Recall Curves are taken into account to tune the models to avoid nuisance alerts as good as possible, which is demanded by the users.

D4.2 [11]	**Human Interpretability Framework for Selected User Stories**	**15/07/2022**	**PU**
The deliverable updates the predictive results obtained through the use of the data infrastructure developed for the project in D4.1 In addition, this report also includes an analysis of the explainability and interpretability of the results obtained from the models in order to make the models transparent and to generate trust between the model's performance and the possible human users. For the interpretation of the results, two types of visualisations: Global feature importance and Local explanation summary are used, based on the results generated by the SHAP (Shapley Additive Explanation) algorithms. In this way, the user can more effectively incorporate these predictions into their decision-making process and develop trust with the ML tool.			
D5.1	**Communication, Dissemination and Exploitation Plan**	**10/11/2022**	**CO**
The deliverable defines the communication and dissemination actions to be taken during the project, and the exploitation of the actions and results. A complete strategy of communication is presented as well as the items and content already prepared for it. The visual content prepared in order to support these activities is also reflected and contained within this deliverable.			
D5.2 [12]	**Communication, Dissemination and Exploitation Report**	**16/12/2022**	**PU**
This deliverable concludes the Communication, Dissemination and Exploitation (CDE) actions of SafeOPS. It covers the actions that were taken during the project, following the strategy and proposed actions in SafeOPS Communication, Dissemination and Exploitation Plan. It compares, where possible, the planned against achieved actions, based on the Key Performance Indicators and Success Criteria. Additionally, it describes the initially not planned CDE actions, that emerged throughout the project duration as joint efforts with SESAR Exploratory Research Projects on similar topics.			

2.6 Communication, Dissemination and Exploitation Activities

This section provides a high-level overview of the performed CDE actions of SafeOPS. For a complete description and assessment of the CDE activities, we refer to D5.2.

2.6.1 SafeOPS.eu Website

Safeops.eu is the project's web presence. The website collects all information on the project, including:

- Publications
- Deliverables
- Workshop / Event dates

2.6.2 SESAR Website

SafeOPS contributed to the SESAR CDEs with:

- E-News feature
- Project of the month article

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Additionally, the RPAS & AI Dissemination Event, a joint dissemination event of 6 ER projects including SafeOPS, was featured on the SJUs website.

2.6.3 Blog Posts

SafeOPS wrote three blog posts for DataScience.aero covering:

- Safe and Resilient AI
- Efficiency vs. Resilience - How Predictive Risk Information Could Influence the Trade-off in ATM
- SESAR Innovation Days 2022

2.6.4 Brochures

SafeOPS contributed and was featured in the following brochures:

- RPAS & AI in Air Traffic Management
- SESAR's Exploring the boundaries of air traffic management
- Cordis Results Pack on AI in Air Traffic Management

2.6.5 Associated Partner Workshops

SafeOPS intended a transparent approach for stakeholders that are not part of the consortium but express interest in the work of SafeOPS. Thus, we offer associated partnerships for these parties. Associated partners are able to provide input to the project approach, feedback on the employed techniques and general recommendations.

Table 5: Associated Partner Workshops

Workshop #	Participants
1 13.07.2021	AISA Austrian Airlines EASA Star Alliance
2 07.02.2022	AISA Artimation Austrian Airline EASA (2x) Eurocontrol FARO
3 12.07.2022	AISA EASA Eurocontrol DB Fernverkehr Austrian SJU

Workshop #	Participants
4 20.12.2022	Air Navigation Solutions (ANSL) AISA (ER4 Project) Artimation (ER4 Project) DB Fernverkehr EASA IABG SafeTEAM (Horizon Europe Project)

2.6.6 Final Dissemination Event / RPAS & AI in Aviation

SafeOPS, in a joint effort with the ER projects URCleared, INVIRCAT, SafeLand, MAHALO and ARTIMATION, organized an in-person event over 2 days in Rome on the 3rd/4th November 2022. All projects presented their results and demonstrated their simulation/validation experiments. The following links provide access to the Agenda, Presentation and Brochure of the event.

2.6.7 Publications

This section summarizes the published papers (Table 6), posters (Table 7) and videos (Table 8).

Table 6: Published Papers

Titel	Authors	Presented in/at
Time in Advance Go-Around Predictions for Decision Support in Air Traffic Management **Green Open Access version of the paper.**	Pablo Hernandez, Lukas Beller, Clara Argerich, Phillip Koppitz	Digital Avionics Systems Conference 18.-22. September 2022
Ergonomics contribution to AI design in safety-critical domains **p.235**	Stefano Bonelli, Matteo Cocchioni, Carlo Abate, Ana Ferreira, Andrea Capaccioli, François Brambati, Anna Giulia Vicario, Nicola Cavagnetto	Congresso nazionale Societa Italiana di Ergonomia e Fattori Umani / L'Ergonomia Gentile per la Salute, la Sicurezza e la Flicita
White Paper: AI in ATM: transparency, explainability, conformance, situation awareness and trust	AISA; ARTIMATION; MAHALO; SAFEOPS; TAPAS	Sesar Innovation Days 2022

Table 7: Published Posters

Titel	Authors	Presented at
From Prediction to Decision Support - An investigation in ATM exemplarily for Go-Around Scenarios	Lukas Beller, Carlo Abate, Pablo Hernandez	Sesar Innovation Days 2021

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Impact Evaluation Method for an AI-Based Decision Support in Initial Development Stage	Lukas Beller	Sesar Innovation Days 2022
Risk Framework for AI-based predictions in ATM. Modelling the impacts of AI predictions in a Go-Around Scenario.	Lukas Beller, Carlo Abate, Elizabeth Humm and Laura Moens	Sesar Innovation Days 2022

Table 8: Published Videos

Titel	Authors	Presented in/at
SafeOPS in 5 Minutes	Lukas Beller, Ines Gomez	Safeops.eu
EASN presentation	Lukas Beller	Safeops.eu
Simulation Demonstration	Lukas Beller	Safeops.eu
SID 2022 Impressions	Paula Lopez-Catala	LinkedIn
Ai support in ATM	AISA; ARTIMATION; MAHALO; SAFEOPS; TAPAS	YouTube
RPAS and AI in Aviation – video story	AISA; ARTIMATION; MAHALO; SAFEOPS; TAPAS	YouTube

3 Links to SESAR Programme

3.1 Contribution to the ATM Master Plan

The modernization of the ATM system for Europe is the SESAR JU's mission (Article 187, TFEU). This modernization covers a wide range of solutions, procedures, concepts of operations and enabling technologies. Many of them target higher levels of automation and digitalization. This is in line with the Commission's policy on mobility and transport.

In addition, the European *Aviation Strategy* places aviation safety on top of its challenges and so *Flightpath 2050* defines the roadmap to achieve a "*clean, competitive, safe and secure European aviation industry*" [12]. Accordingly, one of the SES high-level goals, set in 2005, is to improve safety in aviation by a factor of 10, which is adapted to a factor of four in Sesar's ATM Masternplan, regarding ATM related accidents [13].

As recognized by the SESAR SPD [14], data-driven and ML technologies are a cost-efficient asset to reduce current fragmentation and upgrade inefficient old technologies. In turn, they bring in new challenges for all ATM stakeholders, from controllers and their training to regulators and certification agencies.

SafeOPS addressed some of these challenges by fostering the ATM modernization based on artificial intelligence tools with an application on safety and resilience through several case studies in the go-around scenario. SafeOPS puts a special focus on the interaction among humans (controllers) and this breakthrough technology. Therefore, it addresses both key performance areas (KPAs) from the *Safety and Resilience ATM Master Plan*.

SafeOPS is a project in the *Fundamental Exploratory Research (FO/AO)* stage. The project's main contribution to the ATM Master Plan is the proposed SafeOPS solution:

SafeOPS Solution: Go-around predictions as decision support for Tower Controllers

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Even though go-arounds occur only around 3 times out of 1000 approaches, they can introduce high peak workloads in the approach and departure handling of Tower Controllers. These peak workloads arise through potentially conflicting departure and missed approach routes. In such situations, especially in high density traffic, immediate action from the Tower Controllers, to separate missed approach and departure and to coordinate further actions with adjacent controllers, is required.

The SafeOPS solution is an AI/ML based tool which predicts from eight, to two miles from threshold the likelihood of an approach to perform a go-around, using live and historical operational data. Thereby, the solution assists Tower Controllers with their decision making in high traffic situations. By presenting time in advance information of potential go-arounds to Controllers (even if the information is probabilistic), SafeOPS expects a positive impact on the KPAs safety and resilience, in the approach and departure handling phase. The foreseen impacts are increased situational awareness and the possibility for Controllers to base their line-up, *departure, and landing clearance decisions on quantifiable go-around predictions.*

The solution targets airports where missed approaches influence the separation to just departed aircraft, foremost when the traffic density is high and therefore spacing between arrivals and departures is at the limits.

Table 9 summarizes the maturity of the solution, achieved with the SafeOPS project. Section 3.2 documents the TRL assessment for the solution performed with the SJU during the maturity gate meeting in Brussels.

Table 9: Project Maturity

Code	Name	Project contribution	Maturity at project start	Maturity at project end
SOL-SafeOPS	Go-around predictions as decision support for Tower Controllers SafeOPS.	See section 3.1 above.	TRL 0	TRL2 on-going

3.2 Maturity Assessment

In this section documents the TRL assessment, performed at the Maturity Gate with SESAR JU on the 29th of November 2022 in Brussels.

3.2.1 TRL 1 Assessment

Table 10: ER Fund / AO Research Maturity Assessment TRL 1

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
TRL-1.1	Has the ATM problem/challenge/need(s) that innovation would contribute to solve been identified? - Where does the problem lie? - Has the ATM problem/challenge/need(s) been quantified that justify the research done? Note: an initial estimation is sufficient	Achieved	Go-arounds occur with a rate of around 2-3 per 1000 approaches. Especially in high traffic congestions, the Controller might realize that a go-around is ongoing, after a departure has been cleared for take-off or is airborne already. The SafeOPS solution focuses on the challenge that arise from conflicting departure and missed approach routes in the go-around handling. These situations need immediate attention and action from the controller to ensure radar and or wake separation and thus drastically increase the workload of the Air Traffic Controller, as well as the Flight Crews. For both airports discussed in SafeOPS, these challenges could be identified. D2.1 documents the described scenarios in detail, referring to the relevant traffic and weather conditions, as well as the relevant involved procedures. It must be emphasized that the described go-around scenarios, including traffic congestion and a possible conflict between missed approach and departure routes, are only a subset of all go-around scenarios. For the investigated airports, an initially estimation is that the relevant weather conditions prevail at around 25% of the operation times, the relevant traffic density

			prevails between 25%-50% of the time and the conflicting procedures occur around 10-25% of the time. With the ambitions of the European Air Traffic Management Master Plan's ambitions in mind however, which envisions a 60% increase in network throughput of IFR flights by 2035, compared to 2012, and an increase of 5%-10% at congested airports [2], the go-around scenarios where the SafeOPS solution will be relevant, will increase.
TRL-1.2	Have the solutions (concepts/capabilities/methodologies) under research been defined and described?	Achieved	The solution under research has been defined with an initial operational concept, which has been refined over the project lifetime. The SafeOPS solution envisions a machine learning algorithm to provide a time-in-advance estimations of go-around likelihoods for arriving aircraft. The idea when providing predictive risk information is, that Air Traffic Controllers are enabled to use proactive tactics instead of the reactive tactics, to avoid the described knock on effects possibly triggered by a go-around. The final concept of operation definition is provided in D2.2, which includes descriptions on the underlying machine learning algorithm's performance capabilities and proposed procedures/methodologies for the operational use of the solution.
TRL-1.3	Have assumptions applicable for the innovative concept/technology been documented?	Achieved	A set of assumptions has been documented and described in greater detail in D2.2. The most relevant can be summarized by: • The solution boundary, which was chosen to be the control zone of the Tower Controller. We stopped investigating at the point of hand-over from Tower

			Controller to Departure/Ground Control. Thus, possible knock-on effects beyond the Tower Controller's influence are not considered at this stage of the project. • We assume for all discussions IMC conditions. The reason therefore is, that in VMC conditions, separation can be established visually by the controller. The relevant metrics regarding separation and wake encounters in IMC are thus clearly defined and can be measured simpler. • True negative and false negative predictions of the machine learning algorithm were excluded from the investigations. The underlying assumption is that these cases are similar to the existing, state-of-the-art, go-around handling.
TRL-1.4	Have the research hypothesis been formulated and documented?	Achieved	The underlying research question of the SafeOPS project are documented and specified in D2.2, as well as in the experimental plan (see Appendix B.2.2). The high-level questions are: • Does the SafeOPS solution provide a safety benefit for the arrival, departure, and go-around handling of the tower controller? • Does the SafeOPS solution provide a resilience benefit for the arrival, departure, and go-around handling of the tower controller?

			For the more detailed and refined research questions and the validation metrics derived thereof, we kindly refer to Appendix B.3.3 of this document and/or D2.2.
TRL-1.5	Do the obtained results from the fundamental research activities suggest innovative solutions (e.g. concepts/methodologies/capabilities? - What are these new concepts/methodologies/capabilities? - Can they be technically implemented?	Achieved	D4.1 and D4.2 investigated the underlying machine learning algorithms for an AI-based go-around predictions and indicate acceptable performance metrics of the underlying machine learning component of the envisioned solution. The research on the operational integration of the researched machine learning component suggests new tactics for the go-around handling. The SafeOPS solution aims at a proactive approach to handle go-arounds, thereby increasing safety and resilience in the arrival, departure, and go-around handling of the tower controller. The concept, including the change in tactics is documented in detail in D2.2. The technical implementation of D4.1 and D4.2 is still simplified. The real-time capability of the underlying machine learning component has still to be demonstrated. However, no showstoppers for the underlying machine learning solution were identified during the project's investigations and suggestions on the next R&D steps have been documented in D2.2.
TRL-1.6	Have the potential strengths and benefits of the solution identified and assessed? - Qualitative assessment on potential benefits. This will help orientate future validation activities. Optional: It may be that quantitative information already exists, in which case it should be used.	Achieved	D3.2 set up a risk framework, which identified benefits and risk of the proposed solution on a qualitative way. These found benefits include: • **increased situational awareness**

			• **more time for ATCOs to perform relevant tasks for safely handling go-arounds** and a **smoothing effect on operators' workload** The drawbacks include: • the eliciting of unsafe behaviours, such as **issuing clearances based on a disproportionate level of confidence** With the simulations performed and documented in D2.2, these risks and benefits could be backed up quantitatively, yielding a safety and resilience benefit in ~10 per ~300.000 approaches (per 30 relevant go-arounds as defined in TRL-1.1). On the contrary, a negative impact on capacity is observed in ~4 per ~300.000 approaches (or per 30 relevant go-arounds). **The limitations of the simulation exercises documented in D2.2 must be considered for this statement.**
TRL-1.7	Have the potential limitations, weaknesses and constraints of the solution under research been identified and assessed? - The solution under research may be bound by certain constraints, such as time, geographical location, environment, cost of solutions or others. - Qualitative assessment on potential limitations. This will help orientate future validation activities.	Achieved	The described solution will not be relevant for every airport. The solution only addresses airports with high traffic congestions. Additionally, the solution in only relevant for airports with conflicting departure and missed approach routes. All relevant assumptions are also documented in D2.2 in greater detail. Additionally, as described in TRL-1.6, the capacity is affected negatively by the solution. However, compared to the overall foreseen increase in traffic, the effect is considered negligible.

TRL-1.8	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	Achieved	The KPAs **safety** and **capacity/resilience** are relevant to SafeOPS. The effects on these KAPs is described in TRL-1.6 and TRL-1.7.
TRL-1.9	Have stakeholders been identified, consulted and involved in the assessment of the results? Has their feedback been documented in project deliverables? Have stakeholders shown their interest on the proposed solution?	Achieved	One ANSP and two airlines are part of the consortium. In their role as stakeholders, they have been continuously involved in the research of the project. Especially the ANSP provided field experts to participate in the validation exercises and evaluate the proposed solution, which is documented in D2.2. Additionally, four Associated Partner Workshops and a final dissemination event were conducted to also obtain feedback from stakeholders outside of the Consortium.
TRL-1.10	Have initial scientific observations been communicated and disseminated (e.g. technical reports/journals/conference papers)?	Achieved	The work of D4.1 and D4.2 on the machine learning component of the solution has been published at DASC 2022 [16]. The work done on Human Factors is published in [17]. The final results of the overall project have been presented at the final dissemination event and at the EASN conference (see D5.2 for details).
TRL-1.11	Are recommendations for further scientific research documented?	Achieved	A set of further R&D steps are documented in D2.2 and summarized in this document. They include: • Demonstration of real-time feasibility of the solution's underlying machine learning algorithms. • A cost-benefit assessment

			• Monte-Carlo based simulations of the conducted validation exercises to widen the significance of the performed exercises

3.2.2 TRL 2 Assessment

Table 11: ER Fund / AO Research Maturity Assessment TRL 2

ID	Criteria	Satisfaction	Rationale - Link to deliverables - Comments
OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle?	Achieved	The SafeOPS solution concept has been initially identified in D2.1 and has been refined over the project lifespan. It is finally documented in D2.2 and summarized in the Rational of criteria TRL-1.1 and TRL-1.2. The SafeOPS solution is built around an AI go-around prediction algorithm, which is identified as the scientific principle. The underlying scientific principle of AI-based go-around predictions has been documented in D4.1 and D4.2 as well as in a publication at DASC2022 [16].
OPS.ER.2	Have the basic scientific principles underpinning the idea/concept been identified?	Achieved	The underpinning idea of an AI-based go-around prediction tool is identified in the Concept of Operations, documented in D2.2. Additionally, D4.1 and D4.2 and a publication DASC 2022 [16] describe the underpinning scientific concept of an AI-based go-around prediction tool. Based on historical performance data and weather data, a machine learning

			algorithm is trained to estimate the likelihood of an arriving aircraft to perform a go-around at some point during the approach phase. Predictions are calculated at 8NM, 6NM, 4NM and 2NM gates and presented to the Tower Controller.
OPS.ER.3	Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?	Achieved	The analysis performed in D2.1 and D2.2 indicate that the proposed solution is relevant only for airports which combine several conditions. These are: • Congested traffic, and • Conflicts in departure and missed approach procedures In D2.1, several real-world scenarios are identified where these criteria are fulfilled. When go-arounds occur and both criteria prevail, safety relevant knock-on effects can occur, which are tackled by the proposed concept. While SafeOPS demonstrates, that there is a need under the described conditions, SafeOPS did not investigate/estimated the number of airports, the proposed solution would be relevant for. Such an investigation is one point of the open R&D needs, specified in the rational of criteria VAL.ER.1.
OPS.ER.4	Has the new concept or technology been described with sufficient detail? Does it describe a potentially useful new capability for the ATM system?	Achieved	The concept has been described in D2.2. The concept does not propose a potential new capability but aims to increase safety and resilience at the Tower Control. By providing time-in-advance information on likely go-arounds, the Controller can use a proactive approach to handle the likely go-around. Thereby, the Controller has more time to resolve the situation. Additionally, the proactive

			approach can increase safety and resilience, as it provides new tactical possibilities, reducing radar separation and wake separation risks. A detailed investigation of the tactics their impacts are documented in D2.2.
OPS.ER.5	Are the relevant stakeholders and their expectations identified?	Partially Achieved	One ANSP and two airlines are part of the consortium. In their role as stakeholders, they have been continuously involved in the research of the project. Especially the ANSP provided field experts to participate in the validation exercises and evaluate the proposed solution, which is documented in D2.2. Additionally, four Associated Partner Workshops and a final dissemination event were conducted to also obtain feedback from stakeholders outside of the Consortium. While the expectations and need of ANSPs have been discussed in great detail, the expectations of airlines have to be elaborated further.
OPS.ER.6	Are there potential (sub)operating environments identified where, if deployed, the concept would bring performance benefits?	Achieved	The Tower Control and especially the approach and go-around handling have been identified as the targeted operation environment in D2.1 and also in D2.2. As indicated in OPS.ER.4, the relevant airports, where benefits are expected, are those with high traffic volume and conflicts in departure and missed approach procedures. In these conditions, operational scenarios occur, for which the solution can provide safety and resilience benefits.
SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?	Partially Achieved	This is briefly discussed in D2.1 from the perspective which tools should provide the additional information and D3.3 [9]

			detailed the Human Factors aspects. However, a targeted investigation still has to be performed.
SYS.ER.2	Have automation needs e.g. tools required to support the concept/idea been identified and described?	Achieved	The need to automatically acquire, clean, fuse and label operational data has been elaborated in D4.1 from the IT Infrastructure perspective. Additionally, the automated training and testing of the machine learning algorithm is described.
SYS.ER.3	Have initial functional requirements been documented?	Partially Achieved	D2.1 provides an initial set of high-level functional, non-functional and data requirements. As proposed in D2.2, further requirements must be worked out. Thereby, the requirements must be further refined, focusing on safety requirements and taking into account the new EASA guidelines on AI in aviation [3] for the machine learning related requirements.
PER.ER.1	Has a feasibility study been performed to confirm the potential feasibility and usefulness of the new concept / idea / Technology being identified?	Partially Achieved	Taking into account the assumptions, documented in D2.2 and summarized in TRL-1.3, the usefulness in terms of safety and resilience benefits of the solution was demonstrated in D2.2. Also, in the workshops regarding Human Factors aspects of the solution, documented in D3.3, the users indicated the solution to be useful, as it could benefit their situational awareness and provide more time for safety relevant decisions. Regarding feasibility, a prototypical implementation of the solution's underlying machine learning constituent was developed and described in D4.1 and in [16].

			Real-time capability of the machine learning constituent was **not** investigated at this stage of the project. Therefore, the feasibility is not finally assessable.
PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?	Not Achieved	While the expected benefits their underlying assumptions have been discussed in D2.2 and summarized in TRL-1.6, an estimation of cost mechanisms has not been performed by the project.
PER.ER.3	Has an initial cost / benefit assessment been produced?	Not Achieved	No cost/benefit assessment has been produced.
PER.ER.4	Have the conceptual safety benefits and risks been identified?	Achieved	The risk framework in D3.2 analyses the safety benefits and risk on a general level for AI-based predictive tools. These found benefits include: • **increased situational awareness** • **more time for ATCOs to perform relevant tasks for safely handling go-arounds** and a **smoothing effect on operators' workload** The drawbacks include: • the eliciting of unsafe behaviours, such as **issuing clearances based on a disproportionate level of confidence** The safety benefits have also been investigated quantitatively in D2.2. (See TRL-1.6 for a short summary)

PER.ER.5	Have the conceptual security risks and benefits been identified?	Not Achieved	No security assessment has been performed by the project.
PER.ER.6	Have the conceptual environmental impacts been identified?	Not Achieved	This has not been investigated thoroughly in SafeOPS. From the results of D2.2, indicating that in false positive predicting cases, actual landings will perform a go-around could negatively impact the environment by additional noise and fuel consumption, needed for a second landing attempt. However, as go-arounds are rare (ca. 3/1.000 approaches) and the false positive prediction rate is also low, this occurs roughly 1/10.000 approaches and was considered negligible at this stage of the project.
PER.ER.7	Have the conceptual Human Performance aspects been identified?	Partially Achieved	An initial study on Human Performance aspects was performed in D3.3. It identifies the eliciting of unsafe behaviours, such as issuing clearances based on a disproportionate level of confidence in the machine learning solution. Also misunderstanding a state of no-go-around prediction as a landing prediction and base decisions on this misunderstanding is a human performance aspect, which needs to be further investigated. Furthermore, trust in the solution is discussed in SafeOPS. Guidelines on how to present the information, provided by the machine learning constituent, to the users in order to build trust is discussed in D3.3 and the white paper [17], composed by the ER-4 related automation projects. The main findings can be summarized to: • Trust does not necessarily need to be built during operations, but can also be acquired in training and

			(de-)briefing , which is found more valuable by the users than online explanations, especially in time or safety critical situations. • The project therefore advocates for additional on-demand explanations that, in less stressful situations or in simulations, help the user develop trust through a better understanding of system behaviour.
VAL.ER.1	Are the relevant R&D needs identified and documented? Note: R&D needs state major questions and open issues to be addressed during the development, verification and validation of a SESAR Solution. They justify the need to continue research on a given SESAR Solution once Exploratory Research activities have been completed, and the definition of validation exercises and validation objectives in following maturity phases.	Achieved	D2.2 states the next relevant R&D needs for the SafeOPS solution and also material that provides guidance therefor. This includes: • Real-time capability demonstration of the solution's underlying machine learning constituent • An investigation on conflicting departure and missed approach procedures for further hubs, at least in Europe. This exercise will help to understand better if the investigated concept will be an "island solution" or could be expended to further airports with a sufficiently large marked and commercial interests. • Monte Carlo based statistical investigations have to be developed, to increase statistical significance of the results.
TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?	Achieved	In D2.3, the concept is measured against EASA Guidance for AI in aviation [3]. Thereby, several important open points could be identified which are important to mature the project. These points include work on the open SYS.ER.1, PER.ER.1, PER.ER.5.

