INDUSTRIAL RESEARCH

SESAR JOINT UNDERTAKING

Impact Evaluation of the Developed Decision Support Concept

Deliverable ID:	D2.2
Dissemination Level:	PU
Project Acronym:	SafeOPS
Grant:	892919
Call:	H2020-SESAR-2019-2
Topic:	SESAR-ER4-06-2019
Consortium Coordinator:	TUM
Edition Date:	05.11.2022
Edition:	00.02.00
Template Edition:	02.00.03

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Authoring & Approval

Authors of the document

Name	Date
Lukas Beller /TUM	05/11/22
Philipp Kurth / DFS	30/09/22
Carlo Abate / DBL	23/09/22
Pablo Hernandez / INX	23/09/22
Phillip Koppitz / TUM	23/09/22
Marco Pfahler / TUM	23/09/22
Gökay Özer / TUM	23/09/22

Reviewers internal to the project

Beneficiary	Date
Lukas Beller /TUM	30/09/2022
Philipp Kurth / DFS	30/09/2022

Reviewers external to the project

Beneficiary	Date

Approved for submission to the S3JU By

Beneficiary	Date
Lukas Beller / TUM	05/10/22

Rejected By - Representatives of beneficiaries involved in the project

Beneficiary	Date

Document History

Edition	Date	Status	Beneficiary	Justification
00.00.01	01/05/22	Initial Outline / Experimental Planning		

00.00.02	02/08/22	Initial documentation and evaluation of experiments		
00.00.03	26/08/22	Draft Document in InGrid		
00.00.04	20/09/22	Debriefing / Review with ATCOs		
00.00.05	30/09/22	Implementation in SJU Template		
00.01.00	05/10/22	Editing/References		
00.02.00	05/11/22	1st Update, addressing comments from the SJU		Update of the abbreviations index, Legend for tables in section 4.2 was added. Coloring of table in section 4.1 was removed Clarification of section 4.3.1 – point 3. Subjective language removed.

SafeOPS

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

This deliverable is part of a project that has received funding from the SESAR3 Joint Undertaking under grant agreement No 892919 under European Union's Horizon 2020 research and innovation programme.

Abstract

SafeOPS proposes a concept of an AI-based decision support, in the context of go-around handling. This deliverable provides an evaluation of the impact, the SafeOPS concept has on safety and resilience of the Tower Control operations. Therefore, the deliverable first describes the envisioned concept from an operational and technical perspective, also including risks and benefits obtained from a risk framework for the concept. Based thereon, the deliverable details the setting up, execution and evaluation of a simulation-based investigation of the proposed concept. Finally, the deliverable presents and discusses the results and provides conclusions regarding TRL and technical feasibility.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Table of Contents

Abstract 3
1 Executive summary 13
2 Introduction 14
2.1 Purpose of the document 14
2.2 Structure of the document 14
2.3 Acronyms and Terminology 14
3 Context of the Validation 16
3.1 SESAR Solution SafeOPS: an extended summary 16
3.2 Summary of the Experimental Plan 33
3.3 Deviations 41
4 SESAR Solution SafeOPS Validation Results 43
4.1 Summary of SESAR Solution SafeOPS Validation Results 43
4.2 Detailed analysis of SESAR Solution Validation Results per Validation objective 47
4.3 Confidence in Validation Results 63
5 Conclusions and recommendations 66
5.1 Conclusions 66
5.2 Recommendations 71
6 References 73
Appendix A Validation Exercise #01 Report 76
A.1 Summary of the Validation Exercise #01 Plan 76
A.1.1 Validation Exercise description 76
A.1.2 Summary of Validation Exercise #01 Validation Objectives and success criteria 80
A.1.3 Summary of Validation Exercise #01 Validation scenarios 87
A.1.4 Summary of Validation Exercise #01 Validation Assumptions 91
A.2 Validation Exercise #01 Results 91
A.2.1 Summary of Validation Exercise #01 Results 91
A.2.2 Detailed Simulation Results for Exercise #01 91
1. Reference Scenarios Landing 91
a. RS.Landing.1 91
b. RS.Landing.2 94
2. Reference Scenarios Go-around 96
a. RS.GoAround.1 96
b. RS.GoAround.2 99
3. Solution Scenario False Positive Predictions 100
a. SS.FalsePositive.1 100
b. SS.FalsePositive.2 103
c. SS.FalsePositive.3 103
d. SS.FalsePositive.4 107

e. SS.FalsePositive.5 ... 108
f. SS.FalsePositive.6 ... 109
4. Solution Scenario True Positive Predictions ... 110
a. SS.TruePositive.1 ... 110
b. SS.TruePositive.2 ... 113
c. SS.TruePositive.3 ... 116
d. SS.TruePositive.4 ... 119
e. SS.TruePositive.5 ... 121
a. SS.TruePositive.6 ... 123
A.2.3 Analysis of Exercise 1 Results per Validation objective ... 125

Appendix B Simulation Environment ... 126

B.1 Arrival Model ... 126

B.1.1 Kinematics ... 126
B.1.2 Kinetics ... 128
B.1.3 Navigation ... 131
B.1.4 Aircraft Controller ... 131
B.1.5 Possible Arrival Scenarios ... 132

B.2 Departure Model ... 134

B.2.1 Kinematics ... 135
B.2.2 Kinetics ... 135
B.2.3 Navigation ... 135
B.2.4 Controller ... 135
B.2.5 Pre-defined Take-off Sequence in the Vertical Plane ... 136
B.2.6 Comparison of Performance ... 138

B.3 Visualization ... 139

B.3.1 Tools ... 139
B.3.2 Resources ... 140
B.3.3 Layout ... 140

List of Tables

Table 1: Acronyms and terminology ... 15

Table 2: High Level Research Questions ... 16

Table 3: Landing Reference Scenario ... 20

Table 4: Go-Around Reference Scenario ... 21

Table 5: Go-around - True positive solution scenario ... 22

Table 6: Strategies for the true positive prediction ... 24

Table 7: Possible Strategies and expected impacts in case of false positive predictions ... 25

Table 8: Size of data set, used in the predictive layer ... 26

Table 9: Collection of features, the predictive tool uses as input ... 26

Table 10: Results of the predictive tool for airport 1 ... 29

Table 11: Results of the predictive tool for airport 2 30
Table 12: Requirements for the predictive layer, defined in D2.1 30
Table 13: Requirements relevant for Risk Framework, defined in D2.1 33
Table 14: Definition of Safety Metric 1 34
Table 15: Definition of Safety Metric 2 35
Table 16: Definition of Safety Metric 3 35
Table 17: Definition of the Wake Separation Metric 1 35
Table 18: Definition of the Wake Separation Metric 2 36
Table 19: Definition of the Resilience Metric 1 36
Table 20: Definition of the Resilience Metric 2 36
Table 21: Definition of Resilience Metric 3 37
Table 22: Definition of the Capacity Metric 1 37
Table 23: Definition of the Capacity Metric 2 37
Table 24: Validation Assumptions 38
Table 25: Validation Assumptions overview 41
Table 26: Summary of Exercise Results 43
Table 27: Airport 2 Precision and Recall 47
Table 28: Obj.S1 Evaluation for 2NM Prediction Point 48
Table 29: Obj.S1 Evaluation for 4NM Prediction Point 48
Table 30: Obj.S1 Evaluation for 6NM Prediction Point 49
Table 31: Obj.S2 Evaluation for 2NM Prediction Point 50
Table 32: Obj.S2 Evaluation for 4NM Prediction Point 50
Table 33: Obj.S2 Evaluation for 6NM Prediction Point 51
Table 34: Obj.S3 Evaluation for 2NM Prediction Point 51
Table 35: Obj.S3 Evaluation for 4NM Prediction Point 52
Table 36: Obj.S3 Evaluation for 6NM Prediction Point 52
Table 37: Obj.S4 Evaluation for 2NM Prediction Point 53
Table 38: Obj.S4 Evaluation for 4NM Prediction Point 54

Table 39: Obj.S4 Evaluation for 6NM Prediction Point 54
Table 40: Obj.S5 Evaluation for 2NM Prediction Point 55
Table 41: Obj.S5 Evaluation for 4NM Prediction Point 55
Table 42: Obj.S5 Evaluation for 6NM Prediction Point 55
Table 43: Obj.R1 Evaluation for 2NM Prediction Point 56
Table 44: Obj.R1 Evaluation for 4NM Prediction Point 56
Table 45: Obj.R1 Evaluation for 6NM Prediction Point 57
Table 46: Obj.R2 Evaluation for 2NM Prediction Point 57
Table 47: Obj.R2 Evaluation for 4NM Prediction Point 58
Table 48: Obj.R2 Evaluation for 6NM Prediction Point 58
Table 49: Obj.R3 Evaluation for 2NM Prediction Point 59
Table 50: Obj.R3 Evaluation for 4NM Prediction Point 59
Table 51: Obj.R3 Evaluation for 6NM Prediction Point 60
Table 52: Obj.C1 Evaluation for 2NM Prediction Point 60
Table 53: Obj.C1 Evaluation for 4NM Prediction Point 61
Table 54: Obj.C1 Evaluation for 6NM Prediction Point 61
Table 55: Obj.C2 Evaluation for 2NM Prediction Point 62
Table 56: Obj.C2 Evaluation for 4NM Prediction Point 62
Table 57: Obj.C2 Evaluation for 6NM Prediction Point 63
Table 58: TRL 2 Criteria and self-assessment 68
Table 59: Illustration of simplified simulation output 78
Table 60: Specified Safey Related Research Questions 80
Table 61: Definition of Safety Metric 1 81
Table 62: Definition of Safety Metric 2 82
Table 63: Definition of Safety Metric 3 82
Table 64: Definition of the Wake Separation Metric 1 84
Table 65: Definition of the Wake Separation Metric 2 85
Table 66: Specified Resilience Research Questions 85