			PER.ER.2, PER.ER.3 and PER.ER.6, which are also not completely achieved in this Project cycle are not covered in D2.3. However, SESAR Guidance Material for Cost/Benefit and Environmental Evaluations is available in STELLAR and is assumed as starting point for these tasks.

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4 Conclusion and Lessons Learned

4.1 Conclusions

The main objectives from the Executive Summary of this document can be further specified from the descriptions in the DoA of SafeOPS. To increase safety and resilience in the scope of the proposed context of go-around handling by Tower Controllers, SafeOPS aimed to:

1. Develop an AI/ML tool for go-around predictions and explore it in terms of achievable performance metrics as well as explainability. This includes:
    a. Develop a data pre-processing pipeline, which performs necessary data cleaning and labelling tasks automatically.
    b. Identify and select a suitable AI/ML algorithm,
    c. Train and deploy and test the selected AI/ML algorithm.
2. Enhance a risk assessment method, such that it can cope with the introduced AI/ML based solution for the described go-around scenario. This includes:
    a. Identify the contributing factors to relevant safety events in the Operational Environment of the proposed solution.
    b. Develop a risk model, accounting for the identified safety events in the Operation Environment of the proposed solution, as well as the risks of the solution itself.
    c. Define how the probabilistic information, which is the outcome of the AI/ML algorithm shall be presented to end users.
3. Investigate the AI/ML based decision support solution for ATM, and evaluate the effects on capacity, safety and resilience of the departure and arrival handling in ATM. This includes:
    a. Determine, select, and acquire the data, necessary to develop a machine learning tool to predict go-arounds.
    b. Define the operational procedures to integrate the machine learning outcome in the Tower Controllers arrival and departure handling process.
    c. Design a framework to and measure the impact of the solution on safety, resilience, and capacity.

Concluding from the performed work, summarized in section 2.3 and the achieved results, presented in section 2.4, we conclude the objectives to be completely achieved by the project for the following reasons:

Objective 1

Using the data sets, identified, and acquired during the requirements definition phase of the project, an automated data pipeline has been developed in python. The data pipeline automatically cleans raw data, fuses different data sources, and computes features which allow the ML algorithms to predict go-arounds and labels the generated data set.

Based on the generated data set, a benchmark study for different machine learning algorithms has been performed and evaluated, using precision and recall metrics, which indicate the quality of a binary classifier. Using the Receiver-Operating-Characteristics-Curve Metric and feedback from the field experts, a suitable trade-off between precision and recall for the best performing machine learning algorithm was chosen. For the selected algorithm type, further training was conducted and a prototypical implementation of an AI/ML tool for go-around predictions has been deployed and discussed with potential end users of the SafeOPS concept. The achieved performance metrics were considered promising for the usage in the described context.

Finally, the explainability of the selected machine learning algorithm was investigated. Therefore, SafeOPS focused on general and local feature importance techniques. General feature importance techniques are relevant to define the overall behaviour of a machine learning solution, which was found useful for training of users with the methodology. Local feature importance techniques explain for each prediction, the relevant features responsible for the models' result. This is especially important, since users asked for the possibility to indicate the contributing factors for a prediction in real time in the radar screen upon request.

Objective 2

SafeOPS performed a methodical analysis of existing risk models, in order to ascertain their suitability for the assessment of risk on the SafeOPS project, specifically assessing the risk associated with the integration of a machine learning, decision support tool. The most appropriate risk model was selected by analysing the models through the lens of a number of acceptance criteria developed in the context of this project. SafeOPS selected the Accident Incident Model (AIM) framework, a model which has been extensively validated, which is capable of showing the change in risk with the addition/change of a technological tool, assesses safety impact qualitatively and quantitatively, and one which allows an extensive coverage of Human Factors aspects.

Therefore, SafeOPS investigated the Human Factors associated with the design and integration of the SafeOPS solution. Several visualization mock-ups were developed, which led to the consensus that visual indications in the radar screen are the preferred option. To avoid information overflow and nuisance warnings, a customizable visualization and a threshold for the predicted go-around probability to trigger visual information was requested.

Further, SafeOPS first identified the operations, decisions and actions which were impacted by the presence of the SafeOPS solution. Thereafter, SafeOPS described and integrated these components into the AIM risk model. Finally, the project described how the individual elements of the model change with the introduction of the SafeOPS solution. Furthermore, the findings about the Human Factors assessment of the SafeOPS solution on operations and human operators were also incorporated into the Risk Framework.

Objective 3

At the project's start, an initial Concept of Operations for the SafeOPS solution was defined, including the definition of operational scenarios of approach and departure handling, where the SafeOPS solution can provide safety and resilience benefits. Based on these scenarios, a set of high level functional, non-functional and data requirements have been defined. Based on the data requirements, the relevant raw data were identified and acquired. The Concept of Operations was further refined over the project's duration, taking into account the results of the work on the machine learning algorithms and the risk framework.

To assess the impact, the solution has on the safety, resilience, and capacity of the Tower Operations, especially the arrival and departure handling, a low-fidelity, real time simulation environment and attendant exercises have been developed. The results of the low fidelity simulation exercises support the findings of the risk framework, which found an overall safety and resilience benefit. However, the simulation also found an adverse impact on capacity. The situations in which the concept provides safety and resilience benefits however outnumbers the situations in which it reduces capacity. If the loss in capacity is acceptable in the ration foreseen through the achievable precision of the ML prototype must be evaluated in a cost assessment which includes potential revenue loss.

With the capacity ambitions of the ATM Master Plan in mind, suggesting a 60% increase of network throughput, which will result in more high traffic situations, the SafeOPS concept can provide a building block to better handle the efficiency/capacity vs. resilience/safety trade-off. Thereby it can indicate for each approach if the state-of-the-art procedures provide sufficient safety margins or if additional safety margins should be implemented.

The framework used for the impact evaluation, performed for the SafeOPS solution, also indicates a way on how to incorporate the uncertainty of simple ML/AI models into the safety assessment of AI/ML based ATM solutions.

4.2 Lessons Learned

4.2.1 Technical Lessons Learned

Deliverable 2.3 covers all technical lessons learned of SafeOPS and provides additional guidelines distilled thereof. In the following, the most important findings are summarized.

Explainability of Machine Learning Solutions

One common approach to build trust in AI on a User Level is Explainable AI. SafeOPS, in agreement with TAPAS and ARTIMATION, finds that during operations, rather than having explanations, the user needs to trust the system. This trust does not necessarily need to be built during operations but can also be acquired in training and (de-)briefing, which is found more valuable by the users than online explanations, especially in time or safety critical situations. Furthermore, Air Traffic Controllers, when under pressure, do not find the time to review explanations from the AI. Therefore, ATCOs prefer a simple design, presenting the AI output. The project therefore advocates for additional on-demand explanations that, in less stressful situations or in simulations, help the user develop trust through a better understanding of system behaviour.

AI/ML Oriented Training of Users

SafeOPS learned that training for ATCOs must be specifically reviewed to encompass the need to support humans with the integration of AI technologies. The training should include the significance of making decisions based on the technology outputs, to avoid over-reliance on AI. This is relevant in SafeOPS, e.g. since the absence of a prediction for one class (Go-around Prediction) does not imply a prediction for the second class (Landing Prediction). With the SafeOPS solution, and the performance of the current prototype, ATCOs have to be aware that decisions must not depend on the absence of a go-around prediction, misinterpreted as a prediction of a landing.

Data Management for Machine Learning Applications

In SafeOPS, we performed a data exploration, however not in a requirements-based approach. We identify a requirements-based data management as the most important task, in case of further work on the concept. SafeOPS learned that a thorough documentation of the input data to an AI/ML solution, is key for people, not directly involved in the AI/ML constituent's development, to assess claims and validity of the AI/ML solution. It is therefore paramount in enabling trust in the AI/ML solution for stakeholders, end users, Human Factors experts, the research community and the funding agencies like the SJU.

Safety Assessment

AI/ML solutions can provide non-deterministic information. It is important to incorporate into the assessment, that the forecast is not certain to occur. In case of binary classification as used in SafeOPS, false positive (a predicted go-around, which will not occur) and false negative (a not predicted go-around which will occur) predictions must also be taken into account, when assessing the impact of a tool. The precision and recall metrics allow to weight the different prediction cases against each other, according to their relative likelihood.

4.2.2 Non-Technical Lessons Learned

Communication, Dissemination and Exploitation

The CDE report (D5.2) describes the evaluation of CDE tasks and the lessons learned thereof in greater detail. In the following, the most important findings are summarized.

Additionally to the CDE actions, defined with the project start in the CDE Plan, a set of CDE actions emerged from joint efforts with similar oriented, exploratory research projects, funded by SESAR JU from the "Digitalisation and Automation principles for ATM" call. With the project starting at the beginning of the Covid-19 period and all meetings / conferences being held virtually until spring/summer 2022, especially the in-person RPAS & AI Event in Rome, a final dissemination event for several projects, provided a fruitful basis for dissemination, communication, and stakeholder engagement; with a reach beyond what could be achieved by virtual means. Joining efforts with similar oriented projects is thus considered a key enabler for good in-person events, as it is difficult for one project to generate enough interesting material for one-two full days and to justify travel costs for in person events, including budged for invited speakers.

Another lesson learned for SafeOPS is the lack of professional video production by the project, especially compared to e.g. Mahalo project. As described in section 2.6.7, SafeOPS released several videos, however in self-production, as no dedicated budget for professional/external video creation was allocated in the cost planning. In future projects, budget should be planned for such purposes, allowing for higher quality video material.

Stakeholder and Field Expert Involvement

Stakeholders are a part of the consortium of SafeOPS. This did not only ensure relevant feedback during the experiments and testing of the proposed concept and solution but most importantly already during development stages. Following the System Thinking approach, involvement of Field Experts in a user-centric development approach, is a key aspect in designing and developing resilient and safe systems. That was all the more crucial, when developing a solution based on technology which is unprecedented. Assessing the impact of AI solution on the operation, already during development phases, requires close synchronisation of stakeholders, field experts and developers.

4.3 Plan for next R&D phase (Next steps)

In case, further research is performed on the discussed topic the following next steps are recommended:

- Predictive Layer:
  - WP4 demonstrated, that based on historical ADS-B and METAR data, accurate predictions for go-arounds can be achieved in an offline manner. The next step is to demonstrate go-around predictions in an online fashion. This increases the technical difficulty and also the computational demands but is paramount for the realization of decision support tools in ATM, where ATCOs have to make decisions with situations evolving in real time.
  - WP4 used open-source ADS-B data. It would be desirable to find an ANSP willing to share their radar data. We are aware that there are severe challenges regarding data protection, but we believe that with data directly from ANSPs the accuracy can be improved further. This is not necessary immediately, however once an online prediction can be demonstrated with good quality, this step has to be taken.
  - For the work in WP4 several requirements have been formulated. Especially in terms of data requirements and data quality requirements more work is needed. This includes requirements specifying all operational conditions for which training data has to be available and also to which granularity this data must be acquired.
  - Next steps on the predictive layer should take into account Eurocae's ED-109a and ED-153, on software assurance in ATM.
- Operational Layer:
  - WP2 demonstrated use cases for an AI based decision support tool in D2.1 [4] and validated them in D2.2. Nevertheless, the limitations documented in section 3.5.1 of D2.2 must be addressed, in case of further investigations.
    - Therefore, we recommend performing an investigation on conflicting departure and missed approach procedures for further hubs, at least in Europe. This exercise will help to understand better if the investigated concept will be an "island solution" or could be expended to further airports with a sufficiently large marked and commercial interests.
    - The results achieved by D2.2 must be demonstrated on a wider operational spectrum. Monte Carlo based statistical investigations should be developed for the demonstrated solution scenarios, and potential new solution scenarios arising from the point above, to increase statistical significance of the results.
  - WP2 focused on the operational impacts of the presented idea. Therefore, further investigations should also investigate potential security, environmental, and cost impacts.
  - The functional requirements for the operational layer in D2.1 [4] were formulated vaguely. This was done intentional, as we started at TRL0. In future stages of

development, a more detailed set of functional requirements, in conjunction with further data-requirements must be written. EASA has published a guideline for machine learning applications in aviation [3], unfortunately after this project developed its requirements. A future project should consider this document and if possible, also be in contact with EASA and Eurocontrol, who contributed to these guidelines to ensure certifiability of the concept as early as possible during the developmental phase.

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Appendix A

A.1 Acronyms and Terminology

Term	Definition
ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
ATCO	Air Traffic Controller
DoA	Description of Action (part of the Grant Agreement defining the technical work, the project will perform throughout the project span)
Dx.y	SafeOPS Deliverable x.y (where x = task number, y = deliverable number)
SESAR	Single European Sky ATM Research Programme
S3JU	SESAR3 Joint Undertaking (Agency of the European Commission)
WP	Work Package

Table 12: Acronyms and technology

Appendix B Experimental Plan

B.1 Introduction

This Experimental Plan defines the SafeOPS experimental approach, its context and validation objectives. Furthermore, it defines the reference and solution scenarios and the to be performed experiments.

B.1.1 Background

The next generation of Air Traffic Management (ATM) systems are pushed more and more towards digitalization, driven by two goals that are hard to combine. Firstly, the demand for capacity and cost-efficiency of air transport operations increases. Secondly, already high levels of safety and resilience in the ATM system must be maintained and then continuously improved. As a mid-term solution, we propose integrating **a digitalized system with human operational management,** introd**ucing quantifiable performance predictions i**nto ATM. This digitalized system will be based on **big data technologies**, including the **fusion of data from different sources**. Organizing and making use of the vast amount of available sources in aviation, will pave the way for **Artificial Intelligence (AI) solutions**, such as **predictive risk estimation** and ultimately **decision support tools**. These solutions will enable safety applications that create a proactive, data-driven approach for safety management, capable of predicting potential safety hazards in real-time.

As an example for safety-critical events, SafeOPS investigates a decision support tool for go-around handling and the involved decision making processes.

Using today's technologies for big data**, large historical datasets of radar data can be annotated with on-board aircraft performance data**. Through predictive analytics, an air traffic control officer (ATCO) could be informed about potential missed approaches ahead of time. A controller having this information at hand could more quickly predict landing traffic, estimate runway capacity and plan for likely go-around events. It can potentially reduce their task- and workload compared to current ATM operations.

The question addressed by SafeOPS is, **how the nature of these information** will change the way the arrivals are managed by the tower control. Beyond **"information overflow",** the ATM human agents will have to adapt to **more**, but also **mostly probabilistic information** provided by big data analytics. Clever HMI refinements will certainly help to mitigate the potential overflow of information. It must show that an increase of capacity and or cost-efficiency can be achieved and also **the safety and resilience of the ATM, especially tower control in case of SafeOPS, is maintained or further improved**. SafeOPS aims to foster a collaborative paradigm that **involves both the ATM and airline operations worlds** to identify possibly hidden safety risks.

B.2 Overview

SafeOPS is an exploratory research project that investigates data-driven techniques for predictive risk estimation and their use as decision support in ATM operations. In particular, SafeOPS investigates this idea in the context of ATM operations at a tower unit during go-arounds. The project's goal is to research, whether a time in advance prediction indicating the probability for an approaching aircraft to perform a missed approach procedure (MAP) can benefit the ATCOs decision making in such way that it increases safety and resilience. This investigation furthermore includes identifying potential risks, introduced to the ATM operations by the inherently probabilistic information data-driven predictions provide.

As basis and guideline in developing this document serve SESAR's Safety Reference Material [18], Guidance to apply SESAR SRM [19], Human Performance Assesment Process and Experimental Approach Guidance for ER [20], the SJUs Accident Incident Models available in STELLAR , and the SJU's Resilience Engineering Guidance [21].

The SafeOPS experimental plan aims to provide a comprehensible summary of the work undertaken in demonstrating the possible benefits and drawbacks of the concept envisioned by SafeOPS on the ATM operation. Thus, in the following subsections, the context of the experimental actions will be laid out, including a description of the envisioned concept, the Research Questions posed and the targeted levels of Maturity / Validation.

B.2.1 Solution to be evaluated

This section describes the SafeOPS Concept. First, we provide a general introduction of the idea behind the SafeOPS Project. Thereafter, based on the requirements defined in SafeOPS Deliverable D2.1 (D2.1) [4], we summarize the relevant achievements of the development phase of SafeOPS, resulting in the SafeOPS Deliverables D3.2 [8], D3.3 [9], D4.1 [10]and D4.2 [11].

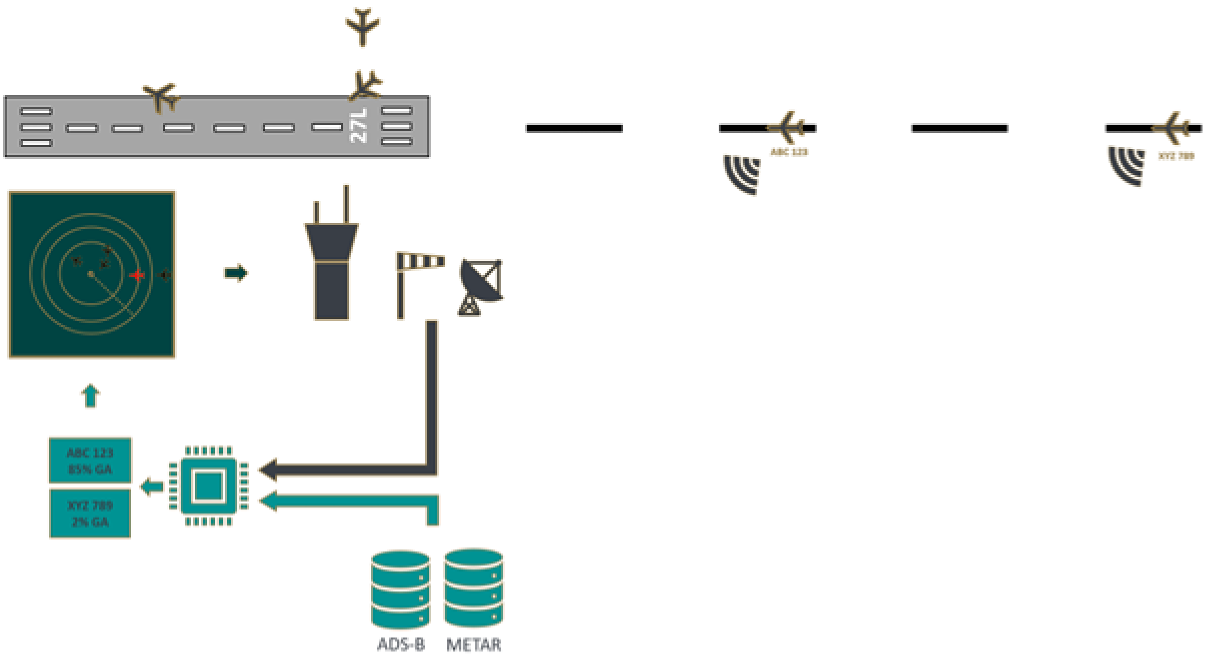


Figure 3: SafeOPS Concept visualization on a high-level basis.

Go-arounds occur with a rate of around 3 per 1000 approaches. Furthermore, go-arounds are considered a standard procedure used to maintain a safe operation by avoiding risks arising from unstable approaches or blocked runways. While the go-around likelihood of an approach is low, and a go-around is performed to avoid imminent arising risks, the go-around itself can result in high peak workloads for pilots and controllers. These high workloads are resulting from potential knock-on effects, the ATCOs and pilots have to bear in mind. If for example the missed approach procedure and the departure route of a preceding, departing aircraft are conflicting, separation and wake vortex related risks might arise which the ATCOs will have to evaluate and coordinate. On top, pilots performing a go-around are primarily focused to configure the airplane for the maneuver, following the "aviate - navigate - communicate" baseline, before communicating with the ATCOs. Thus, the situational awareness of the ATCOs can lag the actual situation, leaving less time for the described coordinative tasks.

Figure 3 illustrates, in a simplified manner, the idea behind solution proposed in SafeOPS. First, the figure implicitly defines the part of air traffic management which is targeted by SafeOPS, the approach and departure handling. While the boundary of the concept is not depicted in this figure, the illustration focuses on the arriving aircraft within around 10NM from the runway threshold and the runway occupations.

In general, operational performance data is available to Air Navigation Service Providers in the form or radar data, more specifically ADS-B and Mode S data. For readers interested in all details of ADS-B and Mode S data, we kindly refer to Junzi Sun's The 1090MHz Riddle [22]. Important to understand for SafeOPS is that ADS-B and Mode S data provide a source for aircraft performance information in almost real time. This information is currently provided to the ATCOs via the radar screen, being one important aspect for ATCOs' situational awareness.

The idea behind SafeOPS is to use this aircraft performance data, in combination with weather data - at this stage Meteorological Aerodrome Reports (METAR) - to build a tool which forecasts whether approaching aircraft have a high tendency to perform a go-around maneuver. Therefore, recorded, historical data shall be used to train a data-driven, machine learning model to predict go-arounds. This information shall be presented to the Tower Air Traffic Controller (ATCO), who - following the idea of SafeOPS - will be able to make more informed decisions in with more time for all adjacent actions. SafeOPS thus proposes to integrate a digital system with human management, which introduces quantifiable performance predictions into ATM, following the "from prediction to decision" paradigm.

The goal of SafeOPS as a project is to investigate, if and how data-driven decision support tools can be used to increase the safety and resilience of ATM systems. The investigation method chosen for SafeOPS is structured threefold: an Operational Layer, a Predictive Layer, and a Risk Framework. This structure is also reflected in the organization of the work packages and deliverables of SafeOPS. In the following subsection, we will summarize the relevant results from the previous deliverables to the point necessary to understand this report. At this stage, it is important to emphasize that SafeOPS is an **Exploratory Research Project,** and the TRL targeted is to fully complete TRL 1 and partially complete TRL 2 , as foreseen for Exploratory Research Projects in the SESAR Maturity Criteria definition. Thus, the outlined concept is not developed in its entirety within this project. Rather, SafeOPS tries to answer, if from the

1. operational perspective:
    1. relevant stakeholders can design and document plausible scenarios, use cases, and foresee potential benefits w.r.t. safety and resilience?
    2. the foreseen benefits can be demonstrated in workshops with stakeholders, through expert judgement and simplified simulation of the documented use cases?
2. predictive perspective:
    1. an IT infrastructure can be setup to automate the relevant tasks of data acquisition, data pre-processing and model training?
    2. the developed ML models used for go-around predictions can achieve an acceptable level of accuracy so that a benefit for safety and resilience in the operational layer can be achieved?
3. risk perspective:
    1. the described concept, which uses probabilistic information for decision support introduces new risks to ATM

2. the envisioned concept, when integrated in state-of-the art risk models, show benefits to safety of the ATM.

1. Operational Layer

D2.1 [4] explains in detail the methodology, used to guide the SafeOPS project, which includes elements from resilience engineering and requirements engineering. As part of the methodology, seven use cases for a go-around prediction tool are described, focusing on real world circumstances of two major European airports. For this deliverable and the targeted impact evaluation, we have decided to generalize the very specific use case descriptions from D2.1 [4] into a generalized use case, to:

- make the results of our experiments easier to transfer to other airport layouts.
- make the results of our experiments more general.
- reduce the number of scenarios, to keep the results lucid and understandable.

This does not go without loss of information; however we argue that even if the generalized use case is not as precise in its local circumstances, the main safety aspects are represented in the generalized use case. The reason for this argument can be found in the main risks, identified for all use cases which are either separation related or wake vortex related. Both primarily arise in all use cases defined in D2.1 [4] as a consequence of close proximities between departure routes and missed approach procedures.

It is important to note that not every missed approach faces these risks, as departure routes depend on many circumstances, such as destination of the departure, meteorological conditions at the departure airport, noise abatement rules or wake turbulence category of the departing aircraft. The use cases described in D2.1 [4] are the subset of all combinations of possible departure routes and missed approach procedures for which these risks are relevant, and where identified by the ATCOs as such in workshops during the work on D2.1 [4].

Generalized Mixed Mode Runway Scenario

For the purpose of the impact evaluation and the reasons stated above, we describe a generalized, mixed mode operated runway scenario for the SafeOPS solution. A mixed mode operated runway is a runway from which departures and approaches are managed. The scenario is divided into reference and solution scenarios, to allow comparison of state-of-the art go-around handling with go-around handling as foreseen with the presented solution. Furthermore, we describe landing and go-around scenarios as well as true positive, true negative, false positive and false negative solution scenarios. For the prediction of go-arounds, a binary classification algorithm is used. The details of the IT-infrastructure, data-pipeline, algorithms, achievable quality and explainability of predictions are covered in D4.1 [10] and D4.2 [11]. The relevant details are summarized in section 2. Since a binary classification tool, as used for the go-around prediction, can produce four types of results, which are true positive, true negative, false positive and false negative ones, four solution scenarios must be considered. The desired solution scenarios are the true positive and true negative prediction cases, undesired solution scenarios are the false negative and false positive prediction. Each of these four scenarios is described below. It is also important to state that it is not possible to know, in the situation, which scenario is occurring. Also, as the controller will act, depending on the information provided by the tool, a posterior classification of the situation in one of the scenarios is not trivial and would require a detailed investigation of the specific situation.

Thus, at this stage of the development, a statistical investigation is feasible. How likely each of the sub-scenarios occurs, is defined exemplarily for two airports by the recall and precision metrics in Table 20 and Table 21. The following solution scenarios are not designed to investigate the likelihood of occurrence but only the operational consequences of the scenarios. The consequences then will have to be weighted by the rate of occurrence, determined beforehand, exemplarily at two airports.

As stated for the reference scenarios, the solution scenarios are also formulated rather generic. Some possible strategies resulting from predictions will be described briefly. The actual strategies the ATCOs used during the experiments will be documented in detail, since they are dependent on the actual precise configuration of each simulation run.

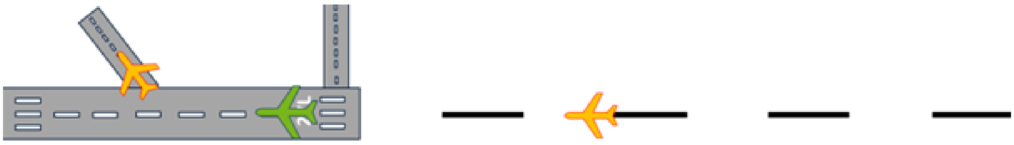
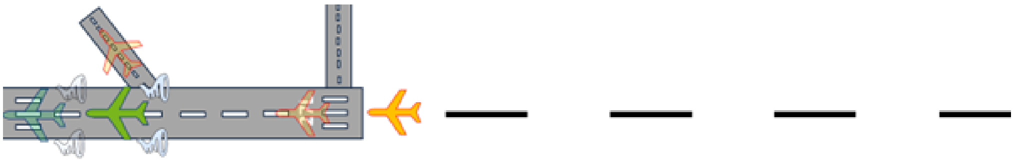
Solution Boundaries

As described in D2.1 [4], SafeOPS focuses on the work of Tower Controllers. Based thereon, D2.1 [4] defines conditions for the proposed solution. Firstly, the prediction shall be displayed to Tower Controllers. Even though ATCOs from adjacent sectors will eventually be involved in handling a go-around, they are not included in the development and evaluation process at this stage. Similarly, no ground or apron operations are considered. Finally, only aircraft induced go-arounds will be considered as target for the prediction algorithm. This condition has been set as flight crew induced go-arounds are unpredictable to ATCOs. Resulting from these conditions, the project focuses on is the control zone and terminal control area in which a Tower Controller is responsible. The handover from the approach controller to the Tower Controller at approximately 8-12 NM from the runway threshold (THR) yields as entry of aircraft, and taxiways as their exit. For departing aircraft, affected by a go-around, taxiways are an entry and the hand-over to the adjacent sectors serve as an additional exit.

Landing Reference Scenario

Table 13: Landing Reference Scenario

Scenario ID:	**Scen.Ref.1**		
Scenario Name:	Mixed Mode Landing	Version No:	1.0
Involved Actors:	Tower Controller, Flight Crew Arrival, Flight Crew Departure		
Description of Traffic Context:	Figure 4 illustrates a runway operated in mixed mode, with aircraft for departure colored green and arriving aircraft colored in yellow. The spacing between the arriving aircraft is such, that a departure can be cleared in between the landings, however the traffic is dense. The aircraft on the runway receive take-off clearance and is performing its take-off. The aircraft, waiting on the taxi way has a conditional line up clearance, for once the aircraft on short final passed it. Figure 5 illustrates the same scenario, once the first arriving aircraft has touched down and is vacating the runway. The first departing aircraft has taken off and the second aircraft lined up and is awaiting take off clearance. From this point onwards, two main lines of how the scenario could evolve exists. **Landing**		

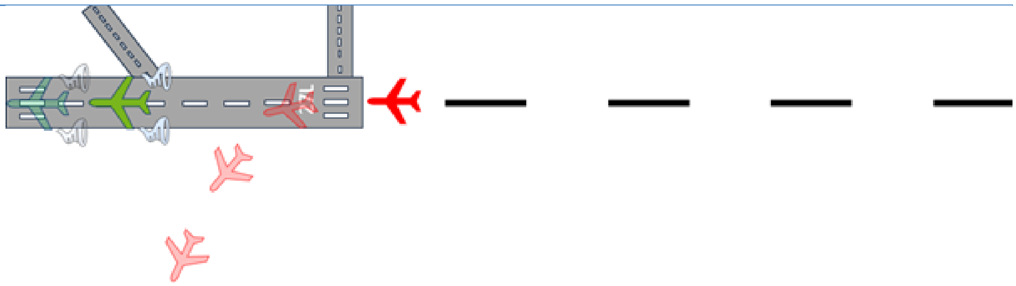
	In Figure 6, the scenario has progressed to where the arriving aircraft has received a landing clearance. The departing aircraft lifts off and proceeds with the departure. The transparent aircraft illustrate how the scenario evolves over time, however, not to scale. The approaching aircraft will touch down and vacate the runway, whereas the departing aircraft will follow the desired departure route. This describes the operation as desired, and is the most likely cases the scenario evolves.
Involved Decision-making:	-
Effect on ATCO / ATM / FC:	This is the nominal case where no conflicts are expected and the scenario would repeat for all inbound and outbound aircraft.
Visualization:	 **Figure 4: Landing reference scenario – Step 1**  **Figure 5: Landing reference scenario - Step 2**  **Figure 6: Landing reference scenario - Step 3**

Go-around reference scenario

Table 14: Go-Around Reference Scenario

Scenario ID:	**Scen.Ref.2**		
Scenario Name:	Mixed Mode Go-Around	Version No:	1.0
Involved Actors:	Tower Controller, Flight Crew Arrival, Flight Crew Departure		

Description of Traffic Context:	The initial setup is similar to Scen.Ref.2. Figure 4 illustrates a runway operated in mixed mode, with aircraft for departure colored green and arriving aircraft colored in yellow. The spacing between the arriving aircraft is such, that a departure can be cleared in between the landings, however the traffic is dense. The aircraft on the runway receive take-off clearance and is performing its take-off. The aircraft, waiting on the taxi way has a conditional line up clearance, for once the aircraft on short final passed it. Figure 5 illustrates the same scenario, once the first arriving aircraft has touched down and is vacating the runway. The first departing aircraft has taken off and the second aircraft lined up and is awaiting take off clearance. **Go-around** There exists an alternative in the scenario, compared to the landing case. In Figure 7, the scenario has progressed further, the departing aircraft has taken off and the second arrival received a landing clearance. In case, the arriving aircraft performs a go-around, and **the departing aircraft is on a departure route that conflicts with the standard missed approach procedure**, imminent action from the controller is needed to guarantee separation between both aircraft. In D2.1 [4], Airport 2 Scenario 2 (Scen.Airport 2.2) gives a real-world example for such a scenario. Airport 1 Scenario 2 (Scen.Airport 1.2) can also be seen as a comparable scenario, having the difference that the departure and approach are not performed on the same but on parallel runways, however with similar consequences. If the departing aircraft is a higher wake turbulence category type than the arriving aircraft, also independent from the departure routes, additional wake separations must be considered. A real-world example is described in D2.1 [4] Airport 2 Scenario 3 but also Airport 1 Scenario 1 (Scen.Airport 1.1) and Airport 1 Scenario 2 (Scen.Airport2 1.2) can be interpreted comparable, with the difference of different runway layouts. Due to high performance, the aircraft performing a missed approach quickly catches up with the departure aircraft. The ATCO aims to separate both aircraft from each other as fast as possible.
Involved Decision-making:	To establish wake turbulence and or radar separation, the ATCO has to decide how the missed approach can be performed.
Effect on ATCO / ATM / FC:	The ATCO has to establish wake turbulence / radar separation between aircraft. Therefore, a solution is to turn missed approach immediately. The workload of the flight crew increases, due to non-briefed missed approach procedure. Furthermore, the missed approach might has to turn below MVA (Minimum vectoring altitude) and below MSA (Minimum Sector Altitude), depending on the airspace layout (see Scen.Airport 2.3 for real world example).

Visualization:	 **Figure 7: Go-around reference scenario**

Go-around - True positive prediction - solution scenario

Table 15: Go-around - True positive solution scenario

Scenario ID:	**Scen.Solution.1**		
Scenario Name:	Mixed Mode Predicted Go-Around	Version No:	1.0
Involved Actors:	Tower Controller, Flight Crew Arrival, Flight Crew Departure		
Description of Traffic Context:	This scenario discusses the main use cases as defined in D2.1 [4]. In this scenario the approaching aircraft will perform a go-around, and the predictive tool would provide this information beforehand to the controller. Thus, various strategies could be applied by the controller, on how to handle the situation, depending on when the predictive information is available, as discussed in D2.1 [4]. Compared to the reference scenarios described in Figure 8 and Figure 4, the second arriving aircraft is predicted to perform a go-around, indicated by the red coloring in Figure 9. Depending on the time/point of this prediction, the ATCO has different options in this scenario, summarized in Table 1. Figure 9 illustrates the time of prediction between line-up and take-off clearance. The first arriving aircraft has touched down and is vacating the runway. The first departing aircraft has taken off and the second aircraft lined up and is awaiting take off clearance. The second arriving aircraft is now predicted to perform a go-around, indicated by the red coloring. In Figure 10, the ATCO has decided to wait with the take-off clearance and requested the arriving aircraft to perform a go-around. We want to emphasize that several strategies exists, which will be described in detail in D2.2		
Involved Decision-making:	Based on the time of prediction, the ATCO has several options to work with the arriving aircraft to avoid upcoming wake or radar separation challenges.		

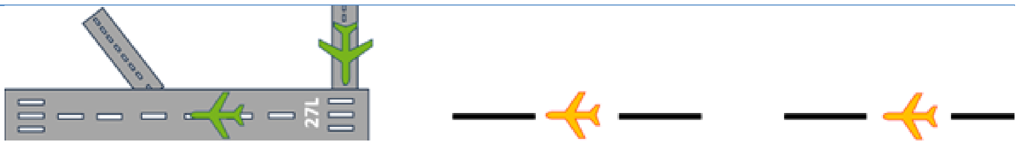
Effect on ATCO / ATM / FC:	Depending on the timing of the prediction, the ATCO could decide between several options, listed in Table 1.
Visualization:	 **Figure 8: Go-around solution scenario - step 1**  **Figure 9: Go-around solution scenario - step 2: prediction**  **Figure 10: Go-around solution scenario - step 3: alternative strategies**

Table 16: Strategies for the true positive prediction

Time/Point of Prediction	Options
after take-off clearance for preceding departure	In this case, the departure is rolling and will take off. The ATCO can thus use the time to brief the arriving aircraft for an alternative missed approach procedure which reduces wake/separation risks.
after line-up clearance and before take-off clearance for preceding departure	In this case, the ATCO can decide whether to give a take-off clearance or not. In case he does not give a take-off clearance, the ATCO has to command a go-around for the arriving aircraft, since the runway is blocked. The aircraft, which is predicted to perform a go-around thus would initiate the go-around based on the ATCOs instructions, without the departing aircraft in the sector. No wake/separation problems occur, however the departing aircraft's take-off will be delayed until the aircraft performing the missed approach, which is flying on runway track, is vectored or has finished the standard missed approach procedure.
before line-up clearance of preceding departure	In this case, the ATCO can decide whether to give a line-up clearance or not. In case he does not give a line-up clearance, the arriving aircraft could continue the approach. In case the predicted go-around is performed, no knock-on effects of wake/separation encounters will occur.

Landing – True negative prediction - solution scenario

This scenario is like the landing reference scenario. In the true negative prediction case, no go-around is indicated by the described solution and the approaching aircraft performs a landing as expected. It must be emphasized that an absence of a go-around prediction should not be understood as a prediction of the aircraft to certainly perform a landing. Based on the results of D4.1 and D4.2, false negative predictions (the tool indicates no go-around however the arriving aircraft will perform a go-around) will occur regularly. Therefore, with the quality of prediction demonstrated in SafeOPS, the state of the art procedures should be followed in case, no go-around is predicted.

Landing – False positive prediction - solution scenario

This scenario differs from the landing reference scenario. In this scenario, the decision support tool falsely indicates a go-around, even if the approaching aircraft would perform a landing. In this situation, controllers apply strategies which are tailored for handling go-arounds. As the options described in the true positive prediction case are all increasing safety measures by sacrificing capacity, false positive predictions will reduce the capacity of the operation. It is the goal of the simulations to estimate quantitatively these negative impacts on capacity in case of false positive predictions as well as the possible benefits for safety in the true positive prediction cases to provide a bases for decision makers whether these trade-offs are acceptable.

Table 17: Possible Strategies and expected impacts in case of false positive predictions

Time/Point of Prediction	Options
after take-off clearance for preceding departure	In this case, the departure is rolling and will take off. The ATCO can thus use the time to brief the arriving aircraft for an alternative missed approach procedure which would reduce wake/separation risks. In case the prediction is wrong however, the arriving aircraft could perform the landing, since the runway is free.
after line-up clearance and before take-off clearance for preceding departure	In case the ATCO does not give a take-off clearance, the ATCO has to command a go-around for the arriving aircraft, since the runway is blocked. In case the prediction is wrong, and the arriving aircraft would have landed, a landing slot will not be used, resulting in a loss of capacity.
before line-up clearance of preceding departure	In case the ATCO does not give a line-up clearance, the arriving aircraft continues the approach. In case the prediction is wrong, the arriving aircraft can perform the landing. The downside of this option is that one gap will be lost for a departure, reducing the airports capacity.

Go-around – False negative prediction – solution scenario

This scenario is similar to the go-around reference scenario. The tool does not indicate a go-around, however the approaching aircraft performs the missed approach procedure. Thus, this scenario is equivalent to the go-around scenario with no tool in place. Something that is not discussed at this stage of the project, but which would have to be investigated in case of further development of the solution are possible effects of familiarization with the tool. At this stage and with the results of D4.1 and D4.2, it must be emphasized that the solution cannot be used as a landing prediction. With this we want to express that the solution, with the current demonstrated accuracies cannot be used to assume an arriving aircraft, which is not predicted to perform a go-around, will perform a landing.

Therefore, the absence of a go-around prediction cannot be a used for decisions of line-up or take-off clearances.

2. Predictive Layer

For the predictive part of the SafeOPS solution, additional requirements were defined in D2.1 [4]. These are summarized in Table 22. Figure 11 visualizes the development process of the predictive layer of the SafeOPS solution, and the interfaces to the operations, called Problem Description and Deployment. The problem description summarizes the requirements and the technical problem statement, described in D2.1 [4], the deployment the intended use which is described in the scenarios and use cases in D2.1 [4]. The development of the predictive part of the SafeOPS solution is done in work package 4 and described in detail in D4.1 and D4.2. In the following, the defined requirements as well as the predictive result obtained are summarized. For detailed information on the developments and discussion of results, the reader is kindly referred to the publicly available documents stated above, which can be obtained on safeops.eu or the CORDIS platform.

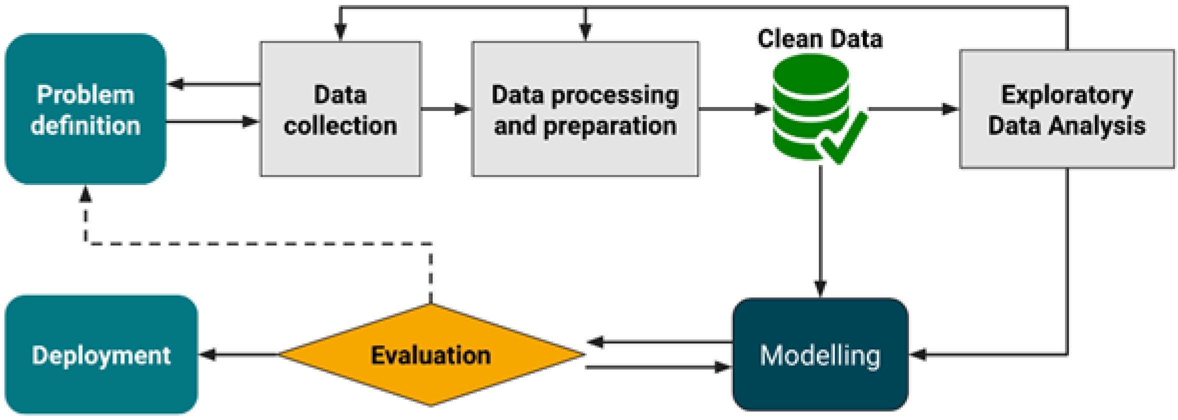


Figure 11: Overview of the IT processes in SafeOPS reference D4.1

Based on the problem definition, the required data set is defined and the data collection process is set up. The requirements FR.D.01 and NF.D.01 specify the way the data shall be stored and the information the data shall contain. For the predictive layer development, nearly two years (646 days) of ADS-B data for Airport 1 and Airport 2, containing both approaches and departures as well as the relevant METAR reports have been captured and stored in a data lake. Table 3 provides an overview on the number of approaches and go-arounds, found in the final dataset used.

Table 18: Size of data set, used in the predictive layer

Airport	Number of approaches in data	Number of go-arounds in data	Go-arounds per 1000 approaches
Airport 2	227044	646	2.85
Airport 1	377712	1237	3.27

For the available data, a data processing pipeline was set up, which performs any data preprocessing, cleaning, error correction and merging tasks automatically, as required by FR.D.02, FR.D.03 and NF.D.01. The complete actions performed on the raw data, to obtain the final data set, used for training the models that shall predict go-arounds is described in detail in D4.1. The important result of the data pipeline, at the moment of writing this experimental plan is a data set which contains the information, specified and grouped into four categories in Table 19, for each of the approaches in the data. This information is available for all flights at 0.5 NM steps between runway threshold and 10NM from runway threshold along the flight path of the aircraft.

Table 19: Collection of features, the predictive tool uses as input

Feature type	Feature name	Sampling	Source	Description
Flight information	Callsign	Static	Available in data	Flight callsign (e.g. DLH94U)
	ICAO24		Available in data	Aircraft unique 24-bit identifier (e.g. 3c4d6c)
	WTC		Engineered feature	Aircraft Wake Turbulence Category
	Approach attempt		Engineered feature	Flight approach attempt
	Hour		Available in data	Hour of the day
	Day		Available in data	Day of the week
	Week		Available in data	Week of the year
Weather data	Wind speed	Nearest available METAR report	Available in data	-
	Wind direction		Available in data	-
	Temperature		Available in data	-
	Visibility		Available in data	-
	Approach type		Engineered feature	IMC or VMC
	Dew point temperature		Available in data	Temperature below which the water will condense

	Ceiling height		Engineered feature	Based of the lowest clouds that cover more than half of the sky relative to the ground
	Cross-wind	Distance from the threshold	Engineered feature	Cross-wind component
	Head/Tail-wind		Engineered feature	Head or tail wind component
Approach performance	Runway ID		Engineered feature	Approached runway ID
	Specific energy level		Engineered feature	Aircraft specific energy level during the approach
	Ground speed		Available in data	Aircraft ground speed
	Vertical speed		Available in data	Descent vertical rate
	Vertical speed variance		Engineered feature	Descent vertical rate variance (window ±30s around time point)
	Track		Available in data	Aircraft track
	Track variance		Engineered feature	Aircraft track variance (window ±30s around time point)
	Altitude		Available in data	Aircraft altitude
	Track/Runway Bearing deviation		Engineered feature	Angular Deviation between aircraft track and runway bearing
	Centerline deviation		Engineered feature	Angular Deviation of aircraft position from runway centerline
	Localizer ddm dev		Engineered feature	Pseudo localizer difference in depth of modulation
	Glideslope ddm dev		Engineered feature	Pseudo glideslope difference in depth of modulation

Airport information	Total go-arounds	Time horizons (previous 10, 30 and 60 minutes)	Engineered feature	Total number of previous go-arounds at the airport
	Runway go-arounds		Engineered feature	Total number of previous go-arounds at the approaching runway
	Departures		Engineered feature	Total number of previous departures at the approaching runway
	Arrivals		Engineered feature	Total number of previous arrivals at the approaching runway
	Last departure time	Closest available flight information	Engineered feature	Time difference with previous departure at the approaching runway
	Last arrival time		Engineered feature	Time difference with previous approach at the approaching runway
	Last departure WTC		Engineered feature	WTC of the previous departure at the approaching runway
	Last arrival WTC		Engineered feature	WTC of the previous arrival at the approaching runway
	Aircraft in front		Engineered feature	Aircraft in front (approach, departure or none)
	Closing time		Engineered feature	2D Closing time in seconds with preceding approach or departure if any

With the dataset produced by the data pipeline, initially various machine learning models were trained to predict go-arounds, following requirements FR.M.01, NF.M.01 and NF.M.02. Therefore, several binary classification tools were developed in a benchmark study. Initially, the prediction point selected was at 4NM from runway threshold only, to check the quality of the data set and initial performance metrics for the predictions. According to FR.C.02, the possibilities for predictions have been expanded to 2NM, 6NM and 8NM from runway threshold, yielding the following performances, specified in Table 20 and Table 21. The Precision value indicates the probability that in case of an event (go-around / landing) being predicted, it will occur. The Recall value indicates the probability of an event (go-around / landing) being detected as such. Due to the strong imbalance of go-arounds vs. landings, these numbers have to be interpreted with caution. A full discussion on the results is described in D4.1.