Table 67: Definition of the Resilience Metric 1 86
Table 68: Definition of the Resilience Metric 2 86
Table 69: Definition of Resilience Metric 3 86
Table 70: Research Question Specified towards Capacity 87
Table 71: Definition of the Capacity Metric 1 87
Table 72: Definition of the Capacity Metric 2 87
Table 73: Template: configuration card departure 89
Table 74: Template: configuration card approach 89
Table 75: Summary of all Sub-Exercises and their composition from reference and solution scenarios 90
Table 76: Configuration Card Dep.Cfg.1 91
Table 77: Configuration Card for App.Cfg.1 92
Table 78: Metric Evaluation for RS.Landing.1 93
Table 79: Configuration Card for Dep.Cfg.2 94
Table 80: Metric Evaluation for RS.Landing.2 95
Table 81: Configuration Card for App.Cfg.2 96
Table 82: Metric evaluation for RS.GoAround.1 98
Table 83: Metrics evaluation for RS.GoAround.2 99
Table 84: Configuration Cart for App.Cfg.6 100
Table 85: Metric evaluation for SS.FalsePositive.1 102
Table 86: Configuration Card for App.Cfg.7 103
Table 87: Configuration Cart for App.Cfg.8 104
Table 88: Metric evaluation for SS.FalsePositive.3 106
Table 89: Metric evaluation for SS.FalsePositive.4 108
Table 90: Metric evaluation for SS.FalsePositive.6 109
Table 91: Configuration Cart for App.Cfg.3 110
Table 92: Metric evaluation for SS.TruePositive.1 112
Table 93: Configuration Cart for App.Cfg.4 113
Table 94: Metric evaluation for SS.TruePositive.2 115

Table 95: Configuration Cart for App.Cfg.5 ... 116
Table 96: Metric evaluation for SS.TruePositive.3 ... 118
Table 97: Metric evaluation for SS.TruePositive.4 ... 121
Table 98: Metric evaluation for SS.TruePositive.5 ... 122
Table 99: Metric evaluation for SS.TruePositive.6 ... 124
Table 100: Summary of States ... 128
Table 101: The weight limits of the aircraft ... 130
Table 102 The weight and balance values used in the arrival model ... 130
Table 103: he controller modes that were included in the arrival model. ... 131
Table 104: Possible Arrival Scnearios and inputs to the simulation model ... 132
Table 105: Main Performance Characteristics of Departure Model Variants ... 134
Table 106: Take Off Sequence of Departure Simulation ... 136
Table 107 Summary of Control Modes of the Departure Model ... 138
Table 108 Comparison of Performance of Departure Model Variants ... 138
Table 109: Color codes for callsigns ... 143

List of Figures

Figure 1: SafeOPS Concept visualization on a high-level basis ... 17
Figure 2: Landing reference scenario – Step 1 ... 21
Figure 3: Landing reference scenario - Step 2 ... 21
Figure 4: Landing reference scenario - Step 3 ... 21
Figure 5: Go-around reference scenario ... 22
Figure 6: Go-around solution scenario - step 1 ... 23
Figure 7: Go-around solution scenario - step 2: prediction ... 23
Figure 8: Go-around solution scenario - step 3: alternative strategies ... 24
Figure 9: Overview of the IT processes in SafeOPS reference D4.1 ... 26
Figure 10: Initial conditions of the simulation ... 77
Figure 11: Illustration of simulation setup, simulation operator and Tower Controller ... 78

Figure 12: Illustration of a sequence diagram, used to visualize the actions of the Tower Controller during the simulation 79

Figure 13: Illustration of the horizontal radar separation metric 83

Figure 14: Illustration of the Wake Separation Metric 84

Figure 15: Illustration of different sub-scenarios for the validation exercise 88

Figure 16: Visualization of RS.Landing.1........ 92

Figure 17: Sequence Diagram RS.Landing.1 93

Figure 18: Visualization of RS.Landing.2........ 95

Figure 19: Sequence Diagram for RS.GoAround.1 97

Figure 20: Visualization of RS.GoAround.1 98

Figure 21: Visualization of RS.GoAround.2 99

Figure 22: Sequence Diagram for SS.FalsePositive.1 101

Figure 23: Visualization of SS.FalsePositive.1........ 102

Figure 24: Sequence Diagram for SS.FalsePositive.3 105

Figure 25: Visualization of SS.FalsePositive.3........ 106

Figure 26: Visualization of SS.FalsePositive.4........ 107

Figure 27: Visualization of SS.FalsePositive.6........ 109

Figure 28: Sequence Diagram for SS.TruePositive.1 111

Figure 29: Visualization of SS.TruePositive.1 112

Figure 30: Sequence Diagram for SS.TruePositive.2 114

Figure 31: Visualization of SS.TruePositive.2 115

Figure 32: Sequence Diagram for SS.TruePositive.3 117

Figure 33: Visualization of SS.TruePositive.3 118

Figure 34: Sequence Diagram for SS.TruePositive.4 120

Figure 35: Visualization of SS.TruePositive.4 121

Figure 36: Visualization of SS.TruePositive.5 122

Figure 37: Visualization of SS.TruePositive.6 124

Figure 38: Definition of Coordinate Frames and Coordinates [13] 126

Figure 39: Body Fixed Coordinates [14] 127

Figure 40: The aerodynamic surface sections of multi-point model representation. Only the right main wing is shown. Orthogonal view 129

Figure 41: The locations of the ILS antennas of Runway 26L in Airport 2 on Google Maps. [28]....... 131

Figure 42 Airport 2 Runway 26L, instrument approach chart with the dashed line showing the standard missed approach route. [29] 134

Figure 43: Airport 2 Runway 26L, the missed approach procedure on the top left. [29] 134

Figure 44: Standard Instrument Departure Airport 2 Runway 26L [29] 137

Figure 45: Illustrating an empty radar screen 141

Figure 46: Illustrating an aircraft on the radar screen with callsign, altitude above ground and indicated airspeed. 142

Figure 47: Simulation setup on a Laptop Screen with inputs and visualizations 143

1 Executive summary

SafeOPS is an exploratory research project, which investigates an AI-based, decision support for Air Traffic Control in the context of go-arounds. The underlying idea is to use the available performance and weather data sources to train machine learning algorithms to predict go-arounds in advance. Air Traffic Controllers (ATCOs) could use the predictive information to adapt their strategies, when handling go-arounds, avoiding knock-on effects that can accompany go-arounds, and thereby increasing safety and resilience. These knock-on effects can originate from conflicting missed approach and departure procedures at airports and cannot always be avoided due to geographical or environmental constraints in the airport vicinity.

At the beginning of the project, SafeOPS identified real world scenarios with conflicting missed approach and departure routes at two European airports. Based thereon, SafeOPS defined use cases for an AI-based decision support tool and documented expected risks and benefits. Furthermore, SafeOPS defined an initial set of requirements for a machine learning based go-around prediction and developed a prototype during the project. Additionally, we formulated a risk framework based on Eurocontrol's Accident/Incident Models investigating safety risks and benefits of the proposed concept.

First, this deliverable provides the latest concept description for the envisioned decision support tool, including all results the project produced so far. Additionally, this deliverable describes a simulation exercise, performed with ATCOs in several workshops, to support or disapprove the expected impacts of the concept outlined in the defined use cases. The underlying technique for the predictive decision support tool is a binary classifier. These types of algorithms can produce four classes of outcomes: true positive, true negative, false positive and false negative predictions. While the use cases discussed in the project so far, concentrated on the true positive case, the goal of this deliverable is to also include the other predictive cases and the possible undesired impacts they have.

Therefore, based on the identified real-world scenarios, this document presents a generalized simulation scenario, as well as a simulation environment. The developed simulation environment includes two aircraft models and a radar screen visualization tool, which can be run on an office laptop. The document further defines metrics to assess the posed research question and impact of the envisioned concept on safety and resilience in the defined scenarios.

The performed simulation study indicates that the proposed concept, in case of true positive predictions, can provide benefits regarding safety and resilience. When using the time in advance information of a possible go-around, the ATCOs adapted their strategies, avoiding possible knock-on effects and also reducing their peak workload. However, in case of false positive predictions, the concept can decrease capacity and produce additional coordinative work for the ATCOs. The ratio of true positive to false positive predictions is a trait of the underlying machine learning model and is regarded in the discussion of the results.

Moving forward, we propose to next investigate online capable predictions of go-arounds. This is the next technical challenge to be addressed after the project demonstrated that go-around predictions are feasible in an offline manner. Additionally, a cost estimation, which incorporates potential losses in capacity is a necessary next step. This would allow a discussion of the safety vs. capacity trade-off, the concept faces, since the potential safety benefits were demonstrated in this work.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

2 Introduction

2.1 Purpose of the document

This document provides the impact evaluation of the SafeOPS concept on safety and resilience of the Tower Operation, especially the approach and go-around handling. Furthermore, this deliverable provides a validation for SafeOPS concept in the FO/AO stage. It describes the results of validation exercises defined in the SafeOPS Experimental Plan and how they have been conducted and provides a set of conclusions and recommendations.

2.2 Structure of the document

The document initially defines the SafeOPS concept in 3.1. Section 3.2 in conjunction with appendix A.1 provide the definition of the planned validation exercise as well as the objectives and metrics to evaluate the SafeOPS concept. Section 4 summarizes the results, which are documented in their completeness in appendix A.2.2, and classifies them according to the documented assumptions for the defined scenarios and methodology, presented in section 3.2.3. Section 5 provides conclusions regarding TRLs and technical feasibility and lists recommendations in case of further research on the concept is done.

2.3 Acronyms and Terminology

Term	Definition
A/C	aircraft
ADS-B	Automatic Dependent Surveillance Broadcast
ATCO	Air Traffic Controller
ATM	Air Traffic Management
ddm	Difference in the depth of modulation
Dx.y	Deliverable Nr. y, from task x (as defined in the Grant Agreement)
EATMA	European ATM Architecture
ER	Exploratory Research
E-ATMS	European Air Traffic Management System
E-OCVM	European Operational Concept Validation Methodology
FC	Flight Crew
KPA	Key Performance Area

KPI	Key Performance Indicator
METAR	Meteorological Aerodrome Report
OSED	Operational Service and Environment Definition
PL	Tower Controller (from german: Platzlotse)
RQ	Research Question
SESAR	Single European Sky ATM Research Programme
S3JU	SESAR3 Joint Undertaking (Agency of the European Commission)
TRL	Technology Readiness Level
VALP	Validation Plan

Table 1: Acronyms and terminology

3 Context of the Validation

SafeOPS is an exploratory research project, investigating a decision support tool for Tower Controllers in the domain of go-around and departure handling. The targeted maturity of SafeOPS is to fully complete TRL1 and partly complete TRL2, as foreseen for Exploratory Research Projects in the SESAR Maturity Criteria definition [1] corresponding to V0/V1 in the European Operational Concept Validation Methodology [2] . At this early stage of the investigation, no dependencies to other projects are known.

The focus of this validation exercise is to investigate the research questions, posed by SafeOPS in the Description of Action and the Experimental Plan, and stated in Table 2.