Table 20: Results of the predictive tool for airport 1

Prediction point	Go-around	Precision	Recall
2NM	True	0.8850	0.4049
	False	0.9980	0.9998
4NM	True	0.9118	0.2510
	False	0.9975	0.9999
6NM	True	0.7846	0.2065
	False	0.9974	0.9989
8NM	True	0.9024	0.1498
	False	0.9972	0.9999

Table 21: Results of the predictive tool for airport 2

Prediction point	Go-around	Precision	Recall
2NM	True	0.8800	0.3411
	False	0.9981	0.9999
4NM	True	0.8710	0.2093
	False	0.9977	0.9999
6NM	True	0.9091	0.0775
	False	0.9974	0.9999
8NM	True	0.7000	0.0543
	False	0.9973	0.9999

Table 22: Requirements for the predictive layer, defined in D2.1

ID	Requirement
FR.D.01	The data sets available to the system shall be stored in a data lake, where they can be accessed as input for the data pipeline.
NF.D.01	The data set provided as input to the system shall contain information on: • A/C performance

	AND • meteorological conditions AND • pilot inputs to the A/C AND • WTC of the A/C
FR.D.02	The system shall contain a data processing pipeline that automates data cleaning and data preparation tasks.
FR.D.03	The system shall contain a data cleaning process, which automates the following tasks: • outlier detection AND • filtering / missing value handling for the data sets available in the data lake.
NF.D.01	The system shall contain a data preparation process, which automates the following tasks: • data fusion AND • target labelling AND • feature engineering for the data sets available in the data lake, and generates training data sets, test data sets and validation data sets.
FR.M.01	The system shall contain a machine learning model training process, which optimizes the prediction of a machine learning model, given a training data set.
NF.M.01	The performance assessment of the system shall include quantifiable metrics on: • true positive, true negative, false positive and false negative ratios AND • accuracy, precision, recall and specificity.
NF.M.02	The model training shall be able to cope with imbalanced training data sets.

FR.T.01	The prediction shall be computed every *prediction update rate* seconds in between a *minimum distance* and *maximum distance* measured from the runway threshold.
FR.C.02	The prediction shall be computed at *specified distance increments* in between a *minimum distance* and *maximum distance* measured from the runway threshold.

3. Risk Framework

One aspect of the incorporation of a predictive technology in the air traffic operating environment, is the risk associated with the technology insertion, management and use. Therefore, it is critical to assess and manage this risk. Work Package 3 of the SafeOPS project was assigned to the investigation of this risk, structured as a 'Risk Framework'. The Risk Framework developed in this project was aimed at analyzing the impact of the technology on the current safety levels being achieved in ATM.

For this aim, WP3 took a two-tiered approach to the development of the Risk Framework, in addition to a third task of deepening analysis of a key aspect of safety and technology insertion, namely the Human Factors Integration (HFI) component of the process.

The first part of the Risk Framework involved the methodical analysis of existing risk models, in order to ascertain their suitability for the assessment of risk on the SafeOPS project, specifically assessing the risk associated with the integration of a machine learning, decision support tool. After filtering and reviewing a number of risk models, the most appropriate risk model was selected by analyzing the models through the lens of a number of acceptance criteria developed in the context of this project. Although none of the models had elements aimed at assessing ML or AI technologies, one important criterion, that ultimately drove the final selection, was that of being able to assess change in an extant system. As such the work recommend the Accident Incident Model (AIM) framework, a model which has been extensively validated, capable of showing the change in risk with the addition/change of a technological tool, assesses safety impact qualitatively and quantitatively, and one which allows an extensive coverage of Human Factors aspects.

The second part of the Risk Framework was to pick up the recommended risk model and use it for the articulation of risk associated with the integration of the SafeOPS tool into the ATC system. This was achieved through three activities; firstly, by identifying the operations, decisions and actions which were impacted by the presence of the SafeOPS tool, secondly by describing and integrating these components into the AIM risk model, and thirdly by describing how the individual elements of the model change after introducing the SafeOPS tool. The first step of this analysis identified at a high level the safety functions fulfilled by the ATCOs before and during the go-around maneuver, namely:

- **Runway management**, which consists in continuous monitoring and issuing the necessary clearances to ensure that the runway is used by only one aircraft, vehicle, or personnel at the time.
- **Traffic separation** monitoring, which, in particular during the go-around, requires the identification of potential conflicts between the standard missed approach procedure and the trajectories of other traffic in the area.
- **Monitoring of the wake category** of the traffic in the area to ensure that a lighter-type aircraft does not encounter the wake vortex generated by a heavier aircraft, a situation which might

become relevant during a go-around depending on the wake categories and climbing performance of the departing and landing aircraft, especially in case of late go-arounds.

- **Trajectory management**, which might require to actively vector the traffic in the area to prevent potentially hazardous situations, for example by telling the departing A/C to climb straight ahead, or by telling the go-around to perform a non-standard MAP, or in some cases by cancelling the take-off clearance if necessary, to prevent potentially hazardous situations.

In this exercise it was possible to effectively identify the base events that were impacted by the introduction of the SafeOPS predictive tool, which in many cases involved the lack of sufficient time to timely assess, and react to, the evolving situation. The analysis revealed that there were several improvements to the safety of the system, from the introduction of the SafeOPS tool. These improvements included i**ncreased situational awareness** in the ATCOs, more time to get an accurate and complete picture of the traffic, and **more time in which to perform their tasks.** These improvements have a **smoothing effect on operators' workload** and thus results in a lower probability of human errors, an increased chance that a potential conflict is identified and a higher likelihood that effective plans are made to anticipate or resolve potentially hazardous situations. Although considered highly unlikely, **the analysis also found a small number of drawbacks.** These include the eliciting of unsafe behaviors, such as **issuing clearances based on a disproportionate level of confidence** that an inbound aircraft will definitely go-around or land; and also, the act of cancelling a take-off clearance resulting in an increased risk of runway excursion.

The final part of WP3 involved analysis of the Human Factors associated with the design and integration of the SafeOPS technology. Therefore, a visualization prototype was developed based on the requirements FR.H.01-FR.H.03, from D2.1 [4]. These requirements define, how the prediction shall be presented to the controller. While also vague at this stage, they condense on what the operating personnel could agree at the earliest stage of the project, regarding how the computed information shall be provided to the controllers. It became consensual that visual indications in the radar screen are the preferred option. To avoid information overflow and nuisance warnings, a customizable visualization and a threshold for the predicted go-around probability to trigger visual information was requested.

Table 23: Requirements relevant for Risk Framework, defined in D2.1

ID	Requirement
FR.H.01	The system output shall be provided as visual indication.
FR.H.02	The content of the visualized indication shall be customizable.
FR.H.03	The prediction shall only be presented, if the predicted probability of a Go-Around is above a quantifiable *minimum Go-Around probability* threshold.

Based thereon, D3.3 [9] introduced and evaluated the Human Factors related specifically to that of a machine learning tool which produces probabilistic information, and thus represents something novel in its scope. This study delivered an overview of Human Factors as it relates to probabilistic information, a review of existing ATM 'safety' tools, presented a format for evaluating the Human Factors of an early prototype of the SafeOPS tool, reported on user feedback elicited through several online workshops, and finally provided Human Factors design requirements and guidance for the tool, according to user feedback, current Human Factors best practice and up to date understanding of Human Factors in AI.

B.2.2 Research Question

For the described solution, SafeOPS plans to answer the following high-level research questions with experimental actions.

Table 24: High Level Research Questions

ID	Research Question
RQ1	**Does the SafeOPS concept provide a safety benefit for the tower operations?**
RQ2	**Does the SafeOPS concept increase resilience of the tower operations?**

Based on these questions, validation metrics are defined in section 3. The validation metrics' purpose is to assess the impact of the SafeOPS solution on ATM operations regarding the posed research questions. Thereby, SafeOPS identified the Key Performance Areas (KPAs), as defined in SESAR's Performance Framework [23]:

- **safety**
- **capacity/resilience**

to be affected by the proposed solution.

B.2.3 Maturity Target

SafeOPS is an exploratory research project. SafeOPS' initial goal is to complete TRL1 as defined by the SESAR Maturity Criteria, corresponding to the European Operational Concept Validation Methodology (E-OCVM) [24]. Table 25: Desired TRL states the TRL objective for SafeOPS.

Table 25: Desired TRL

Solution / Concept	Initial Maturity	Min. Desired Maturity	Desired Maturity
Data-Driven Go-Around Prediction	-	TRL1	TRL1 complete TRL2 partially

B.3 Objectives / General Approach / Methodology

B.3.1 Exercise Execution

In D2.1 [4], an initial concept has been laid out for SafeOPS, including use cases and reference and solution scenario description. These were developed in workshops with Air Traffic Controllers of two airports. Thereby, we also defined expected impacts of an AI-based go-around prediction. The expectations from D2.1 [4] are, that a solution, as now further defined in section B.2.11 could benefit the safety and resilience of the tower operation, especially in the approach and go-around handling, by reducing separation challenges but also coordinative actions and high peak workloads.

In WP3 and especially in SafeOPS Deliverable D3.2 [8], an operational risk assessment is presented for the solution described in section B.2.13. Section 2.2 of D3.2 [8] provides an overview of the relevant tasks the Tower ATCOs perform during approach, departure and go-around handling. The main tasks identified are:

- Runway Monitoring,
- Separation Monitoring,
- Wake Vortex Monitoring and,
- Trajectory Management.

Accordingly, D3.2 [8] identified the relevant Accident Incident Models (can be found on the SJU's intranet) for Mid-Air-Collisions during Final Approach Phase, Wake Encounters during Final Approach Phase, Runway Collisions and Controlled Flight Into Terrain, which model the relevant safety risks and the operational barriers in place to prevent incidents and accidents. The focus of D3.2 [8] was to semi-qualitatively describe the benefits and disadvantages as well as the changes in safety and risks, introduced by the SafeOPS solution. As stated in D3.2 [8], the SafeOPS solution is not mature enough for Human-in-the-Loop simulations.

However, the work performed in this deliverable aims to set up simplified simulations to support or disapprove the previous results of D3.2 [8] and the expectations of D2.1 [4] with quantitative metrics. Therefore, based on the use case described in section B.2.11 and the reference and solution scenarios of D2.1, several simulation exercises have been defined to test against our momentary claims.

The simulation environment, developed for this task consists of three ingredients:

- a simulation model of a departure aircraft, implemented in Matlab Simulink,
- a simulation model of an arriving aircraft, implemented in Matlab Simulink,
- and a visualization of a radar screen, which is implemented in Python.

Both aircraft models send their information via User Datagram Protocol (UDP) to the visualization tool, which displays the relevant information in a mimicked radar screen. Each simulation ingredient is described in more detail in Appendix C.

Execution of the Exercise

From the initial situation, illustrated in Figure 12, onwards, the simulation computes in real time the position and velocities of the two simulated aircraft. Both aircraft are controlled by algorithms, which let them fly the Standard Instrument Departure (SID) and Standard Arrival Route (STAR) automatically. The control structure for each aircraft is described in more detail in the respective Appendix sections C.1.3 and C.2.3.

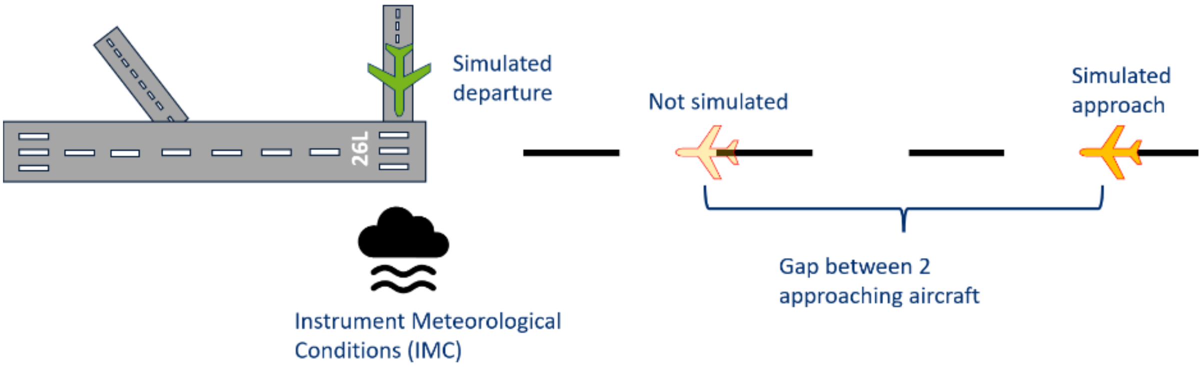


Figure 12: Initial conditions of the simulation

For the departure aircraft, there are several inputs available which can be manipulated during the simulation, which are:

- a line-up clearance switch, which lets the aircraft move on the runway,
- a take-off clearance switch, which initiates the automated take-off and departure sequence. If no further input is given, the departure follows the procedure defined in the SID, as described in Appendix C.2.5,
- a heading input, which once activated turns the aircraft to the commanded heading,
- an altitude input, which once activated commands the aircraft to climb to the set altitude, and
- a speed input, which accelerates/decelerates the aircraft to the commanded speed.

which allow the Tower Controller to vector the departing aircraft.

The approaching aircraft follows the localizer and glideslope signal, once the simulation starts. It will continue until touchdown, if not commanded otherwise. Several inputs for the approaching aircraft are possible, which are:

- a go-around switch, which once activated performs a go-around sequence specified in the SID,
- a heading input,
- an altitude input, and
- a speed input.

During the simulation, the Tower Controller gets the simulated scenario visualized in real time on a radar screen simulation. Our usual setup was to use a television in a conference room, connected to the simulation computer. A television was used to display the radar simulation for the controller, and the simulation operator could control the aircraft, following the Tower Controllers commands, as illustrated in Figure 13.

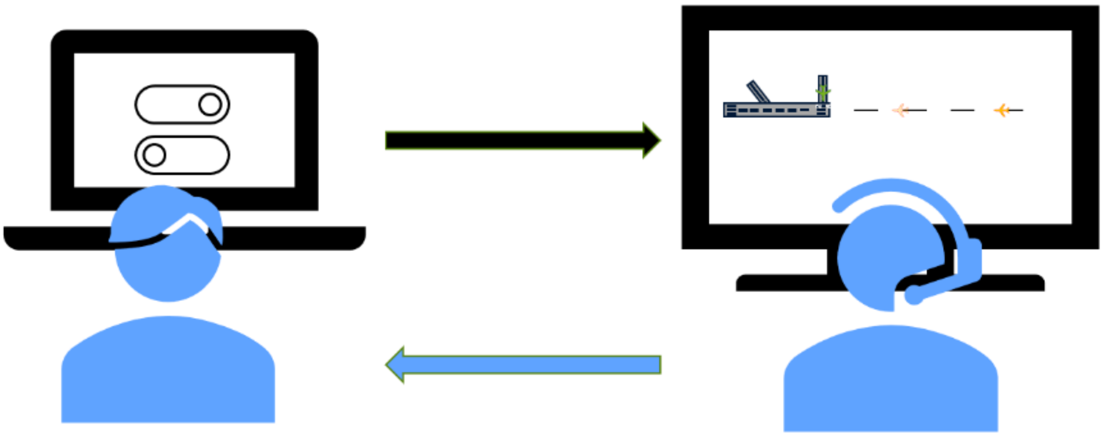


Figure 13: Illustration of simulation setup, simulation operator and Tower Controller

The simulation of the scenario ends when the approaching aircraft performed a touchdown, or in case of a missed approach, all safety relevant challenges have been cleared and the departure and missed approach are handed over to the departure controller.

Expected Outcome of the Simulation

From each simulation, we generate two artifacts, which will be used for the evaluation of the simulations. The first on is the position timeseries of both simulated aircraft. Table 26 illustrates an excerpt of a data set.

Table 26: Illustration of simplified simulation output

Time in seconds	Latitude of Departure Aircraft in degrees	Longitude of Departure Aircraft in degrees	Hight Above Ground of Departure Aircraft in meters	Latitude of Approach Aircraft in degrees	Longitude of Approach Aircraft in degrees	Elevation Approach in meters
0.01	48.34589	11.805218	443.71	48.35720	11.96199	843.42
0.02	48.34589	11.80521	443.71	48.35720	11.96199	843.42
⋮	⋮	⋮	⋮	⋮	⋮	⋮
195.74	48.34101	11.75839	726.62	48.28554	11.81787	1523.59

Additionally, we document the actions of the Tower Controller during the simulation in sequence diagrams, similar to the ones in SafeOPS D2.1 [4] . A toy example is provided in Figure 14.

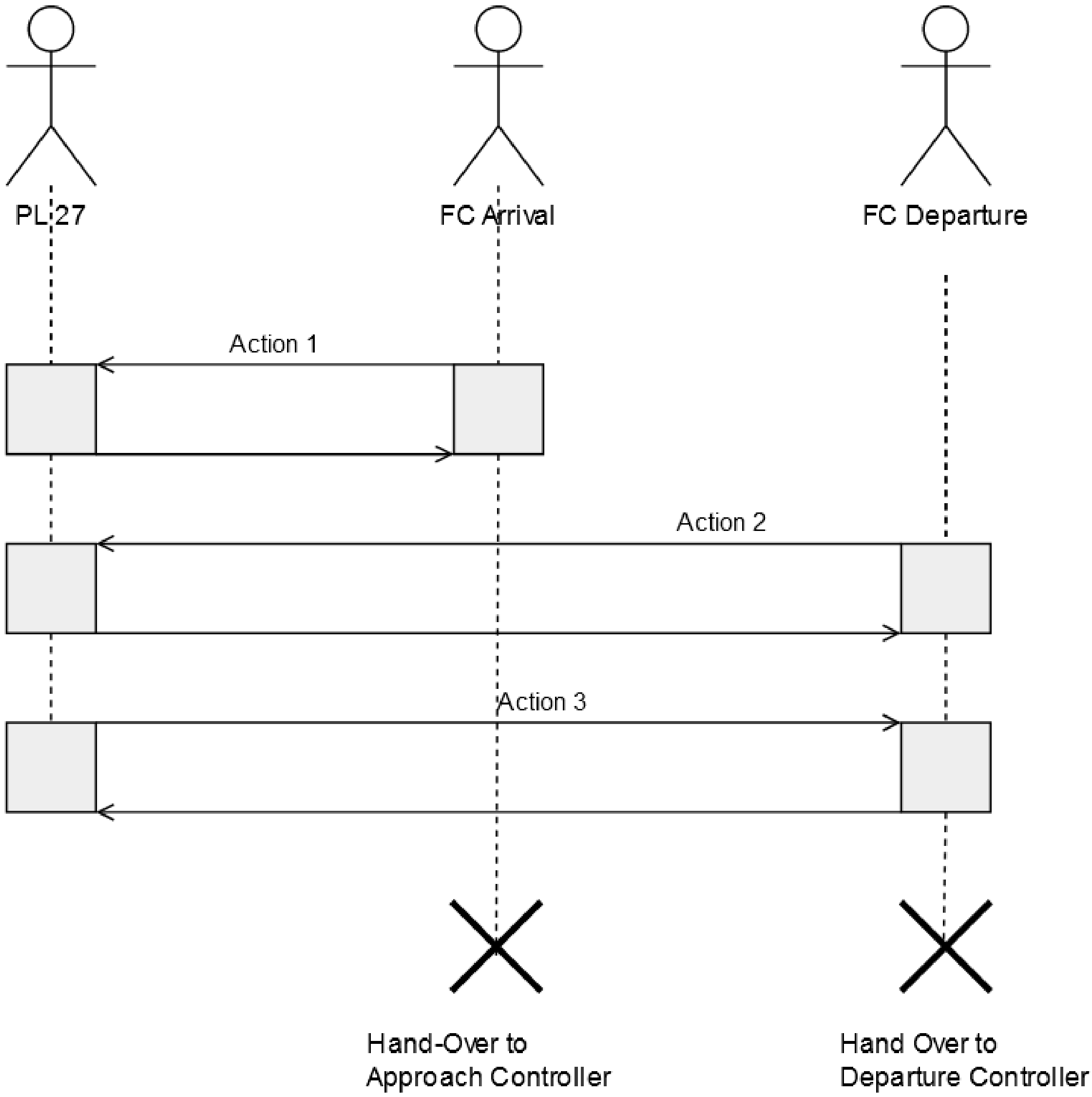


Figure 14: Illustration of a sequence diagram, used to visualize the actions of the Tower Controller during the simulation

Disclaimer

The simulation exercise aims to quantify the safety benefit, the predictive decision support tool can have, when directly compared to the state-of-the-art go-around handling. What cannot be quantified with the simulation exercise described here is potential loss of skill, misuse of the tool and adaption effects which could occur after getting used to predictive decision support tools.

Potential misuse of the tool could be e.g. to assume if no go-around is indicated, a landing is certainly going to happen and based on this assumption do not make plans for a potential go-around. However, the quality levels as demonstrated by the prototype as described in D4.1, especially the low recall values imply that this solution cannot be used as landing predictor!

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Nevertheless, the indicated Human Factor topics have to be investigated in later stages of the development of a predictive decision support tool, when more advanced testing is available.

B.3.2 Simulation Environment

The simulation Environment is described in detail in Appendix C.

B.3.3 Evaluation Metrics

The high-level research questions for the SafeOPS concept are described in B.2.2. Based on these questions, validation metrics are defined. The validation metrics' purpose is to assess the impact of the SafeOPS solution on ATM operations regarding the posed research questions. Thereby, SafeOPS identified the Key Performance Areas (KPAs), as defined in SESAR's Performance Framework [23]:

- **safety**
- **capacity/resilience**

to be affected by the proposed solution.

Safety

In this section, the identified safety criteria to assess the impact of the SafeOPS solution on the safety of the go-around handling are defined. The identification of criteria was twofold, based on the information obtained during the initial workshops where the scenarios and use cases were defined and the Accident Incident Models (AIMs) 2020, provided within STELLAR, the SJU's extranet platform.