Table 2: 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 the initial research questions and the SafeOPS solution concept, explained in 3.1, refined research questions and subsequently evaluation metrics and success criteria are elaborated. The SafeOPS Experimental Plan initially documented this process, which is further documented in appendix A.1.2. Section 3.2.2 presents only the resulting metrics and success criteria.

3.1 SESAR Solution SafeOPS: an extended summary

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) [3], we summarize the relevant achievements of the development phase of SafeOPS, resulting in the SafeOPS Deliverables D3.2 [4], D3.3 [5], D4.1 [6]and D4.2 [7].

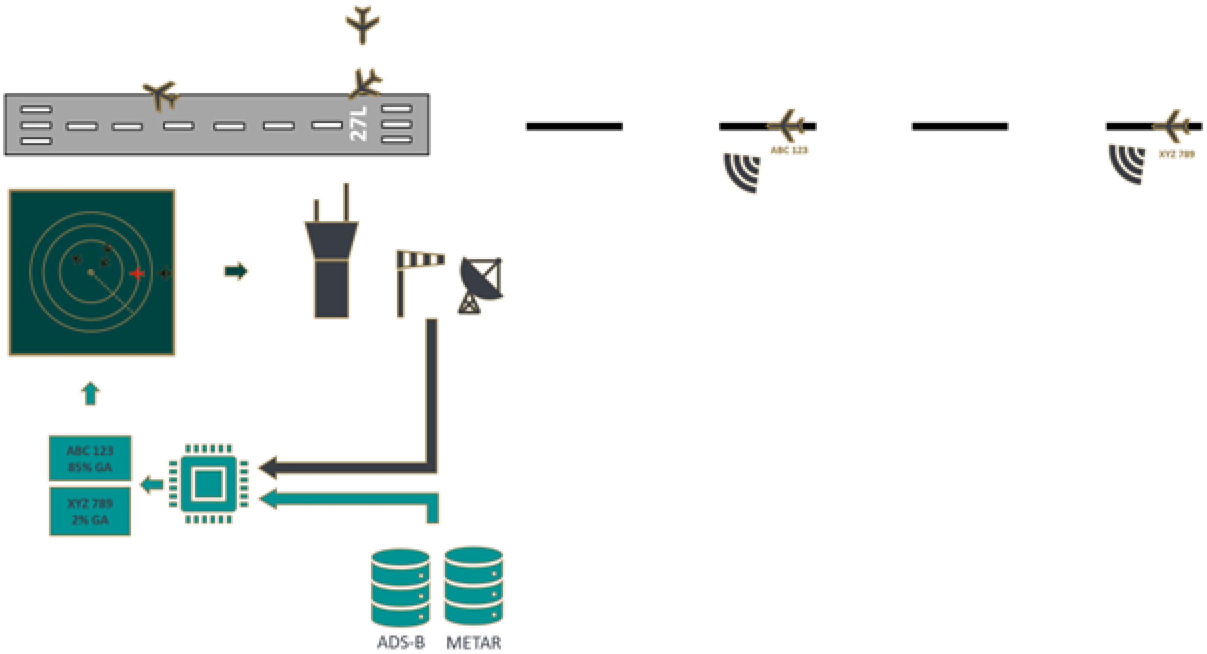


Figure 1: SafeOPS Concept visualization on a high-level basis.

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 1 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 [8]. 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.

3.1.1 Operational Layer

D2.1 [3] 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 [3] 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.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

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 [3] 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 [3] 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 [3].

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 [6] and D4.2 [7]. The relevant details are summarized in section 3.1.2. 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 10 and Table 11. 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 are documented in detail in section A.2.2, since they are dependent on the actual precise configuration of each simulation run.

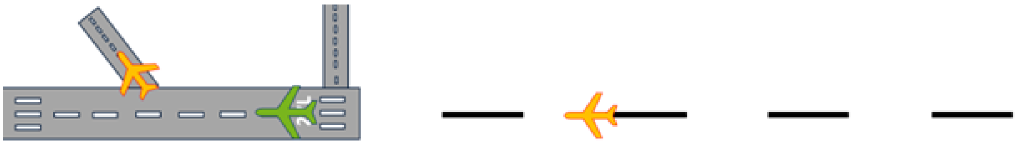
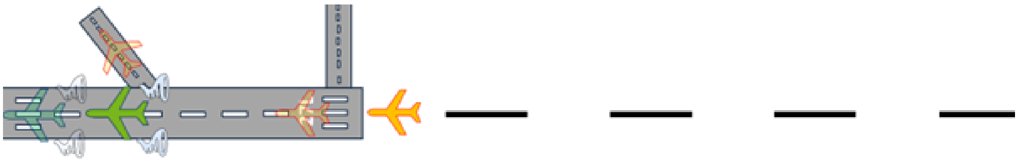
Solution Boundaries

As described in D2.1 [3], SafeOPS focuses on the work of Tower Controllers. Based thereon, D2.1 [3] 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 (FC) 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 3: Landing Reference Scenario

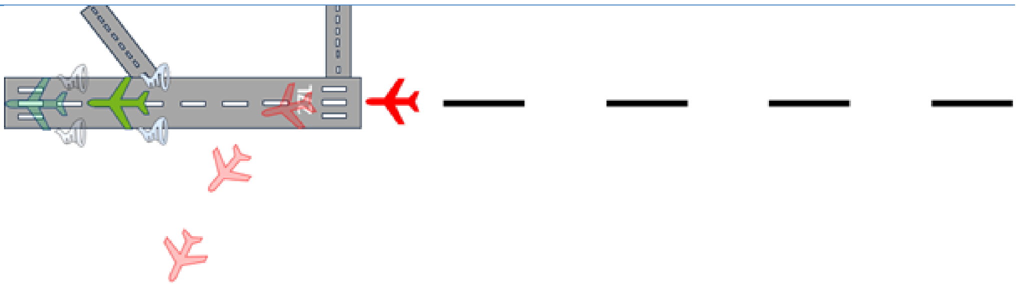
Scenario ID:	**Scen.Ref.1**		
Scenario Name:	Mixed Mode Landing	Version No:	1.0
Involved Actors:	Tower Controller, Flight Crew Arrival, Flight Crew Departure		
Description of Traffic Context:	Figure 2 illustrates a runway operated in mixed mode, with aircraft for departure colored green and arriving 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 3 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 4, 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 2: Landing reference scenario – Step 1**  **Figure 3: Landing reference scenario - Step 2**  **Figure 4: Landing reference scenario - Step 3**

Go-around reference scenario

Table 4: Go-Around Reference Scenario

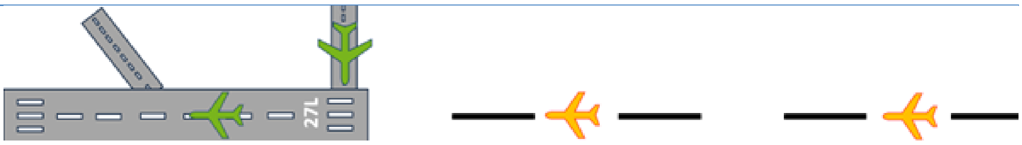
Scenario ID:	**Scen.Ref.2**		
Scenario Name:	Mixed Mode Go-Around	Version No:	1.0
Involved Actors:	Tower Controller, Flight Crew Arrival, Flight Crew Departure		
Description of Traffic Context:	The initial setup is similar to Scen.Ref.2. Figure 2 illustrates a runway operated in mixed mode, with aircraft 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 3 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 5, 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 [3], 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 [3] 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 5: Go-around reference scenario**

Go-around - True positive prediction - solution scenario

Table 5: 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 [3]. 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 [3]. Compared to the reference scenarios described in Table 3 and Table 4, the second arriving aircraft is predicted to perform a go-around, indicated by the red coloring in Figure 6. Depending on the time/point of this prediction, the ATCO has different options in this scenario, summarized in Table 6. Figure 7 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 8, 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 section A.2.2.
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 6.
Visualization:	 **Figure 6: Go-around solution scenario - step 1**  **Figure 7: Go-around solution scenario - step 2: prediction**

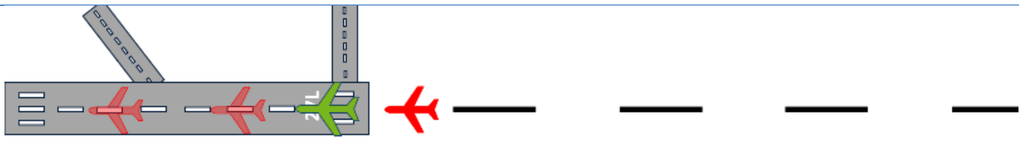


Figure 8: Go-around solution scenario - step 3: alternative strategies

Table 6: 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 7: 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.

3.1.2 Predictive Layer

For the predictive part of the SafeOPS solution, additional requirements were defined in D2.1 [3]. These are summarized in Table 12. Figure 9 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 [3], the deployment the intended use which is described in the scenarios and use cases in D2.1 [3]. 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.

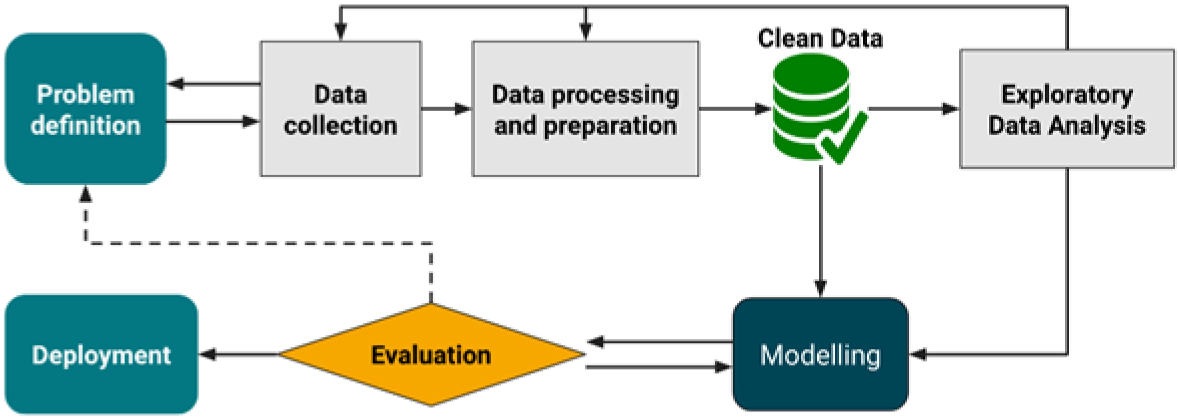


Figure 9: Overview of the IT processes in SafeOPS reference D4.1

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 8 provides an overview on the number of approaches and go-arounds, found in the final dataset used.

Table 8: 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 9, 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 9: 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 10 and Table 11. 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 10: 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 11: 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 12: 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.

3.1.3 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 [3]. 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 13: 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 [5] 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.

3.2 Summary of the Experimental Plan

Since the Experimental Plan for SafeOPS is not a contractual deliverable and has not been published yet, it is summarized in Appendix A.1.

3.2.1 Experimental Plan Purpose

As basis and guideline in developing this SafeOPS' Experimental Plan serve SESAR's Safety Reference Material [9], Guidance to apply SESAR SRM [10], and Experimental Approach Guidance for ER [11], the SJUs Accident Incident Models available in STELLAR , and the SJU's Resilience Engineering Guidance [12].

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.

The SafeOPS Experimental Plan defines and plans the actions performed in this deliverable, to evaluate the impact of the proposed concept on safety and resilience in the defined scenarios. The Experimental Plan contains:

- an exercise description which is also documented in the appendix A.1.1
- the objectives and validation criteria, applicable for the validation exercise, which are summarized in section 3.2.2 and detailed in appendix A.1.2
- the reference and solution scenarios, based on the concept description from section 3.1.1, described in A.1.3.

Furthermore, the Experimental Plan defines the simulation environment, used for the exercise. The simulation environment is described in detail in Appendix B, containing a simulation model for approach aircraft in section B.1, a simulation model for departure aircraft in section B.2 and a visualization tool to mimic a radar screen in section B.3.

The simulation exercises have been performed in the course of 4 Workshops during May 2022 – September plus one additional Workshop on the end of September 2022 for debriefing. Each workshop was scheduled for 4 hours. In total five Air Traffic Controllers participated in the simulations.

3.2.2 Summary of Validation Objectives and success criteria

Appendix A.1.2 contains a detailed description on the objectives and success criteria. In this section we provide the definitions and success criteria only. For justifications on how the objectives and success criteria were defined, please see to Appendix A.1.2. We defined objectives regarding the KPAs safety and resilience/capacity.

3.2.2.1 Safety

Table 14: 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 15: 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 13 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 16: 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.

Table 17: Definition of the Wake Separation Metric 1

ID:	**Obj.S4**
Objective	Assess 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.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Table 18: Definition of the Wake Separation Metric 2

ID:	Obj.S5
Objective	Assess 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.

3.2.2.2 Resilience and Capacity

Table 19: Definition of the Resilience Metric 1

ID:	Obj.R1
Objective	Assess 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 20: Definition of the Resilience Metric 2

ID:	Obj.R2
Objective	Assess 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 21: Definition of Resilience Metric 3

ID:	**Obj.R3**
Objective	Assess 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.

Table 22: Definition of the Capacity Metric 1

ID:	**Obj.C1**
Objective	Assess 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 23: Definition of the Capacity Metric 2

ID:	**Obj.C2**
Objective	Assess 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.

3.2.3 Validation Assumptions

This section summarizes the assumptions, underlying the definition of the scenarios in section 3.1.1 and their implementation in the simulation environment used for this deliverable. Furthermore, the impact of the assumption on the assessment of the SafeOPS concept in this deliverable is described.

Table 24: Validation Assumptions

Identifier	Title	Description	Justification	Impact on Assessment
VA.1	Weather conditions	For all scenarios, we assume IMC conditions.	In IMC conditions, the ATCOs cannot use reduced separation means (visual separation). Thus, the applicable separation minima are larger compared to VMC conditions. Also, in VMC conditions, special procedures in airport 2 like reduced runway separation applies (Described in detail in D2.1 [3], Section 3) which would make the results very tailored to airport 2 conditions.	IMC conditions prevail with a chance of around 20-25% for airport 2, according to ATCOs. This means, that for 75%-80% of the time, VMC conditions prevail and the safety related metrics regarding radar separation cannot be applied, and reduced separation means are valid. In these cases, ATCOs reported in the workshops, that they would rely on visual separation in these situations but work as described in the reference scenarios and use the predictive information only for situational awareness.
VA.2	Traffic situation	In all scenarios, we assume that the traffic is dense. This means the approach controller constantly delivers the approaching aircraft with gaps of 5-6NM, depending on the departing aircraft's	For the ATCOs we worked with in our workshops, these traffic situations were common before Covid-19 and expected to become common again in the near future. The ATCOs stated that they expect	The discussed use-cases of the SafeOPS solution unfold their effects especially in dense traffic patterns, when missed approaches conflict with departures. If the sector for a missed approach is clear because no conflicting departure aircraft is in

		wake turbulence category	dense traffic for several hours a day.	the sector, the investigated knock-on effects are not relevant.
VA.3	Scenario Boundaries	The scenario boundaries have been described in section 3.1.1. In the scenarios, we only investigate the control zone of the Tower Controller, who handles the departures and go-arounds. We stop 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	At this early stage in the investigation, tickle down effects is not in the scope of investigation. We plan to first understand if there is a benefit for the direct users. Once this is understood, possible tickle down effects later in the system can be investigated.	The assessment only investigates direct impacts on the intended user at this stage of investigations.
VA.4	Prediction Accuracy and Go-around Statistics	All ATCOs were briefed on the achieved accuracies from D4.1/D4.2. The precision and recall metrics have been explained and discussed in detail, however it is hard to imagine how experiencing false/true predictions in real operations is. We directly simulated the scenarios as described and will weight them by the statistics.	Go-arounds itself are rare. Thus, in the simulation exercises performed we cannot simulate the number of approaches necessary to reproduce the real-world statistics of go-arounds. (Each scenario simulation is ca. 4-5 minutes) Per 1000 approaches, on average 2-3 go-arounds occur.	The main goal of the simulation exercise is to validate the use cases of D2.1 [3] and generate measurable metrics on safety, resilience and capacity. With the validation exercise as implemented now, there are no "surprises" of go-arounds occurring.

		Thus, the ATCOs knew beforehand, that a go-around will or will not occur.		
VA.5	Conflicting Missed Approach and Departure Routes	The investigated knock-on effects arise from conflicting missed-approach and departure routes. Therefore, it is dependent on the actual SIDs/STARs at each airport if and how much the investigated solution can provide an impact.	In D2.1 [3], we identified several cases of real-world scenarios, based on this assumption/limitation. Oftentimes it is not possible to rule out all possible conflicts of departure and missed approach procedures due to noise abatement / terrain or other limitations. However, it must be assessed at each airport individually.	We found at two airports we investigated, that several real-world scenarios exist. However, it remains open on how frequent these limitations are present at other airports. Also, it has to be emphasized that not all departure routes are conflicting with the missed approach procedures. The affected departures are therefore only a subset of all departures.
VA.6	True Negative and False Negative Predictions	The prediction cases true negative and false negative have only been considered from the point of being equal to the reference landing and reference go-around scenario.	When simply comparing these scenarios, this assumption holds. For an initial investigation of the operational consequence of each of these scenarios, this assumption can be made.	Based on this assumption, SafeOPS can estimate the operational impact of each scenario. However, loss of skill due to customization or unintended misuse of the concept as landing-prediction have to be investigated, in later stages. To investigate these however, long term studies must be performed.
VA.7	Initiation of the go-around / Fixed values for parameters	For the simulation exercise, the go-around initiation was set at 0.9NM from runway threshold. Similarly, various	From the data in D4.1 and the feedback from the ATCOs that is a realistic point for a go-around initiation. However, a go-around	The selected parameter values are documented in the configuration card for each simulation. We chose the values to be

	of the simulations	other parameters must be set to representative values, limiting the investigated operational spectrum.	can of be initiated anywhere along the glideslope up to the touch-down point. As with other parameters in the simulation, we needed to choose a representative value, since only a limited number of simulations including humans is possible due to time constraints.	representative for common operational situation. Due to the vast number of possible permutations of parameters, only a representative sample for daily operational conditions was selected for the simulation exercise. To investigate over a wider range of operational conditions, a Monte Carlo based simulation setup is necessary.

Table 25: Validation Assumptions overview

3.2.4 Validation Exercises List

As this is the initial validation exercises in the context of SafeOPS, no validation exercise list exists.

3.3 Deviations

3.3.1 Deviations with respect to the S3JU Project Handbook

At this stage of the project, there are no deviations from the SJU Handbook to be reported.

3.3.2 Deviations with respect to the Experimental Plan

Only a few changes have been made, compared to the Experimental Plan that was submitted in T0+14.

Metrics

- Safety:
  - Regarding the Safety Metrics, appendix A.1.2 specifies in more detail how to compute S1 and S2.
- Resilience:
  - In the previous version of the Experimental Plan, we defined 5 metrics regarding resilience. Three of them covered coordinative actions, but each with different actors. We decided to include all cooperative actions into one metric, to make the investigations more concise.

Simulation Environment

In this deliverable, we added an extensive description of the Simulation Environment used for the validation exercise in Appendix B. Also, in appendix A.1.1, the Exercise Description has been laid out in further details.

Co-funded by the European Union

4 SESAR Solution SafeOPS Validation Results

4.1 Summary of SESAR Solution SafeOPS Validation Results

This section summarizes the exercise results. Table 26, lists a summary for each objective defined in Appendix A.1.2. The detailed results, including the simulation configuration cards, sequence diagrams, visualizations and metric evaluations are presented in A.2.2, whereas the analyses per objective is detailed in 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 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.

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.