Starting from the overall research question regarding safety that is framed as: **Does the SafeOPS solution benefit the safety of the Tower Operations?** The ATCOs identified two concrete safety related questions:

Table 27: Specified Safety Related Research Questions

ID	Research Question
RQ1.1	**Does SafeOPS solution improve the (radar) separation in the go around scenarios?**
RQ1.2	**Does SafeOPS solution improve the A/C WT separation in the go-around scenarios**

Identified Safety Criteria from ATCOs / Workshops

In D2.1, the ATCOs identified several safety relevant situations which can occur during go-around handling. In D2.1, these can be found in section 3 - Scenarios in the **Involved Decision making** and **Effect on ATCO / ATM / Cockpit Crew** of the scenario description. As the Experimental Plan aims to be more generic than D2.1, we summarize the safety relevant criteria airport independent and will refer to the airport specific scenarios described in D2.1.

Radar Separation:

- Conflicting Departure and Missed Approach Route (Scen.Airport2.1)
- Parallel Aircraft on Departure and Missed Approach (Scen.Airport1.1)

Wake Separation:

- Possible Catch-Up effects of the Aircraft performing a missed approach (Scen.Airport1.2 and Scen.Airport2.3)

Identified Safety Criteria from AIM Models and D3.2

Bases for this section are the Accident Incident Models 2020 (AIMs). For our investigation, the AIMs for Mid Air Collision Risk on Initial Departure, Mid Air Collision Risk on Final Approach, Wake-Induced Risk on Initial Departure and Wake-Induced Risk on Final Approach are considered. Following the SJU SRM, the precursors of the AIM can be used as Safety Criteria. From the above mentioned AIMs and starting from the ATCOs Safety Criteria, the following precursors were identified to be relevant for the SafeOPS experiments:

- Mid-Air Collision Risk on Initial Departure → ME.FF.3**: Imminent Minimum Radar Separation infringement** on initial departure due to MRS conflict induced when second aircraft already airborne
- Mid-Air Collision Risk on Final Approach → MF11: **Aircraft on published Missed Approach in potential conflict with another traffic** (e.g. Scen.Airport2.1)
- Mid-Air Collision Risk on Final Approach → MF11a: **Aircraft on ATC-managed break-off/go around in potential conflict with another traffic** (e.g. Scen.Airport2.1)
- Wake-Induced Risk on Initial Departure → WE8.b.1: **Imminent infringement on departure due to 1st or 2nd aircraft deviation from expected behavior** - second a/c already airborne

A quantitative assessment of the listed precursors is done by computing the minimum separation distances of the aircraft in the scenario. According to ICAO DOC 4444, we distinguish between horizontal and vertical separation. The minimum distance provides a continues metric for each simulation. On top, as a binary classification of the criticality of the scenario, one can evaluate, if the minimum measured distance between the aircraft is a separation infringement, as defined in ICAO DOC 4444. This allows to distinguish whether a possible impact is significant regarding the addressed safety concerns, or if there is a change in the scenario, but the reference scenario itself is safe and does not necessarily need improvement.

- For vertical separation, the applicable separation minimum for our Simulation Scenario is 300m, according to Section 5.3.2a of ICAO DOC 4444.
- The horizontal separation, the applicable separation minimum for our Simulation Scenario is 3NM, according to Section 8.7.3.2a of ICAO DOC 4444.

Therefore, we define the following metrics regarding radar separation. Note that S1 and S2 are "softer" metrics in case S3 allows no differentiation between solution and reference scenarios. A change in S3 has to be considered a higher impact.

Table 28: Definition of Safety Metric 1

ID:	**Obj.S1**
Objective	Assess the impact of the SafeOPS solution on the radar separation

KPA to be investigated	Safety
Metrics	Minimum vertical distance between A/Cs, when the horizontal distance is below 3NM.
Success Criteria:	Described sequence of action of ATCOs increases the simulated minimum vertical radar separation distance in the solution scenario, compared to the reference scenario.

Table 29: Definition of Safety Metric 2

ID:	**Obj.S2**
Objective	Assess the impact of the SafeOPS solution on the radar separation
KPA to be investigated	Safety
Metrics	Minimum horizontal distance between A/Cs, when vertical separation is below 300m. Figure 15 illustrates this metric.
Success Criteria:	Described sequence of action of ATCOs increases the simulated minimum horizontal radar separation distance in the solution scenario, compared to the reference scenario.

Table 30: Definition of Safety Metric 3

ID:	**Obj.S3**
Objective	Assess the impact of the SafeOPS solution on the radar separation
KPA to be investigated	Safety
Metrics	Situation which requires immediate action by the Tower Controller to ensure separation.
Success Criteria:	Described sequence of action of ATCOs prevents a situation in the solution scenario, in which the ATCO must immediately act to ensure separation, compared to the reference scenario.

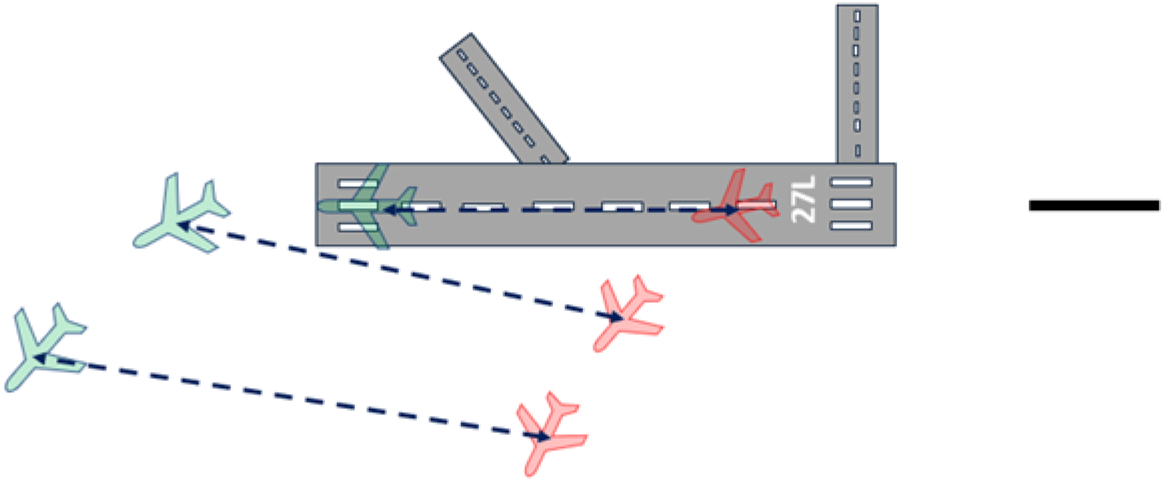

Figure 15: Illustration of the horizontal radar separation metric

Wake separation only applies, if the departing aircraft has a higher wake turbulence category than the approaching aircraft.

Similarly, for the wake separation in approach and departure phase, ICAO DOC 4444 Section 8.7.3.4 defines a 5NM separation minima when an aircraft operates behind the higher wake category aircraft at the same altitude down to 300m below. As in our scenario, the 5NM separation minima will not be met, we measure the height difference between the departure and approach aircraft, when the approach is operating in a 100m radius from top view to where the departure was flying. In case the height difference is such that the approaching aircraft is between 0m to 300m below the departing aircraft when in the 100m proximity, we count a wake separation infringement, addressed by S5. Using the height difference additionally, we get a measure of how close a wake separation infringement was during the scenario, even if no actual infringement occurred, indicated by S4. Note that a change in S5 generally states a higher impact than a change in S4. S4 can be used to assess the change in case S5 does not change from reference to solution scenario.

The 100m proximity from the top view is chosen, as it is approximately the sum of half the wing span of both aircraft. Figure 16 illustrates the way, the height difference is computed for one position of the departing aircraft. This procedure is repeated for each position of the departure in a one second interval. Table 31 and Table 32 document the two metrics regarding wake separation.

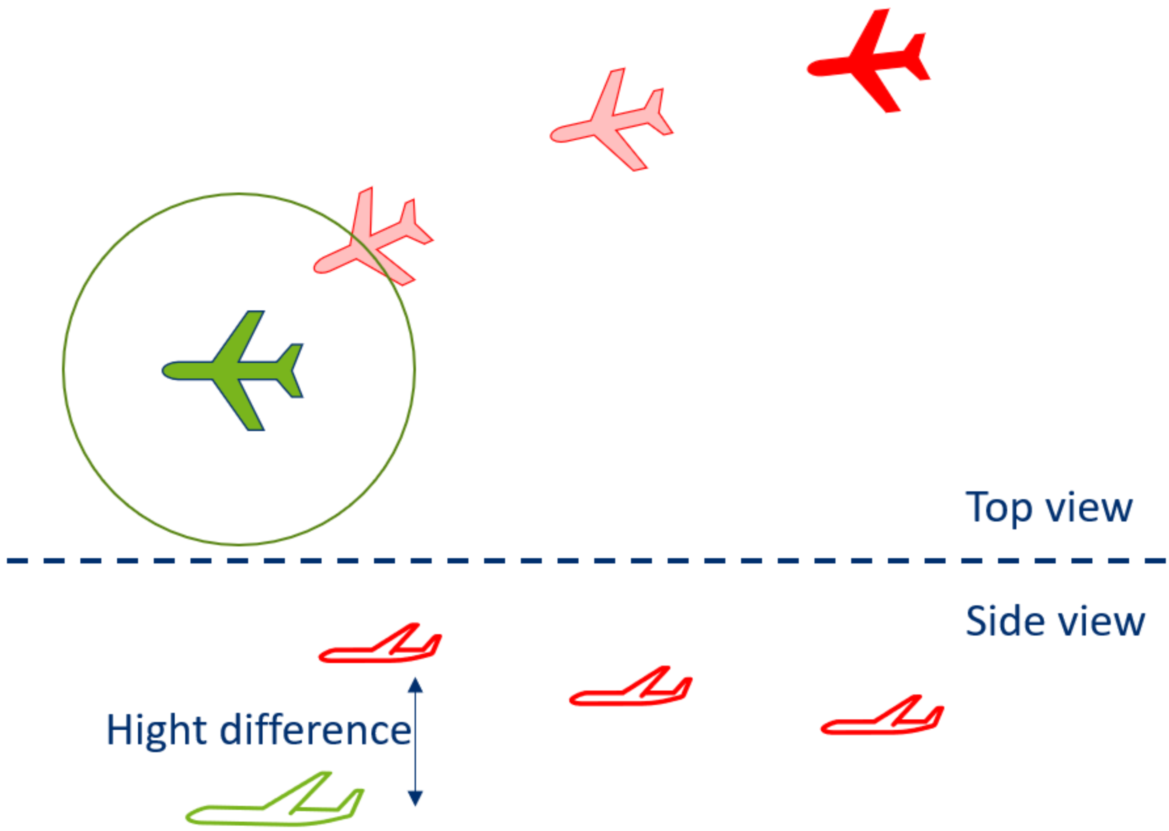

Figure 16: Illustration of the Wake Separation Metric

Table 31: Definition of the Wake Separation Metric 1

ID:	Obj.S4
Objective	Asses the impact of the SafeOPS solution on the wake separation
KPA to be investigated	Safety
Metric	Minimum height difference between approaching and departing aircraft, when the approach is operating in a 100m radius from top view to where the departure was flying, and the approach has lower wake turbulence category than the departure.
Success Criteria:	Described sequence of action of ATCOs increases the minimum simulated wake separation distance in the solution scenario, compared to the reference scenario.

Table 32: Definition of the Wake Separation Metric 2

ID:	Obj.S5
Objective	Asses the impact of the SafeOPS solution on the wake separation
KPA to be investigated	Safety
Metric	Minimum height difference from S4 is below 0 and above -300m. Wake Separation Infringement.
Success Criteria:	Described sequence of action of ATCOs increases the minimum simulated wake separation distance in the solution scenario, compared to the reference scenario.

Resilience and Capacity

In this section, the identified resilience criteria to assess the impact of the SafeOPS solution on the resilience of the ATM operation are defined. The identification is based on the information obtained during the initial workshops where scenarios and use cases were defined and the sequence of actions for reference and solution scenarios were worked out.

The overall research question regarding resilience was framed as: **Does the SafeOPS solution increase resilience of the tower operation?** This general question can be split up in more specific questions by asking:

Table 33: Specified Resilience Research Questions

ID	Research Question
RQ2.1	Does the SafeOPS solution reduce the necessary (coordinative) actions of the Tower Controller to resolve the scenario
RQ2.2	Does SafeOPS solution reduce unbriefed Missed Approaches (increased / unforeseen Workload)?

Unbriefed missed approach procedures are a result of safety relevant situations described in the scenarios in D2.1 [4]and are considered a resilience metric, following the arguments from D2.1 [4] - Section 3.1.3. Missed approach procedures are safety relevant situations managed by knowing the options and decisions to be made beforehand by briefing the published procedure. This is not given in the described scenarios where aircraft are vectored and do not follow the published missed approach procedure. This is increasing the (unforeseen) workload of the flight crew during a missed approach procedure. When having information of a potential missed approach to be performed, the ATCO could brief the flight crew beforehand to prepare for a different, vectored missed approach, allowing an (earlier) adaption to a possible upcoming situation for the flight crew.

Also, the coordinative actions of involved personnel can be measured to asses the adaptive and restorative resilience. Thereby, one can asses how the tower controller returns to normal operation, after a rare event, like a go-around, has occurred and how his actions change, in case he is prepared for a go-around beforehand. A human operator is considered key in providing resilience to the operation. Reducing peak workload by providing a lager time frame to take actions and shifting tasks into less demanding periods, or decreasing the overall tasks increases the cognitive flexibility of the ATCOs. Therefore, the following metrics to assess the impact of SafeOPS on the resilience of ATM are defined.

Table 34: Definition of the Resilience Metric 1

ID:	Obj.R1
Objective	Asses the impact of SafeOPS on the restorative resilience of ATM operations
KPA to be investigated	Resilience
Metric	Number of coordinative actions of the ATCOs after the initiation of a go-around with involved Actors, if departure and missed approach are airborne.
Success Criteria	Described sequence of action (sequence diagram) of the solution scenario reduces the coordinative actions with ATCOs after go-around, compared with reference scenario.

Table 35: Definition of the Resilience Metric 2

ID:	Obj.R2
Objective	Asses the impact of SafeOPS on the adaptive resilience of ATM Operations
KPA to be investigated	Resilience
Metric	Number of overall coordinative actions of the ATCO from the sequence of action, described by ATCO in moderated workshops
Success Criteria	Described sequence of action (sequence diagram) of the solution scenario reduces the coordinative actions with ATCOs, compared to the reference scenario

Table 36: Definition of Resilience Metric 3

ID:	Obj.R3
Objective	Asses the impact of SafeOPS on the adaptive resilience of ATM Operations
KPA to be investigated	Resilience
Metric	Number unbriefed missed approaches during simulation

Success Criteria	Described sequence of action (sequence diagram) of the solution scenario reduces the number of unbriefed missed approaches, compared to the reference scenario.

The last research question targets the impact of SafeOPS on the capacity in the defined scenarios.

Table 37: Research Question Specified towards Capacity

ID	Research Question
RQ2.3	Does the SafeOPS solution affect the capacity of the ATM operation

The following metrics are defined to measure the impact of SafeOPS on the capacity.

Table 38: Definition of the Capacity Metric 1

ID:	Obj.C1
Objective	Asses the impact of SafeOPS on the capacity of ATM Operations
KPA to be investigated	Resilience/Capacity
Metric	Did the departure aircraft use the planned gap for a departure
Success Criteria	If the departure in the solution scenario **can use** the same gap as in the reference scenario, meaning the departure is not delayed by one gap.

Table 39: Definition of the Capacity Metric 2

ID:	Obj.C2
Objective	Asses the impact of SafeOPS on the capacity of ATM Operations
KPA to be investigated	Resilience/Capacity
Metric	Number of successful landings in the scenario
Success Criteria	If the number of landings in the solution scenario is **not smaller** than in the reference scenario.

B.4 Experimental/Validation Approach

Based on the generalized scenario, presented in the solution description in section B.2.11 and from the availability of ATCOs from airport 2, we implemented a mixed mode runway scenario at airport 2. The simulations shall compare the current ATM system with the envisioned SafeOPS solution, therefore the scenario is split in reference and solution scenarios, as was done for the generalized mixed mode runway scenario in the solution description. In these scenarios, SafeOPS investigates two possible outcomes, a landing and go-around case. This yields four subcategories, illustrated in Figure 17. As was discussed in B.2.11, in the solution case, we focus on investigating the false positive and true positive prediction case of the go-around prediction, since a false negative prediction is similar to the reference go-around scenario and the true negative prediction is similar to the reference landing scenario.

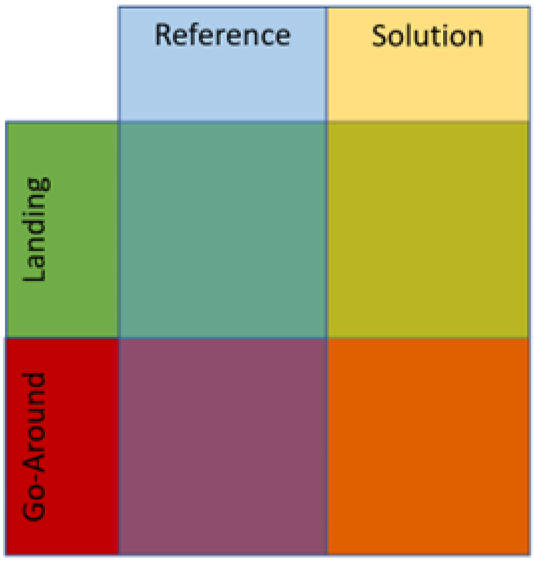

Figure 17: Illustration of different sub-scenarios for the validation exercise

Each simulation run starts similarly. The simulated approach is at 7NM from runway threshold with an approach speed of 135kts. The simulated departure is waiting at the holding point, awaiting the line-up clearance. We assume a second approach, which is not simulated to be in front of the simulated approach, with a specified gap. The gap is such that the departure can use it for take-off, once the not simulated approach touches down. Therefore, we assume the gap between the two approaching aircraft to be constant until the touchdown of the not simulated approach, implying the controller has requested similar approach speeds for both aircraft. The weather conditions are assumed to be of Instrument Meteorological Conditions (IMC), implying radar separation to be applied. Figure 12 illustrates the described initial condition.

The decision to not simulate the first approaching aircraft was made, since it simplifies the simulation model, which can be run on a desktop computer, while not omitting anything from the meaningfulness of the simulation results. All safety relevant events originate from the trajectories of the simulated aircraft. While it can be debated if this decision leads to a less immersive simulation, we make the argument that this simulation was designed as a simple and fast way to produce results at a very early stage of the development process.

In the simulation, several different aircraft configurations are investigated, to cover a wider spectrum of the operation. At this stage of the project however, we focus on aircraft which are commonly used in commercial aviation, since these contribute most to the overall traffic. To define and document the initial situation in a simulation and further specify which aircraft configuration is simulated, configuration cards are used. These are simplified versions of testcards, which are commonly used for simulator runs in pilot training.

Departure Configurations

For the departure aircraft, the configuration card template is used to store the relevant information, defined with Table 40. For the departing aircraft, we differentiate between medium and heavy wake turbulence type aircraft. Thereby, we cover different safety relevant aspects like wake turbulence and radar separation challenges. Based on the wake turbulence category, also the size of the gap is chosen, for which the departing aircraft is planned. This yields two overall configurations for the departing aircraft, abbreviated with Dep.Cfg.1 and Dep.Cfg.2. Furthermore, depending on the aircraft type, the decision speed (V1), rotation speed (VR) and the take-off speed (V2) are specified. Also, the runway, standard departure route (SID) and weather conditions (WX) are specified.

Table 40: Template: configuration card departure

ID:					
Airport 2	RWY (take-off)	SID	Gap between approaches		
WX					
Aircraft Type			V1	VR	V2

Approach Configurations

Similar to the departure configuration, we define a approach configuration, using a configuration card. For the arriving aircraft, we simulate a medium type aircraft, as these typically accelerate and climb fast when performing a go-around, closing the gap to the departing aircraft faster. For the arriving aircraft, we vary if a predictive tool is available (reference vs. solution), as well as the point where a prediction will appear. Also the configuration specified if the approach would land and where and if a go-around will be initiated is specified. Furthermore, the Instrument Approach Procedure (IAP) is defined together with the Approach Speed (VAPP) for the aircraft. This yields in total 8 Approach Configurations abbreviated with App.Cfg.1 - App.Cfg.8.

Table 41: Template: configuration card approach

ID:				
Airport 2	IAP	Landing, if not requested otherwise by the controller.	Distance from Threshold where Missed Approach Initiated, if not requested otherwise by the controller.	Missed Approach Predicted at

WX	
Aircraft Type	VAPP

Table 42 summarizes all planned sub-exercises and their composition from the reference and solution scenarios. Each sub-exercise compares on reference and solution scenario, where each reference and solution scenario is defined by a departure and approach configuration. Note that we compare three solution scenarios with one reference scenario. Thereby, we account for the different prediction points at 2NM, 4NM and 6NM for the predictive tool. Furthermore, we distinguish between a medium and heavy type departure for each scenario, to account for wake turbulence situations.

Table 42: Summary of all Sub-Exercises and their composition from reference and solution scenarios

Exercise ID:	**Reference Scenarios**			**Solution Scenario**		
	Scenario ID	Departure Configuration	Approach Configuration	Scenario ID	Departure Configuration	Approach Configuration
FP.1	RS.Landing.1	Dep.Cfg.1	App.Cfg.1	SS.FalsePositive.1	Dep.Cfg1	App.Cfg.6
FP.2				SS.FalsePositive.2		App.Cfg7
FP.3				SS.FalsePositive.3		App.Cfg.8
FP.4	RS.Landing.2	Dep.Cfg.2		SS.FalsePositive.4	Dep.Cfg2	App.Cfg.6
FP5				SS.FalsePositive.5		App.Cfg.7
FP.6				SS.FalsePositive.6		App.Cfg.8
TP.1	RS.GoAround.1	Dep.Cfg.1	App.Cfg2	SS.TruePositive.1	Dep.Cfg1	App.Cfg.3
TP.2				SS.TruePositive.2		App.Cfg4
TP.3				SS.TruePositive.3		App.Cfg.5

TP.4	RS.GoAround .2	Dep.Cfg.2		SS.TruePositive .4	Dep.Cfg2	App.Cfg.3
TP.5				SS.TruePositive .5		App.Cfg4
TP.6				SS.TruePositive .6		App.Cfg.5

B.5 Simulation Configuration for Subexercises

This section provides details for every performed simulation. Therefore, we list the simulation configuration that defines the initial conditions for the simulation.

B.5.1 Reference Scenarios Landing

This section covers the two reference landing scenarios, RS.Landing.1 and RS.Landing.2.

RS.Landing.1

Simulation Configurations

In this scenario, the departure aircraft is configured according to Table 43.

Table 43: Configuration Card Dep.Cfg.1

ID:	**Dep.Cfg1**				
Airport 2	**RWY (take-off)**	**SID**	**Gap between approaches**		
	26L	S-SID	5NM		
WX	IMC Conditions, no wind, ISA standard				
Aircraft Type			**V1**	**VR**	**V2**
Medium twin engine			142 kt	142 kt	150 kt

Furthermore, the approaching aircraft is configured according to the configuration cared in Table 44, indicating that no prediction tool is available and the aircraft is performing a landing.

Table 44: Configuration Card for App.Cfg.1

ID:	**App.Cfg.1**			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed approach initiated from RWY threshold, if not**	**Missed approach predicted at xxNM**

			requested from ATCO earlier.	from RWY Threshold
	ILS 26L	Yes	n.a.	n.a.
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

Therefore, RS.Landing.1 is a scenario in which a medium type arrival aircraft lands, after a medium departure took off.

RS.Landing.2

Simulation Configurations

In this scenario, the departure aircraft is configured according to Table 45

Table 45: Configuration Card for Dep.Cfg.2

ID:	**Dep.Cfg.2**				
Airport 2	**RWY (take-off)**	**SID**	**Gap between approaches**		
	26L	S-SID	5NM		
WX	IMC Conditions, no wind, ISA standard				
Aircraft Type			**V1**	**VR**	**V2**
Heavy four engine			146 kt	146 kt	154 kt

The approach configuration is specified in Table 44 (same as RS.Landing.1), indicating that no prediction tool is available, and the aircraft is performing a landing. Therefore, RS.Landing.2 is a scenario in which a medium type arrival aircraft lands, after a heavy type departure took off.

B.5.2 Reference Scenarios Go-around

This section covers the two reference go-around scenarios, RS.GoAround.1 and RS.GoAround.2.

RS.GoAround.1

Simulation Configuration

The configuration for the RS.Goaround.1 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.1, and specified in Table 43 The approach configuration is specified in the following. It indicates no prediction tool is available and the approach performs a go-around at 0.9NM from runway threshold.

Table 46: Configuration Card for App.Cfg.2

ID:	**App.Cfg.2**			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed approach initiated from RWY threshold, if not requested from ATCO earlier.**	**Missed approach predicted at xxNM from RWY Threshold**
	ILS 26L	No	0.9NM	n.a.
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type	**VAPP**			
Medium twin engine	135 kt			

RS.GoAround.2

Simulation Configuration

The configuration for the RS.Goaround.2 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.2, defined in Table 45. The configuration for the approach is similar to RS.GoAround.1, specified in Table 46. Therefore, RS.Goaround.2 is a scenario in which a medium type, approaching aircraft performs a go-around after a heavy type departure took off.

B.5.3 Solution Scenario False Positive Predictions

This section describes the false positive solution scenarios SS.FalsePositive.1 – SS.FalsePositive.6.

SS.FalsePositive.1

Simulation Configuration

The configuration for the SS.FalsePositive.1 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.1, specified in Table 43. The approach configuration is specified in Table 47, indicating a prediction to take place after the take-off clearance has been given to the preceding departure aircraft. In contrast to App.Cfg.3 from SS.TurePositive.1 (which is the equivalent true positive prediction scenario), the aircraft does not initiate a go-around and will land, if not commanded otherwise by the controller.

Table 47: Configuration Cart for App.Cfg.6

ID:	**App.Cfg.6**			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed Approach Initiated from RWY Threshold, if not**	**Missed approach predicted at xxNM from RWY Threshold**

			requested from ATCO earlier.	
	ILS 26L	yes	N.a.	2
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

SS.FalsePositive.2

Simulation Configuration

The configuration for the SS.FalsePositive.2 simulation are defined the following. The departure configuration is similar to the configuration in RS.Landing.1, specified in Table 43. The approach configuration is specified in Table 48, indicating a prediction to take place after the line-up clearance and before the take-off clearance has been given to the preceding departure aircraft. In contrast do App.Cfg.4, from SS.TurePositive.2 (which is the equivalent true positive prediction scenario), the aircraft does not initiate a go-around and will land, if not commanded otherwise by the controller.

Table 48: Configuration Card for App.Cfg.7

ID:	**App.Cfg.7**			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed Approach Initiated from RWY Threshold, if not requested from ATCO earlier.**	**Missed Approach Predicted**
	ILS 26L	yes	N.a.	4
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

Therefore, SS.FalsePositive.2 is a scenario in which a medium type arrival aircraft is falsely predicted to go-around at 4NM from runway threshold with a preceding a medium type departure cleared for take-off.

SS.FalsePositive.3

Simulation Configuration

The configuration for the SS.FalsePositive.3 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.1, specified in Table 43. The approach configuration is specified in Table 49, indicating a prediction to take place after the take-off clearance has been given to the preceding departure aircraft. In contrast to App.Cfg.5 from SS.TurePositive.3 (which is the equivalent true positive prediction scenario), the aircraft does not initiate a go-around and will land, if not commanded otherwise by the controller.

Table 49: Configuration Cart for App.Cfg.8

ID:	**App.Cfg.8**			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed Approach Initiated from RWY Threshold, if not requested from ATCO earlier.**	**Missed approach predicted at xxNM from RWY Threshold**
	ILS 26L	yes	N.a.	6
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

SS.FalsePositive.4

Simulation Configuration

The configuration for the SS.FalsePositive.4 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.2, specified in Table 45. The approach configuration is specified in Table 47, indicating a prediction to take place after the take-off clearance has been given to the preceding departure aircraft, similar to SS.FalsePositive.1

SS.FalsePositive.5

Simulation Configuration

The configuration for the SS.FalsePositive.5 simulation are defined the following. The departure configuration is similar to the configuration in RS.Landing.2, specified in Table 45. The approach configuration is specified in Table 48 Table 48, indicating a prediction to take place after the line-up clearance and before the take-off clearance has been given to the preceding departure aircraft.

Therefore, SS.FalsePositive.5 is a scenario in which a medium type arrival aircraft is falsely predicted to go-around at 4NM from runway threshold with a preceding a heavy type departure cleared for take-off.

SS.FalsePositive.6

Simulation Configuration

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The configuration for the SS.FalsePositive.6 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.3, specified in Table 45Table 43. The approach configuration is specified in Table 49, indicating a prediction to take place before the line-up clearance has been given to the preceding departure aircraft, similar to SS.FalsePositive.3.

B.5.4 Solution Scenario True Positive Predictions

This section defines the true positive solution scenarios SS.TruePositive.1 – SS.TruePositive.6.

SS.TruePositive.1

Simulation Configuration

The configuration for the SS.TruePositive.1 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.1, specified in Table 43. The approach configuration is specified in Table 50, indicating a prediction to take place after the take-off clearance has been given to the preceding departure aircraft. Therefore, SS.TruePositive.1 is a scenario in which a medium type go-around is predicted when the approach is at 2NM from runway threshold, with a preceding a medium type departure cleared for take-off.

Table 50: Configuration Cart for App.Cfg.3

ID:	**App.Cfg.3**			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed Approach Initiated from RWY Threshold, if not requested from ATCO earlier.**	**Missed approach predicted at xxNM from RWY Threshold**
	ILS 26L	no	0.9NM	2
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

SS.TruePositive.2

Simulation Configuration

The configuration for the SS.TruePositive.2 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.1, specified in Table 43. The approach configuration is specified in Table 51 , indicating a prediction to take place after the line-up and before the take-off clearance has been given to the preceding departure aircraft. Therefore, SS.TruePositive.2 is a scenario in which a medium type go-around is predicted when the approach is at 4NM from runway threshold, with a preceding a medium type departure cleared for line-up.

Table 51: Configuration Cart for App.Cfg.4

ID:	App.Cfg.4			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed Approach Initiated from RWY Threshold, if not requested from ATCO earlier.**	**Missed approach predicted at xxNM from RWY Threshold**
	ILS 26L	no	0.9NM	4
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

SS.TruePositive.3

Simulation Configuration

The configuration for the SS.TruePositive.3 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.1, specified in Table 43. The approach configuration is specified in Table 52, indicating a prediction to take place before the line-up and before the take-off clearance has been given to the preceding departure aircraft. Therefore, SS.TruePositive.3 is a scenario in which a medium type go-around is predicted when the approach is at 6NM from runway threshold, with a preceding a medium type departure waiting for line-up clearance.

Table 52: Configuration Cart for App.Cfg.5

ID:	App.Cfg.5			
Airport 2	**IAP**	**Landing, if not commanded otherwise by controller.**	**Missed Approach Initiated from RWY Threshold, if not requested from ATCO earlier.**	**Missed approach predicted at xxNM from RWY Threshold**
	ILS 26L	no	0.9NM	6
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		
Medium twin engine		135 kt		

SS.TruePositive.4

Simulation Configuration

The configuration for the SS.TruePositive.4 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.2, specified in Table 45. The approach configuration is specified in Table 50, indicating a prediction to take place after the take-off clearance has been given to the preceding departure aircraft. Therefore, SS.TruePositive.4 is a scenario in which a medium type go-around is predicted when the approach is at 2NM from runway threshold, with a preceding a heavy type departure cleared for take-off.

SS.TruePositive.5

Simulation Configuration

The configuration for the SS.TruePositive.5 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.2, specified in Table 45Table 43. The approach configuration is specified in Table 51, indicating a prediction to take place after the line-up and before the take-off clearance has been given to the preceding departure aircraft. Therefore, SS.TruePositive.5 is a scenario in which a medium type go-around is predicted when the approach is at 4NM from runway threshold, with a preceding a heavy type departure cleared for line-up.

SS.TruePositive.6

Simulation Configuration

The configuration for the SS.TruePositive.6 simulation are the following. The departure configuration is similar to the configuration in RS.Landing.2, specified in Table 45. The approach configuration is specified in Table 52, indicating a prediction to take place before the line-up and before the take-off clearance has been given to the preceding departure aircraft. Therefore, SS.TruePositive.6 is a scenario in which a medium type go-around is predicted when the approach is at 6NM from runway threshold, with a preceding a heavy type departure waiting for line-up clearance.

B.6 Exercise Planning

The current planning of the workshops with the ATCOs is as follows:

From airport 1, six ATCOs will participate in the workshops planned for 2022. From airport 2, ATCOs are confirmed to participate in the workshops, however the concrete number or even specific ATCOs are to this date not fixed, due to personnel planning at airport 2.

Figure 18 illustrates the overall planning of Task 2.2 of SafeOPS, which includes the experimental actions. In February 2022, a draft version of the experimental plan is handed over to the SJU to debate the exercise approach of SafeOPS. In March to May, the simulations will be fully defined and prepared and documented in the experimental plan. In May to July, the workshops in which the experiments will be performed will be held and the experiments will be evaluated. Finally, from August to September, a final evaluation will be performed, D2.2 will be written and reviewed also by ATCOs, which will be concluded in a designated workshop.

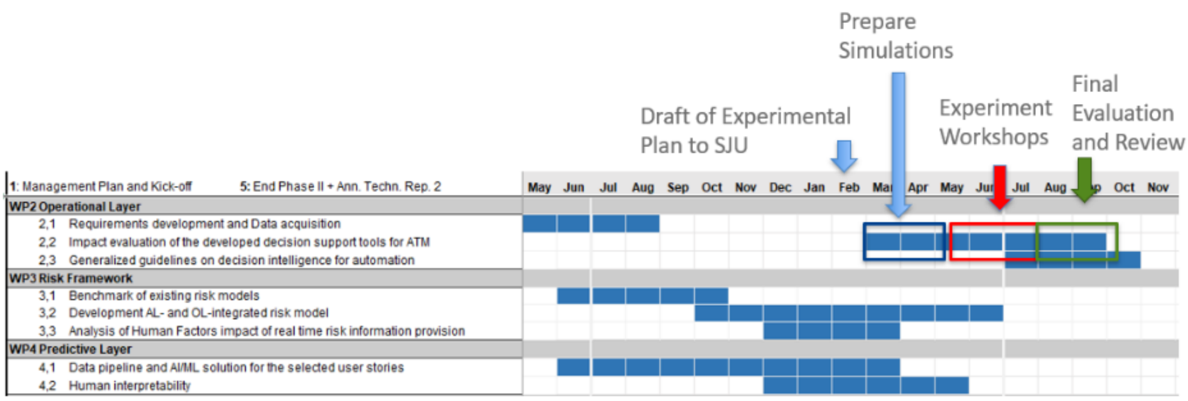

Figure 18: General Planning of Task 2.2

The general planning is further specified by Figure 19 and Figure 20. In beginning of 2022, workshops are scheduled to familiarize ATCOs with the visualization tool, introduced in section C.3, and include their feedback into the visualization used in the experiment. For these experiments, 2 blocks of workshops are scheduled in May as well as June/July.

Workshop Nr.	Date	Time	(Validation) Exercise	Airport	Video call / In person	ATCOS:
1	11 Jan 2022	13:00 - 17:00	Introduction to Visualization Tool for upcoming evaluation exercises + Feedback and additional features.	AP1: ✓	Video call	1ATCO.1 1ATCO.2
✗	12 Jan 2022	13:00 - 17:00		AP2: ✗	Video call	
2	19 Jan 2022	13:00 - 17:00	Introduction to Visualization Tool for upcoming evaluation exercises + Feedback and additional features Scen1: Prediction: 5NM Confidence: 90% Additional Traffic:	AP1: ✓ AP2: ✗	Video call	1ATCO.1 1ATCO.3
3	15 Feb 2022	13:00 - 17:00	Introduction to Visualization Tool for upcoming evaluation exercises + Feedback and additional features WP3 / T3.3	AP1: ✓ AP2: ✗	Video call	1ATCO.4 1ATCO.5

Figure 19: Workshop Planning Beginning 2022

Workshop Nr.	Date	Time	(Validation) Exercise	Airport	Video call / In person	ATCOS:
		17:00	Severity False Negative / False Positive Predictions	AP2: ✓		1ATCO.5 2ATCO.tbd 2ATCO.tbd
11	29 Apr 2022	13:00 - 17:00	WP2/3: Severity False Negative / False Positive Predictions	AP1: ✓ AP2: ✓	Video call	1ATCO.5 1ATCO.3 2ATCO.tbd
12	10 May 2022	13:00 - 17:00	WP2: D2.2 Safety and Resilience Exercise	AP1: ✓ AP2: ✓	Airport 1 - In person ?	1ATCO.1 1ATCO.4 2ATCO.tbd 2ATCO.tbd
13	24 May 2022	13:00 - 17:00	WP2: D2.2 Safety and Resilience Exercise	AP1: ✓ AP2: ✓	Video call	1ATCO.1 1ATCO.3 2ATCO.tbd 2ATCO.tbd
14	31 May 2022	13:00 - 17:00	WP3: Debriefing and D3.2 review	AP1: ✓ AP2: ✓	Video call	1ATCO.5 2ATCO.tbd 2ATCO.tbd
15	21 Jun 2022	13:00 - 17:00	WP2: D2.2 Safety and Resilience Exercise	AP1: ✓ AP2: ✓	Video call	1ATCO.4 1ATCO.5 2ATCO.tbd 2ATCO.tbd
16	26 Jul 2022	13:00 - 17:00	WP2: D2.2 Safety and Resilience Exercise	AP1: ✓ AP2: ✓	Airport 2 - In person ?	1ATCO.4 1ATCO.5 2ATCO.tbd
17	12 Sep 2022	13:00 - 17:00	Debriefing / D2.2 review	AP1: ✗ AP2: ✓	Video call	2ATCO.tbd 2ATCO.tbd

Figure 20: Workshop Planning Mid 2022

B.7 Data and Software Input

The data necessary to develop the SafeOPS concept is stored in DataBeacon, an IT infrastructure build for machine learning projects in the aviation environment and operated by Innaxis. The IT – Infrastructure and Data Handling is described in D4.1.

For the experiments, a visualization software, described in section C.3 is developed, allowing the demonstration of the SafeOPS concept in the radar screen environment. Additionally, a model to simulate the aircraft trajectories used in the simulation is needed, which has been detailed in section C.1 and C.2. Based on the results of D4.1, D4.2 and D3.3 the visualization as well as the initial conditions of the scenarios simulated for the exercises, are defined in B.5.

The results are twofold. The simulated and visualized trajectories (time series and video data) will be recorded on the computer used to simulate and visualize the trajectories shown in the experiments. To ensure storage, the TUM servers as well as DataBeacon will be used to ensure redundancy in the storage of digital results. The strategies of the ATCOs to handle the scenarios will be documented as sequence diagrams, which will be generated and stored in InGrid, the SafeOPS internals information storage, maintained by Innaxis and will also be documented within this document and D2.2. The minutes of the workshops will be generated and stored in InGrid, and will if desired, be appended to this document.

B.8 Research Coordination and Development

The data management for SafeOPS is done, using Data-Beacon, a IT infrastructure for Big-Data Analyses tailored to the aviation needs. The data handling will be documented in D4.1, as was agreed in the Intermediate Review Meeting on 25th of Jan. 2022.

The SafeOPS experiments combine computer simulations with workshops of ATCOs to discuss the simulations and especially the strategies to handle the simulated scenarios. Regarding the computer-based simulations, the models used will be documented in D2.2 and the scenario simulations' initial conditions are documented within this document. Therefore, these parts of the experiment are reproduceable. The ATCOs planned for the experiments are working at the two airports, at which the scenarios are defined. Therefore, a dependency between the achieved results and the ATCOs in the workshops is to be expected.

Appendix C Simulation Environment

C.1 Arrival Model

The arrival model used for the simulation part of the project is essentially a nonlinear generic transport aircraft flight model that includes both longitudinal and lateral dynamics. The modeled aircraft can be classified as a narrow-body twin-engine. In addition to the flight mechanics model, several autopilot modes which resemble the industry standards have been implemented. The simulation of an arrival requires automating the pilots' behavior; therefore, several predefined pilot actions are realized throughout the runtime.

C.1.1 Kinematics

The main objectives of the model are to simulate the scenarios as seen by the ATC operators and also allow a pilot to fly the aircraft manually under different circumstances. Thus, a model which could support 6 Degrees of Freedom (DOF) was required to allow the pilots to fly the aircraft and evaluate the scenarios when required. The reference was selected to be the center of the world, and the Earth Centered Earth Fixed (ECEF) reference frame is used.

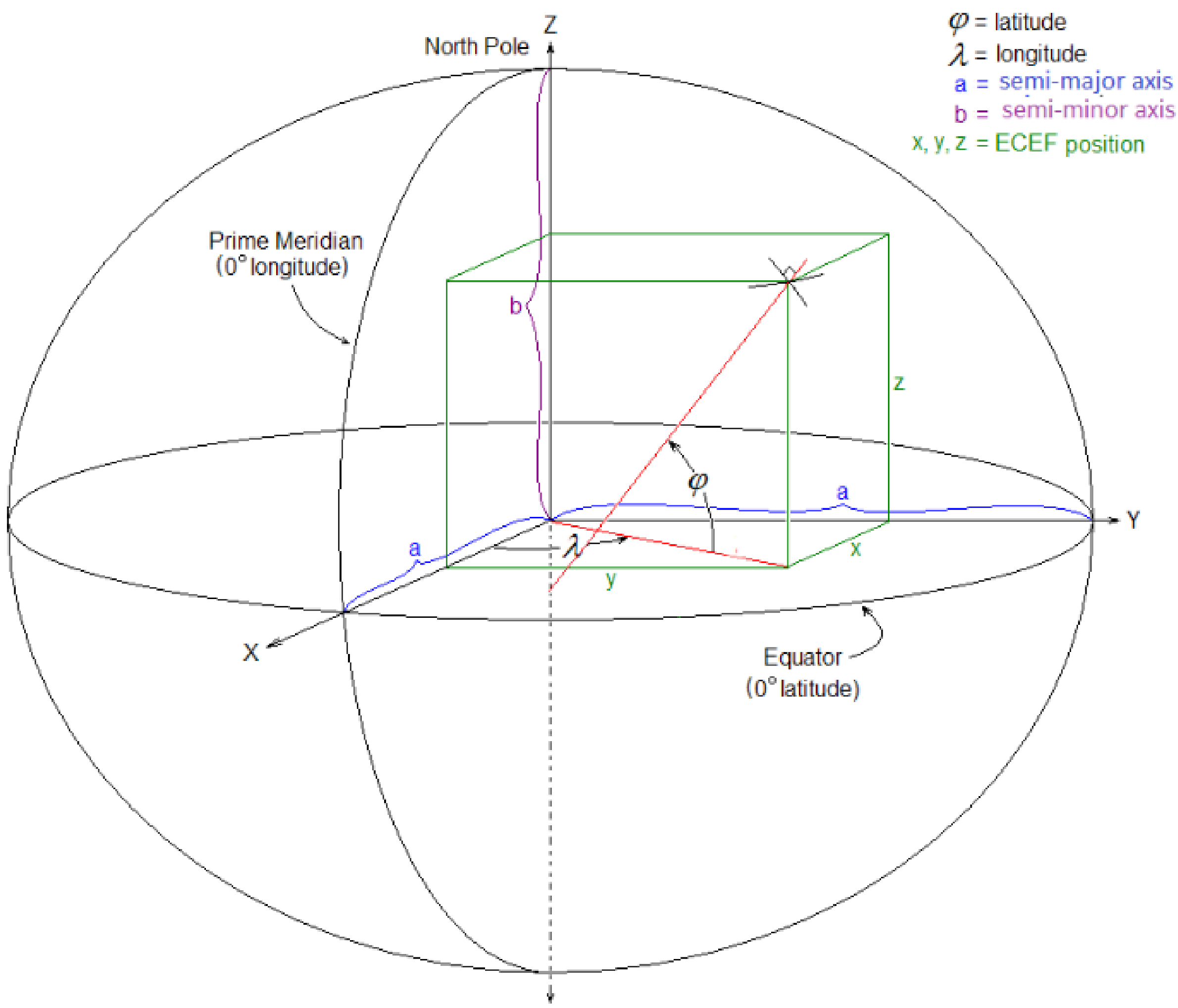

Figure 21: Definition of Coordinate Frames and Coordinates [25]

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The states used in the model can be divided into four different categories, which are listed below.

Position Propagation

For the position Propagation, the Earth is assumed to be ellipsoidal, and integration is done in ECEF coordinate system. However, the geodetic coordinates are also calculated and provided as an output. Geodetic coordinates consist of both longitude and latitude used in navigation and the altitude values. Integrating ECEF coordinate system states rather than the geodetic states prevents singularities that arise with geodetic coordinates.

Translation Dynamics

The translational dynamics are represented by the kinematic velocity components of the body-fixed coordinate system. The kinematic velocity is the velocity of the center of gravity of the rigid aircraft. The body-fixed reference frame can be seen below.