Table 26: Summary of Exercise Results

Validation Exercise #01 Validation	Validation Exercise #01 Validation Objective Title	Validation Exercise #01 Success Criterion	Exercise #01 Validation Results	Validation Exercise #01 Validation Objective Status

Objective ID				
Obj.S1	Increase the minimum vertical distance between A/Cs, when the horizontal distance is below 3NM.	The minimum vertical separation distance, when aircraft are closer than 3NM horizontally, increases in the solution scenario, compared to the reference scenario.	Summarizing we can state that for each simulated scenario the metric either remains equal between reference and solution scenarios or improves. It is noteworthy to state that this also holds for the false positive predictions.	Ok
Obj.S2	Increase the minimum horizontal distance between A/Cs, when the vertical distance is below 300m.	The minimum horizontal separation distance, when aircraft are closer than 300m vertically, increases in the solution scenario, compared to the reference scenario.	Also, this metric either remains constant or improves, when comparing solution and reference scenarios. The false positive predictions do not worsen situations, whereas true positive predictions either improve the situation or remain constant.	OK:
Obj.S3	Prevent situations, which require immediate action by the Tower Controller, to ensure separation.	If the solution scenario does not evolve to a situation which requires immediate action by the Tower Controller to ensure separation, compared to the reference scenario.	Especially in the 4NM and 6NM prediction points, the true positive prediction achieves, that the situation in the simulation evolves in a way no immediate action by the ATCO is necessary to ensure separation. This is a clear improvement to the reference scenarios. Therefore, the success criteria is met. In the false positive cases, the solution scenario remains comparable with the reference scenarios regarding this objective.	OK
Obj.S4	Increase the height difference between aircraft in the simulation,	If the height difference increases in the solution scenario, compared to the reference scenario. (Or the	For the true positive cases with predictions at 4NM and 6NM the solution scenarios meet the success criteria. For the 2NM and all false positive prediction	OK

	when the medium approach is operating behind the heavy departure	approach is not operating behind the departure in the solution scenario, compared to the reference scenario)	cases, no change compared to the reference scenario can be observed.	
Obj.S5	Reduce the number of wake separation infringements.	If the number of wake separation infringements in the solution scenarios is reduced, compared to the reference scenarios	No wake separation infringement could be measured in either reference or solution scenarios.	Partially Ok, No wake separation infringements could be measured in either the reference or solution scenarios. Obj.S4 however indicates that the margin towards a wake separation infringement is equal or becomes larger in the solution scenarios.
Obj.R1	Number of coordinative actions of the ATCOs after the initiation of a go-around with the involved Actors, if departure and missed approach are airborne.	If the number of coordinative actions after the initiation of a go-around, decreases in the solution scenarios, compared to the reference scenarios.	On average, the number of coordinative actions, after the initiation of a go-around, is reduced by the solution scenarios, compared to the reference scenarios. The true positive cases are either improved or equal to the reference scenarios. The false positive solution scenarios are either equal or worse to the reference. Weighted by the precision of the prediction, the solution on average improves the situation.	Partially OK: As stated on average, the situation improves but it is possible that false positive predictions mean more work for the controller, compared to the reference scenario.

			Therefore, the success criterion is met on average but not in every simulated scenario	
Obj.R2	Number of the overall coordinative actions of the ATCOs with the involved Actors.	If the number of overall coordinative actions decreases in the solution scenario, compared with the reference scenarios.	Behaves similar to Obj.R1. On average, the coordinative actions decrease. In the true positive cases with predictions at 4NM and 6NM, the coordinative actions reduce, compared to the reference scenario. For the false positive cases with 4NM predictions the solution scenario increases coordinative tasks, compared to the reference.	Partially OK: As stated on average, the situation improves but it is possible that false positive predictions cause more work for the controller, compared to the reference scenario.
Obj.R3	Number of unbriefed missed approaches.	If a missed approach which in the reference scenario is not according to the standard missed approach, can be performed as standard missed approach in the solution scenario.	For the 4NM and 6NM true positive predictions, the success criterion is met. For the 2NM true positive prediction and the false positive prediction, the solution and reference scenario behave similar.	OK
Obj.C1	Is the departure aircraft using the planned gap for its departure.	If in the solution scenario, a gap which is used for departure in the reference scenario is not missed.	For the 6NM true positive and false positive prediction scenarios, the departing aircraft cannot use the planned gap for a departure. For the remaining solution scenarios, the metric does not change compared to the reference scenarios	NOK
Obj.C2	Does the approaching aircraft perform a landing.	If in the solution scenario, an aircraft which lands in the solution scenario also lands.	For the 4NM false positive prediction scenario, the approaching aircraft performs a missed approach, compared to a landing in the reference scenario, therefore	NOK

Co-funded by the European Union

			decreasing the throughput of the operation. For the remaining solution scenarios, the metric does not change, compared to the reference scenarios	

4.2 Detailed analysis of SESAR Solution Validation Results per Validation objective

For each objective, we compare the false positive with the true positive prediction exercise, as defined in Table 75. Note that for each prediction point the precision and recall varies. All precision and recall values are defined in Table 11 and summarized Table 27. The precision defines the ration between true positive and false positive prediction. A precision of 88% means that in case of a go-around prediction, the true positive scenario arises with 88% chance and the false positive with 12%. The recall indicates how many go-arounds are predicted as such and provides a measure on how many go-arounds occur without being predicted. A recall of 34% indicates that if a go-around occurs, 66% of the time it will not be predicted, resulting in a false negative prediction.

Table 27: Airport 2 Precision and Recall

Prediction Point	Precision	Recall
2NM	0.88	0.34
4NM	0.87	0.21
6NM	0.91	0.08

While the precision remains around 87%-90% for all prediction points, the recall values drop with the prediction distance from 34% to only 8%. This originates from the works of WP3 and WP4, resulting to tune the prediction for high precision, in order to reduce the likelihood of false positives, as ATCOs clearly wanted to avoid nuisance alerts. Contrary ATCOs were not too concerned about false negative predictions as these are similar to the state-of-the-art reference scenarios.

For the evaluation of the success criteria of the following ten criteria, we color code the evaluation table column in the following:

- Green: objective met the success criteria (solution scenario performs better than reference scenario)
- Red: objective failed the success criteria (reference scenario performs better than solution scenario)
- No color: solution and reference scenario behave similarly, regarding the metric underlying the objective.

4.2.1 Obj.S1

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.S1, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 28 summarizes the results for the 2NM predictions, Table 29 for the 4NM predictions and Table 30 for the 6NM predictions.

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for S1, the solution at 2NM has no measurable impact w.r.t. Obj.S1.

For the prediction point at 4NM and 6NM, the true positive predictions meet the success criteria for Obj.S1, whereas the false positive predictions do not change the evaluation of Obj.S1.

Table 28: Obj.S1 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	not applicable, since in case of successful landing separation is based on runway separation	not applicable, since in case of successful landing separation is based on runway separation	No change between solution and reference scenario is observed
FP.4	not applicable, since in case of successful landing separation is based on runway separation	not applicable, since in case of successful landing separation is based on runway separation	No change between solution and reference scenario is observed
TP.1	0m	0m	No change between solution and reference scenario is observed
TP.4	78m	85m	A small increase of S1 in the solution scenario is observed, the difference in marginal and will be counted as no change

Table 29: Obj.S1 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	not applicable, since in case of successful landing separation is based on runway separation	1042m	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we measure 1042m of minimum vertical separation. We count this as no change in, since the measured minima is more than three times the applicable minima.
FP.5	in case of successful landing separation is guaranteed by runway separation	horizontal separation is always given, when both aircraft airborne	No change between solution and reference scenario is observed, since horizontal and vertical separation minima are met.

 Co-funded by the European Union

TP.2	0m	1042m	In this exercise, the success criterion is met, since the solution scenario increases the vertical separation by ~1000m.
TP.5	78m	horizontal separation is always given, when both aircraft are airborne.	This exercise fulfills the success criteria. The solution scenario provides better horizontal separation.

Table 30: Obj.S1 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	in case of successful landing separation is guaranteed by runway separation	in case of successful landing separation is guaranteed by runway separation	No change between solution and reference scenario is observed. In the reference scenario and solution scenario, the metric does not apply since runway separation holds.
FP.6	in case of successful landing separation is guaranteed by runway separation	in case of successful landing separation is guaranteed by runway separation	No change between solution and reference scenario is observed. In the reference scenario and solution scenario, the metric does not apply since runway separation holds.
TP.3	0m	1057m	In this exercise, the success criterion is met, since the solution scenario increases the vertical separation by ~1000m.
TP.6	78m	horizontal separation is always given, when both aircraft are airborne.	This exercise fulfills the success criteria. The solution scenario provides better horizontal separation.

4.2.2 Obj.S2

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.S2, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 31 summarizes the results for the 2NM predictions, Table 32 for the 4NM predictions and Table 33 for the 6NM predictions.

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.S2, the solution at 2NM has no measurable impact w.r.t. Obj.S2.

For the prediction point at 4NM and 6NM, the true positive predictions meet the success criteria for Obj.S2, whereas the false positive predictions do not change the evaluation of Obj.S2.

Table 31: Obj.S2 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	not applicable, since in case of successful landing separation is based on runway separation	not applicable, since in case of successful landing separation is based on runway separation	No change between solution and reference scenario is observed
FP.4	not applicable, since in case of successful landing separation is based on runway separation	not applicable, since in case of successful landing separation is based on runway separation	No change between solution and reference scenario is observed
TP.1	2.1NM	2.1NM	No change between solution and reference scenario is observed
TP.4	2.6NM	2.6NM	No change between solution and reference scenario is observed

Table 32: Obj.S2 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	In case of successful landing separation is based on runway separation	Vertical and horizontal separation always kept	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we observe that horizontal and vertical separation minima always are met. We count this as no change.
FP.5	in case of successful landing separation is guaranteed by runway separation	Vertical and horizontal separation always kept	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we observe that horizontal and vertical separation minima always are met. We count this as no change.
TP.2	2.1NM	radar separation is always given, when both aircraft airborne.	In this exercise, the success criterion is met, since the solution scenario increases the horizontal separation.
TP.5	2.6NM	radar separation is always given,	This exercise fulfills the success criteria. The solution scenario provides better horizontal separation.

		when both aircraft airborne	

Table 33: Obj.S2 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	in case of successful landing separation is guaranteed by runway separation	in case of successful landing separation is guaranteed by runway separation	No change between solution and reference scenario is observed. In the reference scenario and solution scenario, the metric does not apply since runway separation holds.
FP.6	in case of successful landing separation is guaranteed by runway separation	in case of successful landing separation is guaranteed by runway separation	No change between solution and reference scenario is observed. In the reference scenario and solution scenario, the metric does not apply since runway separation holds.
TP.3	2.1NM	radar separation is always given, when both aircraft airborne	In this exercise, the success criteria is met, since the solution scenario increases the horizontal separation.
TP.6	2.6NM	radar separation is always given, when both aircraft airborne	This exercise fulfills the success criteria. The solution scenario provides better horizontal separation.

4.2.3 Obj.S3

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.S3, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 34 summarizes the results for the 2NM predictions, Table 35 for the 4NM predictions and Table 36 for the 6NM predictions.

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for S3, the solution at 2NM has no measurable impact w.r.t. Obj.S3.

For the prediction point at 4NM and 6NM, the true positive predictions meet the success criteria for Obj.S3, whereas the false positive predictions do not change the evaluation of Obj.S3.

Table 34: Obj.S3 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	The ATCO must not act immediately to ensure separation.	The ATCO must not act immediately to ensure separation.	No change between solution and reference scenario is observed

FP.4	The ATCO must not act immediately to ensure separation.	The ATCO must not act immediately to ensure separation.	No change between solution and reference scenario is observed
TP.1	The ATCO must act immediately to ensure separation.	The ATCO must act immediately to ensure separation.	No change between solution and reference scenario is observed
TP.4	The ATCO must act immediately to ensure separation.	The ATCO must act immediately to ensure separation.	No change between solution and reference scenario is observed

Table 35: Obj.S3 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	The ATCO must not act immediately to ensure separation.	The ATCO must not act immediately to ensure separation.	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we observe that horizontal and vertical separation minima always are met. We count this as no change.
FP.5	The ATCO must not act immediately to ensure separation.	The ATCO must not act immediately to ensure separation.	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we observe that horizontal and vertical separation minima always are met. We count this as no change.
TP.2	The ATCO *must* act immediately to ensure separation.	The ATCO *must not* act immediately to ensure separation.	In this exercise, the success criterion is met, since the solution scenario the situation w.r.t. separation does not require immediate action.
TP.5	The ATCO *must* act immediately to ensure separation.	The ATCO *must not* act immediately to ensure separation.	In this exercise, the success criterion is met, since the solution scenario the situation w.r.t. separation does not require immediate action.

Table 36: Obj.S3 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	The ATCO must not act immediately to ensure separation.	The ATCO must not act immediately to ensure separation.	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we observe that horizontal and vertical separation minima always are met. We count this as no change.

FP.6	The ATCO must not act immediately to ensure separation.	The ATCO must not act immediately to ensure separation.	In the reference scenario, the metric does not apply since runway separation holds. In the solution scenario, we observe that horizontal and vertical separation minima always are met. We count this as no change.
TP.3	The ATCO *must* act immediately to ensure separation.	The ATCO *must not* act immediately to ensure separation.	In this exercise, the success criterion is met, since the solution scenario the situation w.r.t. separation does not require immediate action.
TP.6	The ATCO *must* act immediately to ensure separation.	The ATCO *must not* act immediately to ensure separation.	In this exercise, the success criterion is met, since the solution scenario the situation w.r.t. separation does not require immediate action.

4.2.4 Obj.S4

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.S4, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 37 summarizes the results for the 2NM predictions, Table 38 for the 4NM predictions and Table 39 for the 6NM predictions. Note that S4 is only applicable to the scenarios with different wake turbulence categories.

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.S4, the solution at 2NM has no measurable impact w.r.t. Obj.S4.

For the prediction point at 4NM and 6NM, the true positive predictions meet the success criteria for Obj.S4, whereas the false positive predictions do not change the evaluation of Obj.S4.

Table 37: Obj.S4 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.4	In case of successful landing separation is based on runway separation, no wake challenge arises.	In case of successful landing separation is based on runway separation, no wake challenge arises.	No change between solution and reference scenario is observed.
TP.4	221m	233m	A minimal increase in the height difference is observed but counted as no change, since the difference between reference and solution is minimal.

Table 38: Obj.S4 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.5	In case of a successful landing separation is based on runway separation, no wake challenge arises.	The trajectories are never in close proximity, no wake challenge arises.	No difference between reference and solution scenario is observed w.r.t. S4
TP.5	221m	The trajectories are never in close proximity, no wake challenge arises.	In this exercise, the success criterion is met. In the reference scenario the missed approach over climbs the trajectory of the departure, whereas in the solution scenario, since the solution scenario, the trajectories of both aircraft can be separated in all 3 dimensions.

Table 39: Obj.S4 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.6	In case of successful landing separation is based on runway separation	The trajectories are never in close proximity, since take-off clearance is given after missed approach overflew the runway. No wake challenge arises.	No difference w.r.t. S4 can be observed, since in both scenarios the approach lands and no proximity of trajectories arises.
TP.6	221m	The trajectories are never in close proximity, since take-off clearance is given after missed approach overflew the runway. No wake challenge arises.	In this exercise, the success criterion is met. In the reference scenario the missed approach over climbs the trajectory of the departure, whereas in the solution scenario, since the solution scenario, the trajectories of both aircraft can be separated in all 3 dimensions.

4.2.5 Obj.S5

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.S5, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 40 summarizes the results for the 2NM predictions, Table 41 for the 4NM predictions and Table 42 for the 6NM predictions. Note that Obj.S5 is only applicable to the scenarios with aircraft of different wake turbulence categories.

For all prediction points (2/4/6NM) none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.S5, the solution at 2NM has no measurable impact w.r.t. Obj.S5.

Table 40: Obj.S5 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.4	No wake turbulence separation arises in the scenario.	No wake turbulence separation arises in the scenario	No change between solution and reference scenario is observed.
TP.4	No wake turbulence separation arises in the scenario	No wake turbulence separation arises in the scenario	No change between solution and reference scenario is observed.

Table 41: Obj.S5 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.5	No wake turbulence separation arises in the scenario.	No wake turbulence separation arises in the scenario	No change between solution and reference scenario is observed.
TP.5	No wake turbulence separation arises in the scenario	No wake turbulence separation arises in the scenario	No change between solution and reference scenario is observed.

Table 42: Obj.S5 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.6	No wake turbulence separation arises in the scenario.	No wake turbulence separation arises in the scenario	No change between solution and reference scenario is observed.
TP.6	No wake turbulence separation arises in the scenario	No wake turbulence separation arises in the scenario	No change between solution and reference scenario is observed.

4.2.6 Obj.R1

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.R1, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 43 summarizes the results for the 2NM predictions, Table 44 for the 4NM predictions and Table 45 for the 6NM predictions.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.R1, the solution at 2NM has no measurable impact w.r.t. Obj.R1.

For the prediction point at 4NM the true positive prediction reduces the coordinative tasks after the initiation of a go-around by 1, whereas the false positive prediction increases coordinative tasks by 2. Given a precision value of 87% at 4NM, on average, the solution reduces the coordinative tasks by $1 * 0{,}87 - 2 * 0{,}13 = \mathbf{0{,}61}$, in case of a prediction.

For the predictions at 6NM, the true positive predictions meet the success criteria for Obj.R1, whereas the false positive predictions do not change the evaluation of Obj.R1. Thus, the tool reduces the average coordinative tasks by $3 * 0{,}91 - 0 * 0{,}09 = \mathbf{2{,}73}$, in case of a prediction.

Table 43: Obj.R1 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	0	0	No change between solution and reference scenario is observed
FP.4	0	0	No change between solution and reference scenario is observed
TP.1	3	3	No change between solution and reference scenario is observed
TP.4	3	3	No change between solution and reference scenario is observed

Table 44: Obj.R1 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	0	2	The solution scenario increases coordinative actions, after the initiation of a go-around. Thus, the success criterion fails.
FP.5	0	2	The solution scenario increases coordinative actions, after the initiation of a go-around. Thus, the success criterion fails.
TP.2	3	2	In this exercise, the success criterion is met, since the solution scenario decreases the coordinative actions, after the initiation of a go-around.
TP.5	3	2	In this exercise, the success criterion is met, since the solution scenario decreases the coordinative actions, after the initiation of a go-around.

Table 45: Obj.R1 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	0	0	No change between solution and reference scenario is observed
FP.6	0	0	No change between solution and reference scenario is observed
TP.3	3	0	In this exercise, the success criterion is met, since the solution scenario decreases the coordinative actions, after the initiation of a go-around.
TP.6	3	0	In this exercise, the success criterion is met, since the solution scenario decreases the coordinative actions, after the initiation of a go-around.

4.2.7 Obj.R2

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.R2, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 46 summarizes the results for the 2NM predictions, Table 47 for the 4NM predictions and Table 48 for the 6NM predictions.

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.R2, the solution at 2NM has no measurable impact w.r.t. Obj.R2.

For the prediction point at 4NM the true positive prediction reduces the coordinative tasks by 2, whereas the false positive prediction does not change the metric. Given a precision value of 87% at 4NM, on average, the solution reduces the coordinative tasks by $2 * 0{,}87 - 1 * 0{,}13 = \mathbf{1{,}61}$, in case of a prediction.

For the predictions at 6NM, the true positive predictions meet the success criteria for Obj.R2, whereas the false positive predictions do not change the evaluation of R2. Thus, the tool reduces the average coordinative tasks by $1 * 0{,}91 - 1 * 0{,}09 = \mathbf{0{,}82}$**,** in case of a prediction.

Table 46: Obj.R2 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	6	6	No change between solution and reference scenario is observed
FP.4	6	6	No change between solution and reference scenario is observed
TP.1	9	9	No change between solution and reference scenario is observed

TP.4	9	9	No change between solution and reference scenario is observed

Table 47: Obj.R2 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	6	7	The solution scenario increases coordinative actions, after the initiation of a go-around. Thus, the success criterion fails.
FP.5	6	7	The solution scenario increases coordinative actions, after the initiation of a go-around. Thus, the success criterion fails.
TP.2	9	7	In this exercise, the success criterion is met, since the solution scenario decreases the overall coordinative actions.
TP.5	9	7	In this exercise, the success criterion is met, since the solution scenario decreases the overall coordinative actions.

Table 48: Obj.R2 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	6	6	No change between solution and reference scenario is observed
FP.6	6	6	No change between solution and reference scenario is observed
TP.3	9	8	In this exercise, the success criterion is met, since the solution scenario decreases the overall coordinative actions.
TP.6	9	8	In this exercise, the success criterion is met, since the solution scenario decreases the overall coordinative actions.

4.2.8 Obj.R3

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.R3, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 49 summarizes the results for the 2NM predictions, Table 50 for the 4NM predictions and Table 51 for the 6NM predictions.

For the prediction point at 2NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.R3, the solution at 2NM has no measurable impact w.r.t. Obj.R3.

For the prediction points at 4NM and 6NM the true positive prediction avoids the unbriefed missed approach procedure, which is flown in the reference scenario, whereas the false positive prediction does not change from reference to solution scenario.