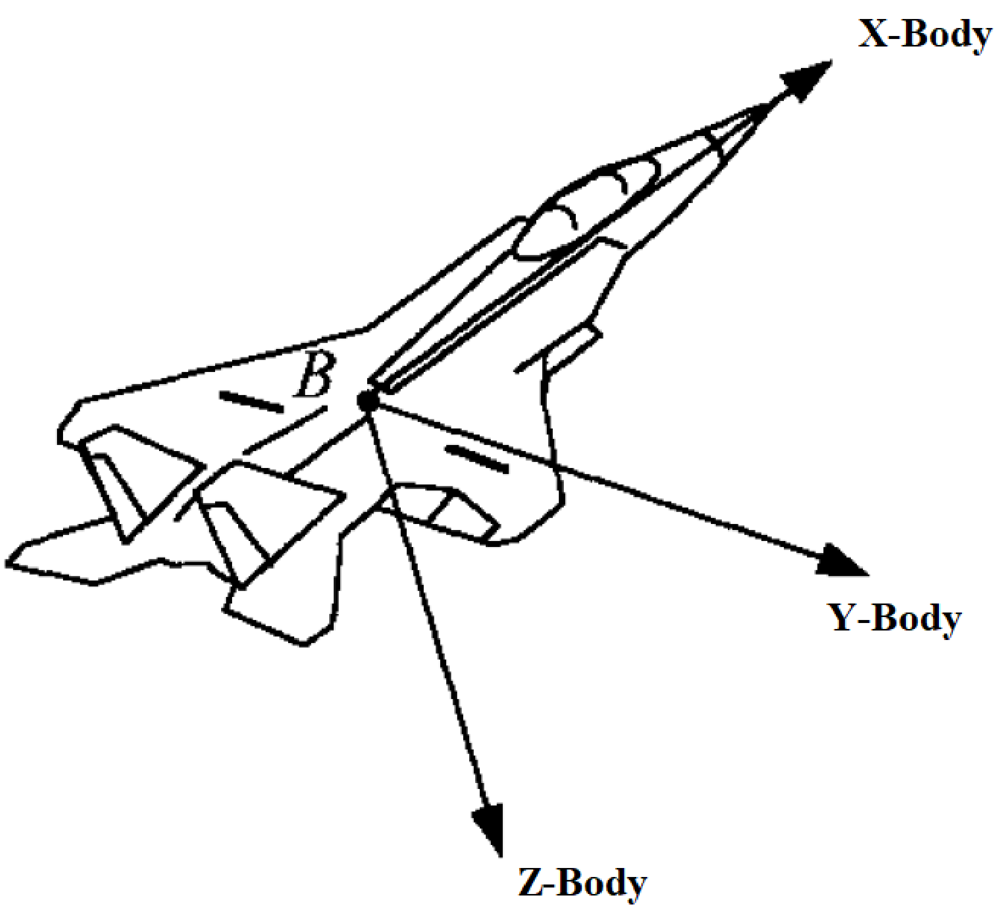

Figure 22: Body Fixed Coordinates [26]

Attitude Propagation

There are several approaches for attitude propagation, but since the model utilizes 6-DOF dynamics, the best option are quaternion states which do not have the drawbacks of the Euler angles, especially the singularities at ±90° pitch angles. Euler angles hold the attitude information of the aircraft, which are heading angle, pitch angle, and roll angle. Contrary to the Euler angles, quaternions represent the attitude of an object with four parameters.

Rotation Dynamics

Just as the translation dynamics, the components of the body coordinate system are used as the rotations states. Since the Earth is assumed to be rotating and elliptical, the states also included the transport rate and the Earth's rotation rate. The transport rate has to be included to take the curvature of the ground into account.

Table 53: Summary of States

Position States		Translational States		Attitude States		Rotational States	
λ	Geodetic Longitude (rad)	$(u_{GK})_B$	Kinematic Velocity in Body Coord. System - x (m/s)	Φ	Euler Roll Angle (rad)	$(p_{GK})_B$	Kinematic Roll Rate (rad/s)
ϕ	Geodetic Latitude (rad)	$(v_{GK})_B$	Kinematic Velocity in Body Coord. System - y (m/s)	Θ	Euler Pitch Angle (rad)	$(q_{GK})_B$	Kinematic Pitch Rate (rad/s)
h	Altitude (m)	$(w_{GK})_B$	Kinematic Velocity in Body Coord. System - z (m/s)	Ψ	Euler Yaw Angle (rad)	$(r_{GK})_B$	Kinematic Yaw Rate (rad/s)

C.1.2 Kinetics

Aerodynamics

Multiple data sources are used to create the aerodynamics library used in the aircraft model. The library's purpose is to generate aerodynamic coefficients using only geometrical data of the aircraft. Therefore, the multi-point model approach was utilized where the lifting surfaces are divided into multiple panels, and aerodynamic effects are calculated at each panel separately. With this, aerodynamic effects can be modeled without extensive model-specific data. To illustrate how the multi-point model approach works, the following graph shows the separation of the right wing into multiple panels.

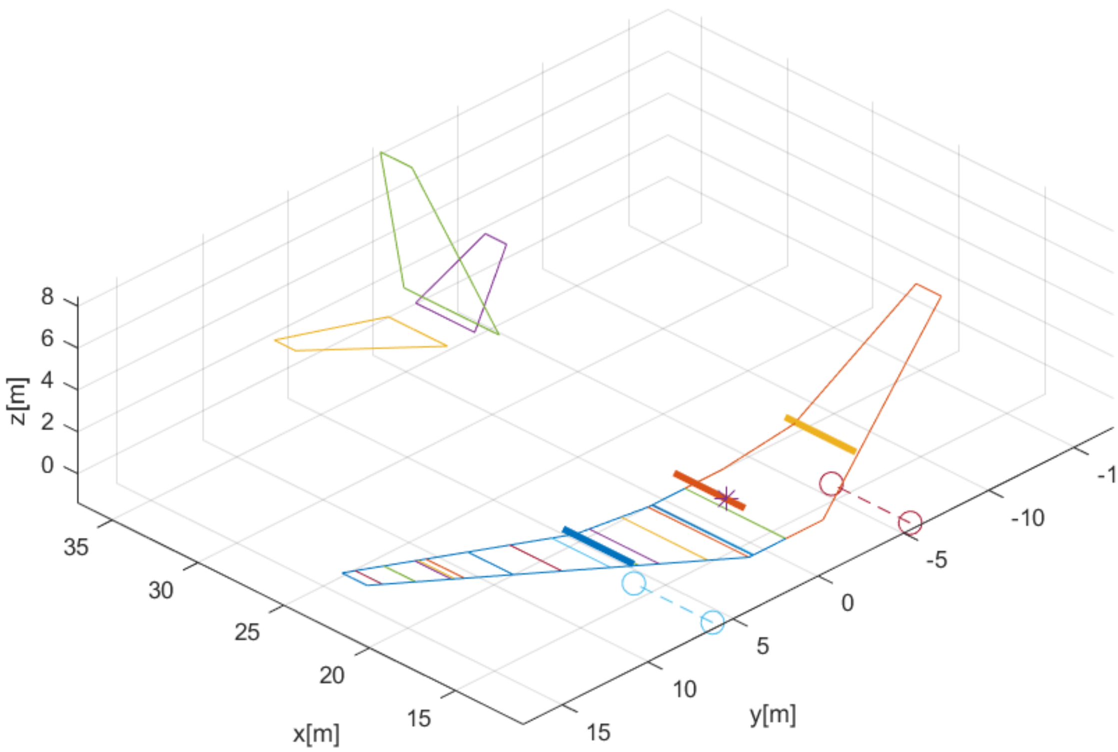

Figure 23: The aerodynamic surface sections of multi-point model representation. Only the right main wing is shown. Orthogonal view

The two-dimensional aerodynamic coefficients were computed using an open-source tool called XFLR5 [27] [28], which uses a high-order panel method and a fully coupled viscous/inviscid interaction method. The mentioned design tool was developed in 1986 and produces reliable data at the linear range of the airfoil, which is sufficiently accurate inside the safe flight envelope of a transport aircraft [29]. The airfoil geometry was taken from a weight-wise similar aircraft [30] [31] [32] [33], considering that most transport aircraft use the comparable transonic airfoil design at the main wings. For the empennage, symmetric airfoils were used with thickness data taken from the reference aircraft.

The three-dimensional effects are critical, especially on high aspect ratio wing designs; therefore, they must be included. At this step, empirical formulas from various flight dynamics and aircraft design books were used to both correct the two-dimensional data and include the additional effects. [34] [35] [36] [37] [38]. All effects from control surfaces, flaps, slats, and basic interactions between the wings and the tail were calculated using the methods provided in these books. These modeling corrections have been the main source for many research projects since the 1980s, and they have been validated by numerous methods for several aircraft throughout the last 40 years. Combining all these effects, the final nonlinear aerodynamics model was created.

Propulsion

Developing an accurate propulsion model for jet engines requires extensive data from the manufacturer, and it is difficult to validate the results. Moreover, there are several extensive aircraft performance databases readily available to be used in research projects. Therefore, the Aircraft Noise and Performance (ANP) Database was selected to be the source for the propulsion model. The Aircraft Noise and Performance (ANP) [39] database is maintained by the US Department of Transportation, EUROCONTROL, and EASA. Normally, this database includes various parameters for the whole aircraft, but only thrust coefficients were used in the current model. The instantaneous thrust of the engines depends on the following parameters during flight:

- Indicated Airspeed (IAS)
- Altitude
- Ambient Temperature
- Ambient Pressure
- Engine Turbine Speed Percent - N1

Weight and Balance

The weight was also selected according to the reference aircraft, and currently, the aircraft is flown with maximum payload weight, alternate fuel, and final reserve fuel. But it can be easily edited according to the scenario's requirements. The center of gravity was selected as an average value inside the safe envelope of the reference aircraft. As mentioned before, the database used for the propulsion also includes fuel consumption values as well. However, the analyzed scenarios only contain a fairly short time interval; therefore, the fuel mass and center of gravity change are assumed to be negligible. The weight and balance range of the aircraft and the used values in the simulation can be seen below.

Table 54: The weight limits of the aircraft

Operating Empty Weight	41144 kg
Max Payload Weight	19256 kg
Maximum Fuel Weight	21005 kg
Minimum Fuel Weight	2500 kg
Maximum Takeoff Weight	73500 kg

Table 55 The weight and balance values used in the arrival model

Operating Empty Weight	41144 kg
Payload Weight	18005 kg
Fuel Weight	3000 kg
Total Weight	62149 kg

Center of Gravity Location	%25 MAC

C.1.3 Navigation

The aircraft is initialized in the final approach 6 NM away from the runway threshold. Since we skip the earlier phases of the approach procedure, only the Instrument Landing System (ILS) is used as a navigation method. An in-house model is used to approximate the localizer and glide slope deviations using the coordinates of the antennas and the current position of the aircraft. The exact location of the antennas was retrieved from Google Maps.

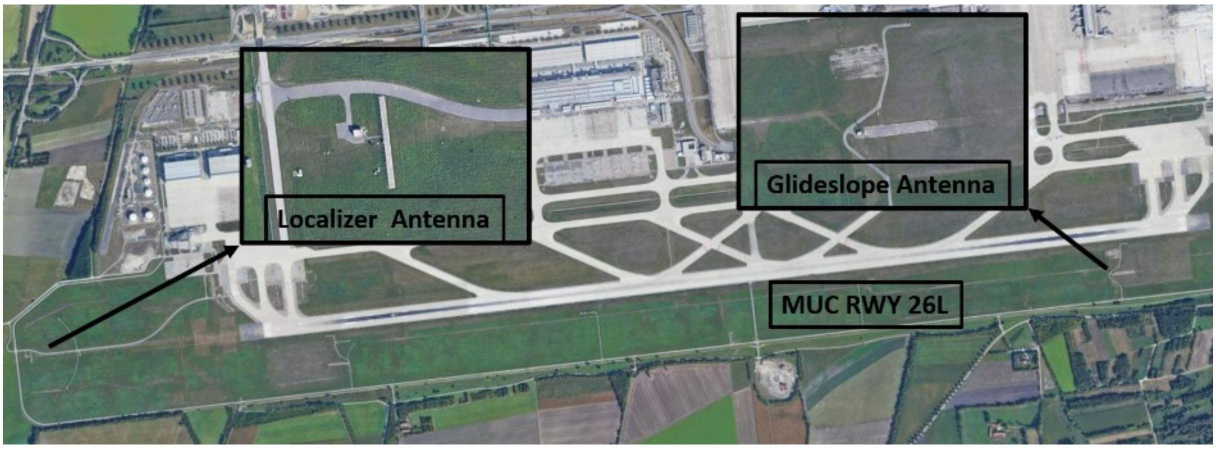

Figure 24: The locations of the ILS antennas of Runway 26L in Airport 2 on Google Maps. [40]

C.1.4 Aircraft Controller

A generic controller suitable for a fly-by-wire civilian aircraft was inserted into the model, which replicates the Normal Law used in Airbus aircraft. The pilot commands a delta load factor to the aircraft for longitudinal motion. This can be simplified as if the pilot gives a flight-path-angle command to the aircraft while flying. For the lateral motion of the aircraft, roll rate command is given, and the bank angle has a limit of 25 degrees as flight protection. Currently, the pedals are not connected to the rudder; nevertheless, the rudder is used for damping the lateral motion and the turn compensation. Furthermore, the speed control is done by an auto thrust controller. On top of these controllers, several additional upper modes were also included in the model, especially one for following ILS signals. The control modes used in the aircraft can be seen below.

Table 56: he controller modes that were included in the arrival model.

Channel	Control Mode
Lateral	Course Hold, Localizer
Longitudinal	Pitch Hold, Flight Path Angle Hold, Altitude Hold, Glideslope
Thrust	Thrust Commanded, Speed Hold

Thrust Channel

During the presented scenarios, both modes are used, and the pilot switches between them. The first mode is actually the throttle lever itself, and the pilot can set it to Maximum Takeoff thrust during the go-around. The second mode uses the Indicated Airspeed (IAS) of the aircraft and adjusts the thrust to maintain the required speed.

Longitudinal Channel

As mentioned before, only the final approach phase is simulated; therefore, a controller maintains the glideslope by taking the glideslope angle signal as input. This data is then used as input to the flight path angle hold mode of the controller structure. As soon as the go-around switch is turned on, the glide slope controller is disengaged, and the altitude hold/acquire controller takes the lead. This mode uses the current altitude as input and feeds it to the inner longitudinal controller. Since the pitch angle of the aircraft is limited to a certain upper limit, the aircraft climbs with the maximum flight path angle possible without exceeding this pitch limit. As the aircraft reaches the commanded altitude, it holds that altitude until further command.

Lateral Channel

In the lateral channel, similar to the longitudinal channel, the simulation starts with the localizer mode engaged. The controller takes the ILS signal as input and maintains the course according to that. The course hold mode takes the heading of the aircraft and turns into the commanded heading direction. During the simulation, depending on the scenario, the pilot may or may not engage the course hold controller to change the heading. If a go-around is initiated, disengaging the localizer mode simply commands the aircraft to hold the same heading as the runway. But if ATC gives directions to the pilot, the course hold mode can be utilized to turn the aircraft to the advised heading.

C.1.5 Possible Arrival Scenarios

Three main scenarios might occur during the final approach phase. These can be listed as:

- A - Standard Landing
- B - Standard Missed Approach
- C - Non-Standard Missed Approach

The table below shows the steps of these maneuvers. To better illustrate the possibilities, Airport 2 Runway 26L standard missed approach steps are shown below.

Table 57: Possible Arrival Scenarios and inputs to the simulation model

<table>
<tr><td colspan="9">1. Standard Final Approach.</td></tr>
<tr><td colspan="3">Thrust: Hold 135 knots</td><td colspan="3">Longitudinal: Glideslope</td><td colspan="3">Lateral: Localizer</td></tr>
<tr><td colspan="9">The aircraft is initialized as descending according to the glideslope signal, 6 NM away from the runway threshold, and the course of the aircraft is aligned with the localizer.</td></tr>
<tr><td colspan="3">2A. Standard landing procedure.</td><td colspan="3">2B. Standard missed approach procedure - Climb straight.</td><td colspan="3">2C. Non-standard missed approach procedure - Climb straight.</td></tr>
<tr><td>Thrust: Hold</td><td>Longitudinal: Glideslope</td><td>Lateral: Localizer</td><td>Thrust: Maximum N1</td><td>Longitudinal: Max Pitch Hold</td><td>Lateral: Runway</td><td>Thrust: Maximum N1</td><td>Longitudinal: Pitch Hold</td><td>Lateral: Runway</td></tr>
</table>

135 knots					Heading Hold			Heading Hold
A go-around is not necessary.			The pilot keeps the same heading, applies maximum takeoff thrust, and climbs with a pitch angle of 15 degrees.			The pilot keeps the same heading, applies maximum takeoff thrust, and climbs with a pitch angle of 15 degrees.		
3A. Touch-down.			**3B. Configuration change.**			**3C. Configuration change.**		
Thrust: None	Longitudinal: None	Lateral: None	Thrust: Maximum N1	Longitudinal: Max Pitch Hold	Lateral: Runway Heading Hold	Thrust: Maximum N1	Longitudinal: Max Pitch Hold	Lateral: Runway Heading Hold
The landing gears and the flare controller are not modeled in the arrival model. Thus, the simulation runs until the aircraft touches the ground, and then it stops.			The flap configuration is changed to FLAPS 2 as the aircraft stops descending.			The flap configuration is changed to FLAPS 2 as the aircraft stops descending.		
			4B. Climb straight ahead to 1.0 NM West of DME DMS or 1900 ft, whichever is later.			**4C. Heading change - Non-standard missed approach.**		
			Thrust: Maximum N1	Longitudinal: Max Pitch Hold	Lateral: Runway Heading Hold	Thrust: Maximum N1	Longitudinal: Max Pitch Hold	Lateral: Course Hold
			If the separation is ensured between the arriving and departing aircraft, the standard missed approach procedure can be followed.			The course of the aircraft is immediately changed according to the directives from the ATC.		
			5B. Heading Change - Left turn direct to OTT DVOR/DME			**5C. Hold altitude at 5000 ft.**		
			Thrust: Hold 200 knots	Longitudinal: Altitude Hold	Lateral: Course Hold	Thrust: Hold 200 knots	Longitudinal: Altitude Hold	Lateral: Course Hold
			After the previous condition is fulfilled, the aircraft turns left to the heading of OTT DVOR/DME.			Climb and hold the altitude according to the directives from the ATC. Ex. 5000 ft.		
			6B. Hold altitude at 5000 ft.					
			Thrust: Hold 200 knots	Longitudinal: Altitude Hold	Lateral: Course Hold			
			Climb and hold the altitude stated in the standard missed approach chart: 5000 ft.					

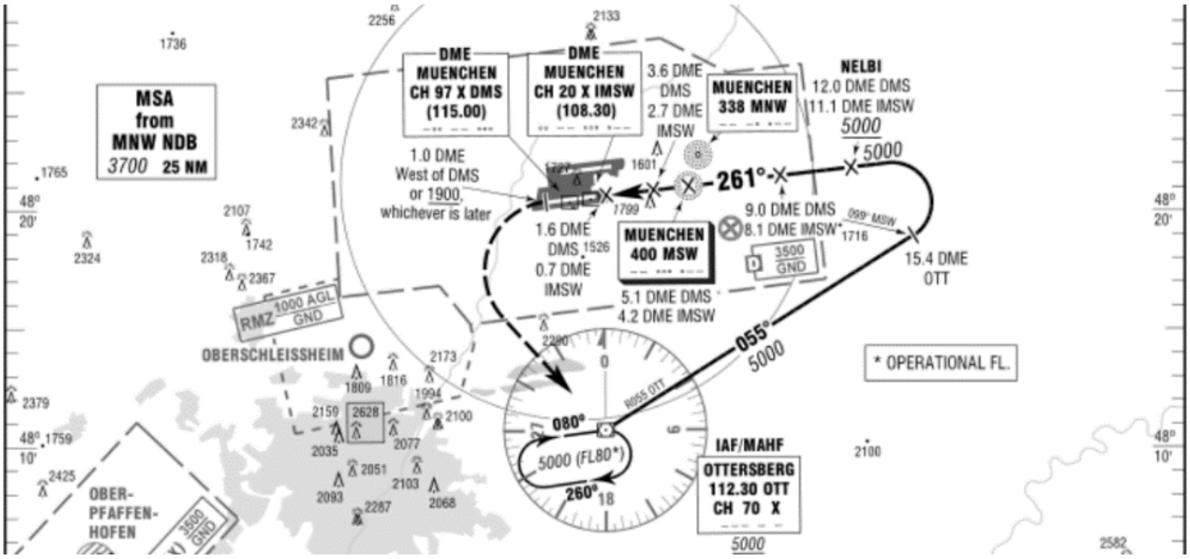

Figure 25 Airport 2 Runway 26L, instrument approach chart with the dashed line showing the standard missed approach route. [41]

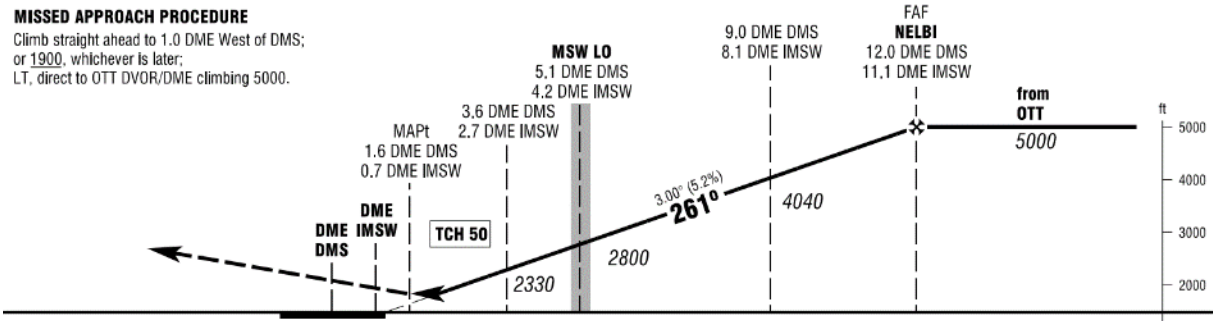

Figure 26: Airport 2 Runway 26L, the missed approach procedure on the top left. [41]

C.2 Departure Model

The departure model is one part of the simulation environment imitating the radar screen of a tower controller. Its purpose is to automate the departure of an aircraft with little to no necessary interaction of a human operator. With the current implementation, three different aircraft characteristics (twin engine narrow body, twin engine wide body and four engine wide body) can be chosen together with a pre-programmed standard instrument departure (SID).

Table 58: Main Performance Characteristics of Departure Model Variants

	twin engine		four engines
	narrow body	wide body	wide body
Take off mass	67.7 t	168.6 t	327.4 t
reference wing area	122.6 m²	361.6 m²	437.0 m²
max take-off thrust	152 kN	366 kN	535 kN

C.2.1 Kinematics

The inertial reference system is a flat-earth north-east-down (NED) system with the departure runway threshold as reference point. The reference point and reference system provide a clear interface with the simulation of the radar screen.

The model has a minimal number of degrees of freedom, especially to simplify the lateral kinematics of an aircraft. The roll angle and roll rate are completely omitted and turns are simulated by directly dictating a yaw rate, whereas the longitudinal dynamics are covered completely.

C.2.2 Kinetics

As mentioned above, the departure model can be initialized for three different aircraft characteristics. This has an influence on the aerodynamics, the thrust, the mass, the landing gear and the pitch angles chosen for the initial climb and the following climb.

The core of the aerodynamics is a symmetric polar between lift and drag for two different configurations. The configurations are the first flap setting and the clean configuration. Additionally the drag effect of the landing gear is computed by a constant value added to the drag coefficient. The rotation around the pitch axis is stabilized with a negative moment coefficient and controlled by the elevator.

With the simplification of omitting the bank angle the only lateral aerodynamic effect simulated is a lateral horizontal force, perpendicular to the flight path due to a side slip angle to be able to incorporate the effect of the wind. A side slip angle leads to a force changing the direction of flight to minimize the side slip.

The thrust is computed using a maximum net thrust depending on the airspeed multiplied by the N1 value (fan speed). This simplistic model provides the possibility to basically have to thrust settings for the initial climb with maximum continuous thrust and the subsequent climb with climb power.

C.2.3 Navigation

For the navigation during the departure initially a centerline tracking is used. This is achieved by using an implementation usually used for a localizer approach. Additionally a DME antenna position as well as a VOR antenna position can be specified. These navigation aids are sufficient for the chosen standard instrument departure. We chose not to use RNAV overlay departures (GPS based departures) for simplification reasons. More complex departures could be implemented with some effort.