Table 49: Obj.R3 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	No unbriefed missed approach procedure flown in this scenario.	No unbriefed missed approach procedure flown in this scenario	No change between solution and reference scenario is observed
FP.4	No unbriefed missed approach procedure flown in this scenario	No unbriefed missed approach procedure flown in this scenario	No change between solution and reference scenario is observed
TP.1	Unbriefed missed approach procedure flown in this scenario.	Unbriefed missed approach procedure flown in this scenario.	No change between solution and reference scenario is observed
TP.4	Unbriefed missed approach procedure flown in this scenario.	Unbriefed missed approach procedure flown in this scenario.	No change between solution and reference scenario is observed

Table 50: Obj.R3 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	No unbriefed missed approach procedure flown in this scenario	No unbriefed missed approach procedure flown in this scenario	No change between solution and reference scenario is observed
FP.5	No unbriefed missed approach procedure flown in this scenario	No unbriefed missed approach procedure flown in this scenario	No change between solution and reference scenario is observed
TP.2	Unbriefed missed approach procedure flown in this scenario.	No unbriefed missed approach procedure flown in this scenario	In this exercise, the success criterion is met, since in the solution scenario no unbriefed missed approach procedure is flown, whereas in the reference scenario an unbriefed missed approach procedure is flown.
TP.5	Unbriefed missed approach	No unbriefed missed approach	In this exercise, the success criterion is met, since in the solution scenario no unbriefed missed approach procedure is flown,

	procedure flown in this scenario.	procedure flown in this scenario	whereas in the reference scenario an unbriefed missed approach procedure is flown.

Table 51: Obj.R3 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	No unbriefed missed approach procedure flown in this scenario	No unbriefed missed approach procedure flown in this scenario	No change between solution and reference scenario is observed
FP.6	No unbriefed missed approach procedure flown in this scenario	No unbriefed missed approach procedure flown in this scenario	No change between solution and reference scenario is observed
TP.3	Unbriefed missed approach procedure flown in this scenario.	No unbriefed missed approach procedure flown in this scenario	In this exercise, the success criterion is met, since in the solution scenario no unbriefed missed approach procedure is flown, whereas in the reference scenario an unbriefed missed approach procedure is flown.
TP.6	Unbriefed missed approach procedure flown in this scenario.	8No unbriefed missed approach procedure flown in this scenario	In this exercise, the success criterion is met, since in the solution scenario no unbriefed missed approach procedure is flown, whereas in the reference scenario an unbriefed missed approach procedure is flown.

4.2.9 Obj.C1

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.C1, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 52 summarizes the results for the 2NM predictions, Table 53 for the 4NM predictions and Table 54 for the 6NM predictions.

For the prediction point at 2NM and 4NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.C1, the solution at 2NM and 4NM has no measurable impact w.r.t. Obj.C1.

For the prediction points at 6NM the true positive prediction always misses a gap for the planned departure, compared to the reference scenario, decreasing the capacity in the scenario.

Table 52: Obj.C1 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria

FP.1	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed
FP.4	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed
TP.1	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed
TP.4	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed

Table 53: Obj.C1 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed
FP.5	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed
TP.2	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed
TP.5	Planned gap is used for departure.	Planned gap is used for departure.	No change between solution and reference scenario is observed

Table 54: Obj.C1 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	Planned gap is used for departure.	Planned gap is **missed** for departure.	In this exercise, the gap which is planned for the departure aircraft is missed in the solution scenario but used in the reference scenario. Therefore, the success criterion fails.
FP.6	Planned gap is used for departure.	Planned gap is **missed** for departure.	In this exercise, the gap which is planned for the departure aircraft is missed in the solution scenario, but used in the reference scenario. Therefore, the success criterion fails.
TP.3	Planned gap is used for departure.	Planned gap is **missed** for departure.	In this exercise, the gap which is planned for the departure aircraft is missed in the solution scenario, but used in the reference scenario. Therefore, the success criterion fails.
TP.6	Planned gap is used for departure.	Planned gap is **missed** for departure.	In this exercise, the gap which is planned for the departure aircraft is missed in the solution scenario, but used in the reference scenario. Therefore, the success criterion fails.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

4.2.10 Obj.C2

In the following section, we provide the results false positive and true positive exercises w.r.t. Obj.C2, for each prediction point. Finally, we compare the false positive and true positive outcomes. Table 55 summarizes the results for the 2NM predictions, Table 56 for the 4NM predictions and Table 57 for the 6NM predictions.

For the prediction point at 2NM and 6NM none of the Solution Scenarios changes in a positive or negative way, indicating that for Obj.C2, the solution at 2NM and 6NM has no measurable impact w.r.t. Obj.C2.

For the prediction points at 4NM the false positive prediction causes the approach to perform a missed approach instead of a landing in the reference scenario, thereby decreasing the capacity in the scenario.

Table 55: Obj.C2 Evaluation for 2NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.1	Approach successfully landed.	Approach successfully landed.	No change between solution and reference scenario is observed
FP.4	Approach successfully landed.	Approach successfully landed.	No change between solution and reference scenario is observed
TP.1	Approach performed missed approach.	Approach performed missed approach.	No change between solution and reference scenario is observed
TP.4	Approach performed missed approach.	Approach performed missed approach.	No change between solution and reference scenario is observed

Table 56: Obj.C2 Evaluation for 4NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.2	Approach successfully landed.	Approach performed missed approach.	In the solution scenario, the approach performs a missed approach, whereas in the reference scenario, the approach lands. Thus, the success criterion fails.
FP.5	Approach successfully landed.	Approach performed missed approach.	In the solution scenario, the approach performs a missed approach, whereas in the reference scenario, the approach lands. Thus, the success criterion fails.
TP.2	Approach performed missed approach.	Approach performed missed approach.	No change between solution and reference scenario is observed

TP.5	Approach performed missed approach.	Approach performed missed approach.	No change between solution and reference scenario is observed

Table 57: Obj.C2 Evaluation for 6NM Prediction Point

Exercise ID	Reference Scenario Result	Solution Scenario Result	Evaluation of Success Criteria
FP.3	Approach successfully landed.	Approach successfully landed.	No change between solution and reference scenario is observed
FP.6	Approach successfully landed.	Approach successfully landed.	No change between solution and reference scenario is observed
TP.3	Approach performed missed approach.	Approach performed missed approach.	No change between solution and reference scenario is observed
TP.6	Approach performed missed approach.	Approach performed missed approach.	No change between solution and reference scenario is observed

4.3 Confidence in Validation Results

This exercise is at the very beginning of the investigation of the solution. The goal was to approve or disapprove the general findings from D2.1 [3] and D3.2 by simulating a real-world example of the described mixed mode runway operation in section 3.1.1. Following the summary of the results in section 4.1, we conclude that there is a good overlap between the expectations documented in D2.1 [3] as well as the general results obtained in D3.2 based on the semi-quantitative work on the Accident Incident Models, and the findings of this exercise. We therefore conclude that the work presented in D2.1 [3] and D3.2 is supported by the results of this simulation exercise.

The use cases and potential benefits for a decision support tool, which were documented in D2.1 [3] based on workshops with ATCOs before the simulation exercise and the expected impacts stated in D2.1 [3] were demonstrated with the simulation environment.

The simulations demonstrate, for the given scenario, that ATCOs are willing to include predictive, probabilistic information in their decision making. Also, the simulations demonstrate that even if the information is probabilistic and potential false predictions must be considered, a safety benefit can be achieved.

Furthermore, the activities for this deliverable investigated and demonstrated the negative impacts of the proposed concept. This allows a fair discussion on the benefits vs. costs, which must be part of the next steps for this work.

4.3.1 Limitations of Validation Results

The exercises performed for this deliverable are however limited in several ways:

EUROPEAN PARTNERSHIP

Co-funded by the European Union

1. The performed exercise only considers two types of wake turbulence category aircraft. A medium and heavy type. While these aircraft certainly make up for a vast amount of traffic, light or super light aircraft have not been considered so far.

2. The aircraft models for the simulations have been initialized with identical parameters for weight, approach speed, flap settings, reaction times etc. Variations in these parameters have an impact on the separation metrics. Therefore, the results must be interpreted as indications of the impact, the go-around prediction tool can have on the tower operation. An investigation over a wide range of parameter settings would be desirable, however for time reasons, this cannot be performed with humans in the loop. A future investigation therefore has to use the obtained strategies from the ATCOs and implement them, together with the simulation environment build for these exercises, in a Monte Carlo type simulation, to allow a statistical investigation over a broader input space of operational conditions.

3. For our experiments in this deliverable, we could work with five Tower Controllers. They all agreed on the strategies in the reference and solution scenarios. For upcoming investigations, a larger number of ATCOs should invited and the selection of ATCOs.

4. The investigated scenarios assumed dense traffic patterns as well as IMC conditions. Furthermore, the investigated safety relevant factors arise from conflicting missed approach and departure procedures. In VMC conditions, the ATCOs stated that they rather ensure separation based on reduced, visual separation minima. In case the traffic is not dense, the safety relevant knock-on effects, investigated in this exercise, might not be applicable, since the sector for the missed approach is not used by a departing aircraft. Therefore, the relevance of the result depends on the airport under investigation.

    a. While at hubs, dense traffic occurs very frequently, less densely trafficked airports might not benefit in the same way from a prediction tool for go-arounds.

    b. Similarly, airports that operate under VMC conditions most of the time, might not have the need for a decision support tool in the go-around domain.

    c. Lastly, it is dependent on the airport layout and geographical factors, if conflicting departure and missed approach procedures exist at an airport. While for the two investigated airports in D2.1 [3], we found several of these conflicts, there might be airports where the geographical factors are such that these conflicts can be completely avoided by procedure design.

4.3.2 Quality of Validation Results

In general, we believe that the demonstrated results are of excellent quality, given the stage of the project. The aircraft models used for the simulation are designed according to state-of-the-art procedures. ATCOs also rated the aircraft model performance as very realistic and the visualization tool for the radar screen imitation as sufficiently good for the intended purpose.

However, considering points 1 and 2 of 4.3.1 and the limited range of demonstrated operational conditions investigated in this simulation exercise, certainly limits the generality of the results. The simulated scenarios were chosen as important cases in typical operational conditions, however statistical investigations are necessary to further support the results and demonstrate their validity over a wider range of the operational spectrum.

4.3.3 Significance of Validation Results

See point 1 and 2 from 4.3.1.

5 Conclusions and recommendations

5.1 Conclusions

This section provides conclusions based on the performed validation exercise.