C.2.4 Controller

The control of the model can be divided in three sections, an initial line up section, a hard coded departure sequence and an autopilot with selected modes allowing direct interference with the model during runtime. The implemented controllers are very simplistic and the corresponding gain tuning was done achieve stable behavior. The controllers are far from the capabilities of professionally used controllers in terms of performance. However, the implementation is sufficient for the generation of realistic trajectories used on a radar screen.

The line-up section allows to switch the position between the holding point before the runway and the line-up position on the runway when the controller gives the clearance. The other two sections are based on the same core controller with three channels. The first channel is the pitch channel where a rate command, attitude hold controller is implemented. This controller is provided with a commanded pitch rate leading to an elevator deflection to achieve a change in pitch angle until the commanded value is zero and the pitch angle is held fixed. The second channel is the yaw channel. A change in heading is achieved by directly computing a necessary yaw rate, limited by a maximum of three degrees per second. The third channel controls the fan speed N1. The higher hierarchy functionalities are mentioned in the following paragraphs providing the departure control separated into vertical plane (pitch and power) and the lateral plane (heading).

C.2.5 Pre-defined Take-off Sequence in the Vertical Plane

The following sequence provides details about the steps carried out during the approach. For each step, the control mode for the channels Thrust and Pitch are mentioned together with additional information where necessary. In general, the Thrust is kept at two constant settings, one for the initial climb and one for the continuous climb. The pitch control changes from a pre-defined pitch after rotation, to a speed control mode (Open Climb) during starting at the acceleration altitude and at the end the option to level off with an altitude hold mode. Additionally, the landing gear retraction and the configuration change to the clean configuration takes place at certain defined point along the vertical flight path.

Table 59: Take Off Sequence of Departure Simulation

1. Start take-off roll		
	Thrust: maximum N1	Pitch: neutral elevator
2. Rotation and initial climb		
	Thrust: maximum N1	Pitch: initial climb pitch attitude
	At 150ft above ground: gear-up leading to less drag	
3. Acceleration Altitude		
	Thrust: climb N1	Pitch : open climb, hold speed
	After passing the acceleration altitude of 1500ft AGL, thrust is set to climb thrust and the pitch channel controls the speed.	
4. Configuration change		
	Thrust: climb N1	Pitch : open climb, hold speed
	When passing a certain defined speed (mostly 200 kts), the configuration changes from first flap position to clean.	
5. Level-Off		
	Thrust: Speed Mode	Pitch: Altitude Hold
	Achieved by switching to Selected Modes during runtime.	

Standard Instrument Departure

The control in the lateral plane is prescribed by the chosen Standard Instrument Departure. This section provides the description of the SID and the used control modes.

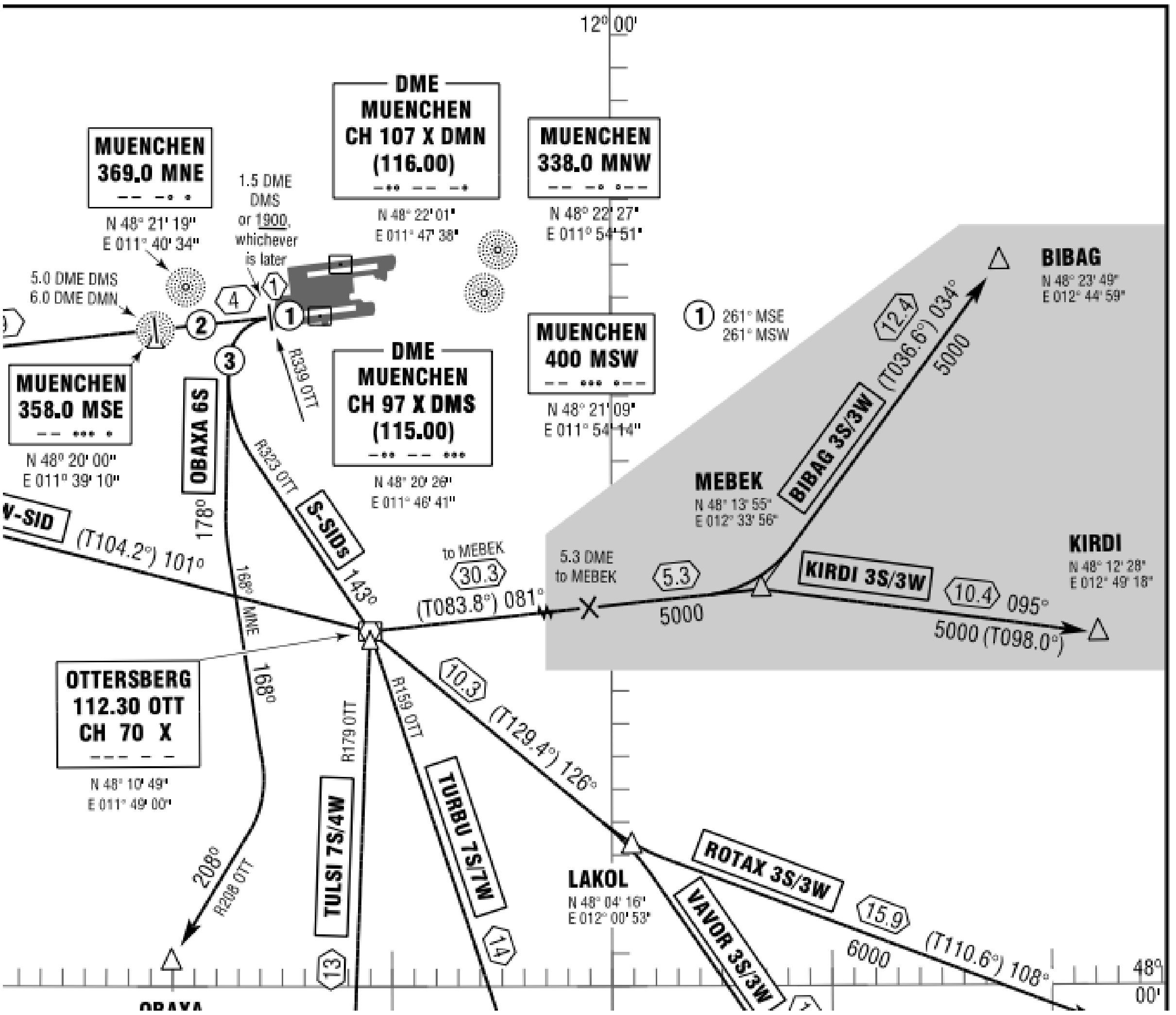

Figure 27: Standard Instrument Departure Airport 2 Runway 26L [41]

For the scenarios analyzed we chose the ROTAX 3S departure, see Figure 27, which is very similar to the missed approach procedure for runway 26L. The first three segments of the departure are currently implemented.

1. Straight out until 1.5 DME from DMS or Altitude 1900 ft, whichever is later
   To achieve this, the heading is controlled with the computed deviation from the centerline. The position of the DME antenna DMS is used to compute the slant range to the current aircraft position.

2. Turn left to course 178°
   When reaching 1.5 DME, the heading of 178° is selected. Wind effects are neglected for the short time until intercept

3. Intercept Ottersberg VOR Radial 323 inbound
   The control mode switches to a mode which holds a specified radial inbound and outbound, comparable to a navigation mode. The position of the Ottersberg VOR and the inbound course are specified

4. Changing to Heading Select mode if necessary

Overview Available Control Modes

In the previous two sections, multiple control modes are mentioned. Table 60 summarizes all available modes.

Table 60 Summary of Control Modes of the Departure Model

Channel	Control Mode
Pitch	Pitch Selected, Open Climb, Altitude Hold
Thrust	Thrust Commanded, Speed Hold
Heading	Navigation modes (Localizer/Centerline, VOR Radial intercept), Heading Hold

C.2.6 Comparison of Performance

To get an overview of the departure performance of the three aircraft characteristics, the variables Altitude, Vertical Speed, Speed and DME distance from DMS DME antenna are compared every two minutes. Table 61 shows the results of this analysis. The results show the low climb performance of four engine aircraft in comparison to twin engine aircraft. After 6 Minutes, the twin engine wide body already reached flight level 110 where as the four engine aircraft only is about to reach flight level 90. The narrow body aircraft shows even better performance. For completion, the vertical speed is provided as well and reveals the same differences. When it comes to speed and track flown, the differences are smaller but noticeable. A four engine wide body aircraft is not only 4800 ft lower than a twin engine aircraft but also 2.6 NM closer to the airport after 6 minutes of flight on the chosen SID.

Table 61 Comparison of Performance of Departure Model Variants

Time	Variable	twin engine		four engines
		narrow body	wide body	wide body
2 min	Altitude	3400 ft	3100 ft	2400 ft
	Vertical Speed	2800 ft/min	1900 ft/min	1350 ft/min
	Speed	210 kts	160 kts	170 kts
	DME distance DMS	2.7 NM	2.4 NM	2.4 NM
4 min	Altitude	8200 ft	6500 ft	4900 ft

	Vertical Speed	2600 ft/min	2200 ft/min	1850 ft/min
	Speed	250 kts	250 kts	230 kts
	DME distance DMS	8.3 NM	7.5 NM	6.9 NM
6min	Altitude	13600 ft	11200 ft	8800 ft
	Vertical Speed	2750 ft/min	2420 ft/min	2000 ft/min
	Speed	250 kts	250 kts	230 kts
	DME distance DMS	16.2 NM	15.2 NM	13.6 NM

C.3 Visualization

Over the past months the SafeOPS team conducted a number of workshops with ATCOs from Airport 2 and Airport 1 tower. Over the course of these workshops we acquired that it is most convenient for the workflow to present information indicating a go around on the radar screen. A simple visualization of a radar screen as in use in Airport 2 and Airport 1 tower is created. This visualization is intended to fulfill two purposes. First, in a series of workshops historical data, based on data provided by OpenSky and our consortium partners Iberia and Pegasus, is used set up the scenarios defined in [Reference to scenarios] to test different ways of visualizing a go around prediction. Based thereon a second series of studies is conducted, in which we simulate certain scenarios and evaluate the ATCOs (re-) actions. Hence, the tool needs to be capable of visualizing data originating from a simulation and as well as animating timeseries data. On a broader scale the visualization tool is an essential part of designing a go around prediction tool and in determining its impact.

According to the HMI requirements of D2.1 [4] various features for the visualization are implemented in this tool. These are mostly display of information which is important for an ATCO to judge a situation, but also guide the development team when implementing the go around prediction.

C.3.1 Tools

The visualization is implemented in the Python (ver. 3.8) programming language and needs to provide an easy to access interface for the aircraft models as well as the capability to animate ADS-B timeseries data. The tool is designed such that no changes need to be made when switching from animating a time series to animating a simulation, besides changing the input source.

- Numpy
  - Array structures
  - Basic Math functions
- Matplotlib
  - Matplotlib.pyplot
  - Basic plotting library for Python scripts
  - Provides all tools required to visualize a static plot
  - Matplotlib.animation
  - Provides additional functionality to animate otherwise static plots

- Socket
    - Part of the Python standard library
    - Provides protocols that enable communication with the simulation environment use to for the aircraft models

UDP provides the Simulink-Python interface. UDP was chosen due its simplicity and the risk of losing individual data packages was found to be acceptable given the non-safety critical use of the visualization. Furthermore, performance of the visualization tool was found to not be affected by loosing individual data packages. For the radar screen to be fully functional, the simulation needs to provide state information of the aircraft, as well as an unique identification and flight phase identifier for each of the illustrated aircraft. The state information comprises latitude, longitude, altitude, groundspeed and vertical rate. A minimum set of information required by the tool comprises only latitude and longitude plus a unique identifier for each aircraft. For the colors to match the corresponding flight phase, a flight phase identifier must be provided by the simulation. Much like the radar screens used in towers Airport 2 and Airport 1, a yellowish tone is used for approaching aircraft and light blue for departing aircraft, see table [color scheme table]. For (predicted) go arounds the development team chose red.

Inputs summarized:

- Minimal Set
    - Latitude, Longitude
    - Aircraft Identifier
- Additional Information
    - Altitude, Groundspeed, Vertical Rate
    - Flight Phase

C.3.2 Resources

All resources required to setup a radar screen like plot are provided by DFS [41]. These are, namely

- AIP Germany, which provides
    - Coordinates of runway thresholds and
    - Coordinates of CTR boundaries, as well as

C.3.3 Layout

This section provides some screenshots of the visualization tool, with Airport 2 CTR serving as an example. The two white bold lines represent the two runways in Airport 2. Extending to the left and right are the extend runway centerline axis. Each dash and the spacing between them each equals 1 NM. The tightly dashed polygon encircling most of the radar screen represents the local CTR.

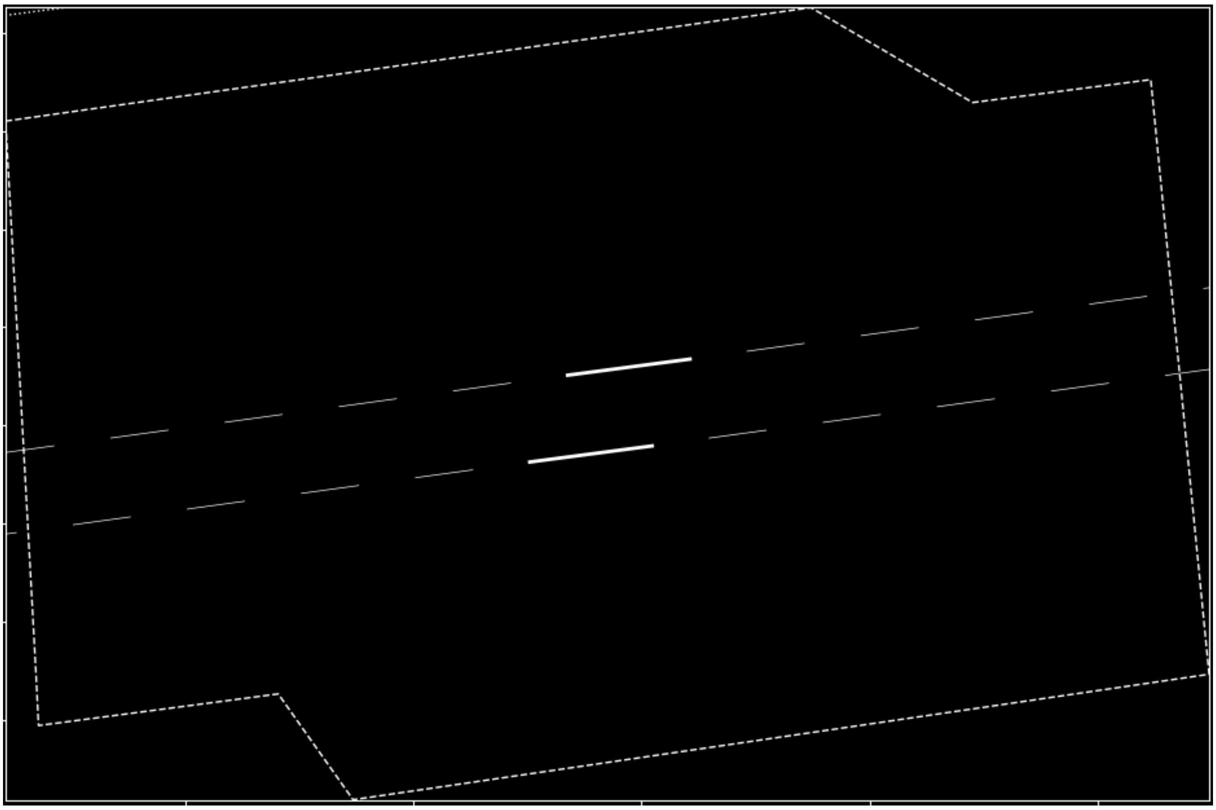

Figure 28: Illustrating an empty radar screen

Aircraft are symbolized by a square. Adjacent one finds the Callsign colorized according to Table 62.. Below the callsign, altitude in 100 ft and indicated airspeed in tens of kts are shown, as illustrated in Figure 29.

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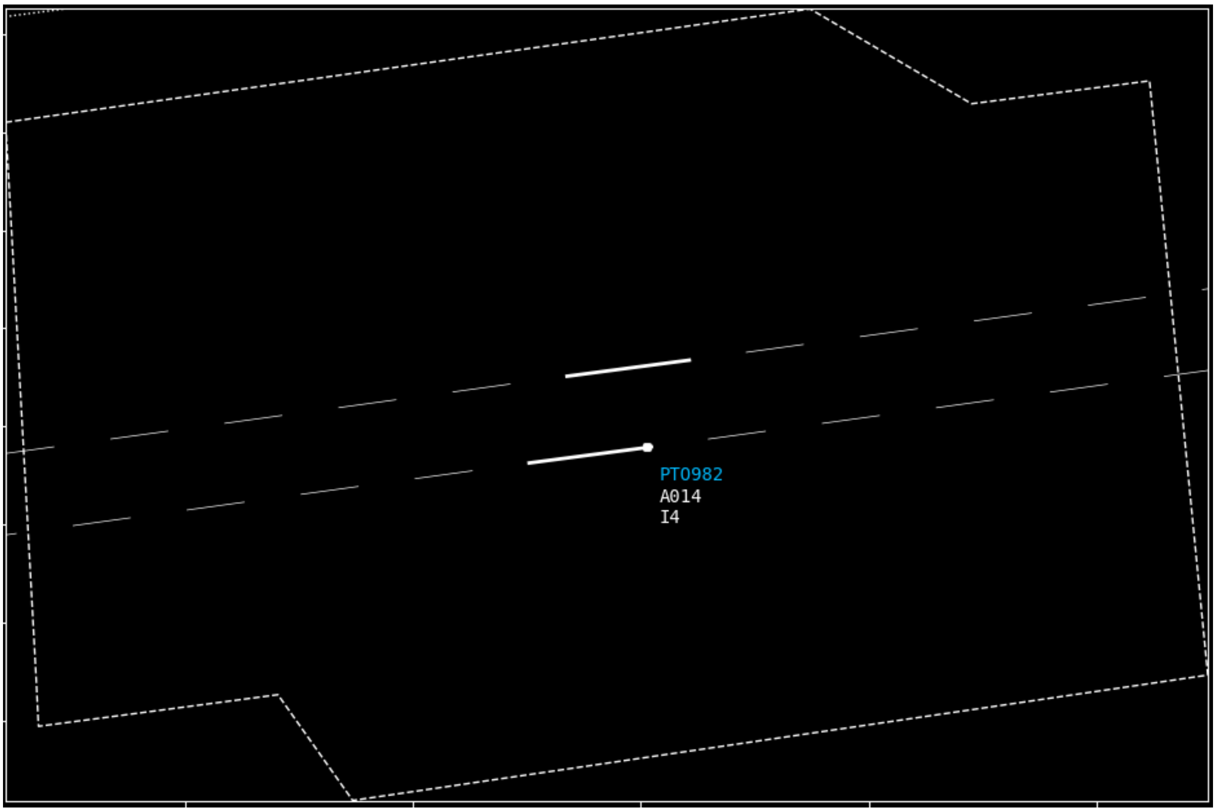

Figure 29: Illustrating an aircraft on the radar screen with callsign, altitude above ground and indicated airspeed.

The whole setup on a single pc is shown in the following Figure 30. On the right side of the screen one can see the (distorted) radar screen with a departure on the runway threshold and a predicted go around at 3 NM final. The top left shows a visualization in Flight Gear, as an ATCO would see from his/her workplace in the tower (not fully functional). On the bottom left Simulink can be seen.

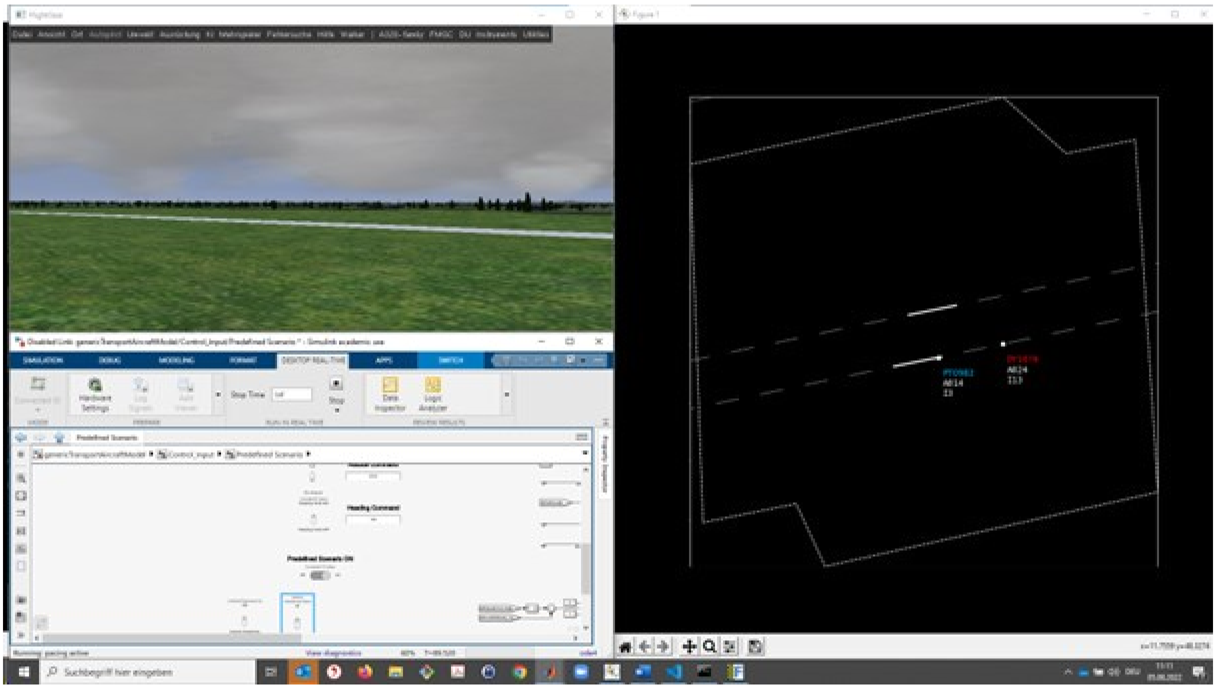

Figure 30: Simulation setup on a Laptop Screen with inputs and visualizations

The color scheme used in the visualization aims to mimic the real radar screen as used in towers Airport 2 and Airport 1. The colors indicate to following:

Table 62: Color codes for callsigns

Color	Hex-code	Meaning
Gold	#FFD700	Approach
Light Blue	#00BBFF	Departure
Red	#FF0000	(Predicted) Go Around

Limitations

Even if the visualization as presented here mimics one of the most important tools a tower ATCO uses in his/her daily work, this does by no means represent a detailed work environment of the towers in Airport 2 and Airport 1, or any other airport. Therefore, the usefulness of this tool is limited to situations in which an ATCO relies mostly on the radar screen. This is the case, for instance, in poor visibility conditions, when ATCOs cannot rely on visual references by looking outside the window, which is also the scenario the development team focused on throughout this project (SEE SECTION XXXXX). For follow-up projects it might be of interest, to also simulate visual references with tools as for instance FlightGear, which provides a tower environment as part of the simulator. Additionally, the TFDPS is not simulated, which might open up a whole new range of use cases.

Furthermore, only the dark background is implemented in the visualization. The real radar screen has the capability of also showing a white background with some dark color for runway, extended runway centerline and CTR boundaries. As most ATCOs however work with the setup as seen above, it was decided that there is no need to implement another color scheme.