5.1.1 Conclusions on SESAR Solution maturity

In this section, the TRL self-assessment is documented. The coding is as follows:

- Green →has been done
- Red → not foreseen in the current project

The final maturity assessment is planned for the 29th November 2022 at the SJU in Brussel. The following tables shall be understood as a self-assessment from the 30st September, when this deliverable was handed in and serve as a bases for discussions at the maturity gate. The final projects results report will provide the final maturity assessment, performed together with the SJU.

5.1.1.1 TRL1

Criteria ID	Criteria	Where?
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	D2.1 [3] initially defined potential use cases, as well as a technical problem statement for the SafeOPS solution. In D2.1 [3] several real-world scenarios describe the challenge that arise from conflicting departure and missed approach routes. These challenges are situations which need immediate attention and action from the controller to ensure radar and or wake separation. For both investigated airports in SafeOPS, conflicting missed approach and departure routes could be identified.
TRL-1.2	Have the solutions (concepts/capabilities/methodologies) under research been defined and described?	An initial solution concept has been outlined in D2.1 [3]. With the results of WP3 and WP4, section 3.1 further specifies the solution concept.
TRL-1.3	Have assumptions applicable for the innovative concept/technology been documented?	Initial assumptions have been documented in D2.1 [3]. An updated

		set of assumptions is documented in section 3.2.3 of this deliverable.
TRL-1.4	Have the research hypothesis been formulated and documented?	An initial set of research questions was defined in the DoA. The current set of research questions is defined in the Experimental Plan and also documented in Appendix A.1.2.
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?	D4.1 [6] and D4.2 [7] investigated AI-based go-around predictions. Based on these results, this deliverable indicates the potential for the AI-based decision support. The technical implementation of D4.1 [6] and D4.2 [7] is still simplified. Suggestions on the next steps have been made in this deliverable.
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.	D3.2 [4] set up a risk framework, which based on D2.1 [3] identified benefits and risk of the proposed solution on a semi-qualitative way. With the simulations performed in this deliverable, these risks and benefits could be backed up quantitatively, however the limitations of the simulation exercises defined in section 4.3.1 must be taken into account 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.	See box above. Additionally, assumptions and limitations have been documented in sections 3.2.3 and 4.3.1 of this document.
TRL-1.8	Do fundamental research results show contribution to the Programme strategic objectives e.g. performance ambitions identified at the ATM MP Level?	The KPA relevant to SafeOPS are identified in this deliverable / Experimental Plan. A contribution to safety and resilience is expected.
TRL-1.9	Have stakeholders been identified, consulted and involved in the assessment of the results?. Has their feedback been documented in project	DFS, PGS and Iberia are part of the consortium and thus continually involved in everything that is done in SafeOPS. Additionally, Associated

	deliverables? Have stakeholders shown their interest on the proposed solution?	Partner Workshops are 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)?	Work of D4.1 [6] and D4.2 [7] has been published at DASC 2022. The work done in this deliverable will be presented at the EASN 2022, end of October.
TRL-1.11	Are recommendations for further scientific research documented?	Recommendations are documented in this deliverable.

5.1.1.2 TRL 2

Table 58: TRL 2 Criteria and self-assessment

Thread	Criteria ID	Criteria	Where?
OPS	OPS.ER.1	Has a potential new idea or concept been identified that employs a new scientific fact/principle?	The SafeOPS solution concept has been initially identified in D2.1 [3]. The underlying scientific principle of AI-based go-around predictions has been documented in D4.1 [6] and D4.2 [7] as well as in a publication at DASC2022. Taking into account the work of D3.2 [4], D4.1 [6] and D4.2 [7] this document updated the solution concept in section 3.1
OPS	OPS.ER.2	Have the basic scientific principles underpinning the idea/concept been identified?	The underpinning idea of AI-based go-around predictions has been documented in D4.1 [6] and D4.2 [7] and has been published at DASC 2022
OPS	OPS.ER.3	Does the analysis of the "state of the art" show that the new concept / idea / technology fills a need?	In D2.1 [3] several real-world scenarios are defined, indicating that confliction missed approach and departure routes can create separation challenges. These conflicts arise from limitations in the airport procedure design, because of e.g. geographical or noise abatement limitations. These challenges are tackled by the proposed concept.

OPS	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?	The concept has been described in section 3.1. The concept does not propose a potential new capability but aims to increase safety and resilience at the Tower Control.
OPS	OPS.ER.5	Are the relevant stakeholders and their expectations identified?	The Stakeholders (DFS/Iberia/Pegasus) are part of the consortium. Their expectations has been the basis of the work done in D2.1 [3].
OPS	OPS.ER.6	Are there potential (sub)operating environments identified where, if deployed, the concept would bring performance benefits?	The Tower Control and especially the approach and go-around handling have been identified as the targeted operation environment in D2.1 [3] and also in this deliverable.
SYS	SYS.ER.1	Has the potential impact of the concept/idea on the target architecture been identified and described?	This was briefly discussed in D2.1 [3] from the perspective which tools should provide the additional information and D3.3 [5] detailed the Human Factors aspects. However, a targeted investigation still has to be performed.
SYS	SYS.ER.2	Have automation needs e.g. tools required to support the concept/idea been identified and described?	This has been elaborated in D4.1 [6] from the IT Infrastructure perspective. Tools to implement the solution have been discussed in D2.1 [3].
SYS	SYS.ER.3	Have initial functional requirements been documented?	D2.1 [3] provides an initial set of functional requirements. As proposed in this document, a set of further requirements must be worked out, taking into account the new EASA guidelines on AI in aviation.
PER & CBA	PER.ER.1	Has a feasibility study been performed to confirm the potential feasibility and usefulness of the new concept / idea / Technology being identified?	This deliverable provides a study for usefulness. A study regarding feasibility, especially on how to incorporate additional information on the radar screens has not been performed so far.
PER & CBA	PER.ER.2	Is there a documented analysis and description of the benefit and costs mechanisms and associated Influence Factors?	This deliverable documents potential benefits, especially regarding safety and resilience. Cost mechanism and associated influential factors have not been investigated.

PER & CBA	PER.ER.3	Has an initial cost / benefit assessment been produced?	TBD
PER & CBA	PER.ER.4	Have the conceptual safety benefits and risks been identified?	The risk framework in D3.2 [4]analyzes the safety benefits and risk on a general level for AI-based predictive tools. This has also been investigated quantitatively in this deliverable for the scenario defined in section 3.1.1.
PER & CBA	PER.ER.5	Have the conceptual security risks and benefits been identified?	TBD
PER & CBA	PER.ER.6	Have the conceptual environmental impacts been identified?	TBD
PER & CBA	PER.ER.7	Have the conceptual Human Performance aspects been identified?	D3.3 [5] identified Human Performance aspects for AI-based decision support in ATM. It also provides a guideline for further tasks, when the maturity of the concept progresses.
VAL	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.*	Regarding the predictive part, this deliverable states the next relevant R&D needs and also material that provides guidance therefor.
TRA	TRA.ER.1	Are there recommendations proposed for completing V1 (TRL-2)?	To this point in time not considered

5.1.2 Conclusions on concept clarification

Section 3.1 describes the current status of the SafeOPS concept. This concept description includes an operational and technical layer. The operational layer describes identified use cases including possible new strategies, the ATCOs could use when handling go-arounds, as well as an initial assessment of expected operational impacts on safety and resilience. With this deliverable, a list of assumptions and limiting factors is added to the concept.

5.1.3 Conclusions on technical feasibility

The predictive layer describes the underlying technical principles, necessary for the concept realization. It provides initial results on achievable accuracies for the machine learning predictions. These results have been achieved in an offline setting. Even though, the computation of the predictions, given the input data is available, can be produced in an online manner, the data pre-processing for the model input has to be performed in an online fashion. An overall online capable go-around prediction is therefore the next step which has to be demonstrated. The difficulty of this task will depend on the available raw data source and quality. Therefore, it would be desirable to implement a go-around prediction tool, using radar data from an ANSP, to understand the necessary pre-processing work and computational demand.

Another input for further technical requirements, regarding the necessary precision of the prediction might stem from a cost estimation for the concept, which includes possible revenue losses from reduced capacity. If a number of acceptable revenue loss can be generated as trade-off for a demonstrated safety increase, the minimum necessary precision for the machine learning algorithm could be quantified and defined as requirement.

5.1.4 Conclusions on performance assessments

In summary, the simulation exercise has shown for the described scenario in section 3.1.1, that the presented SafeOPS concept can, in case of true positive predictions, increase the safety by preventing challenging situations regarding separation, and reduce overall, as well as, peak workload of the Tower Controller. For the 6NM prediction cases, the ATCOs proposed strategies which also reduce capacity to gain safety, by not using a gap for a departure. On the contrary, for false positive predictions, the SafeOPS concept reduces the capacity and can result in higher workloads but has no negative effect on safety. How much weight has to be put on the true positive results and the false positive results, depends on the precision of the used AI-tool for the go-around prediction. The currently achieved precision by D4.1, is between 87%-91%, meaning that for every false positive prediction there are 8-9 true positive predictions.

A question that arises from the capacity versus safety and resilience trade-off, is how high the precision needs to be, for the solution concept to be acceptable, from an ANSP perspective. ANSPs' revenue in parts depends on the number of movements. Therefore, implementing a solution which negatively impacts capacity requires good arguments. In favor of safety, one could always generally reduce movements, this is not the point taken here. However, the presented concept and the underlying go-around prediction might provide new information to evaluate in a situation, when exactly it would be beneficial to reduce the movements by one departure, to increase safety. Regarding the safety considerations, this deliverable provides initial insights. What is missing to evaluate the trade of is a cost estimation, including the potential revenue loss, which is not in the scope of this project

5.2 Recommendations

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 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 [3] and validated them with this deliverable. Nevertheless, the limitations documented in 3.5.1 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 this deliverable have to be demonstrated on a wider operational spectrum. Monte Carlo based statistical investigations have to be developed for the demonstrated use cases, and potential new use cases 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 [3] 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 [13], unfortunately after this project developed its requirements. A future project should consider this document and if possible, also be in contact with EASA and Euro control, who contributed to these guidelines.

6 References

[1] SESAR, „Introduction to SESAR Maturity Criteria," 2018. [Online]. Available: https://ec.europa.eu/research/participants/data/ref/h2020/other/guides_for_applicants/h2020-sesar-er4-26-2019_intro-maturity-criteria_en.pdf. [Zugriff am 30 09 2022].

[2] Eurocontrol, „European Operational Concept Validation Methodology V3," 2018. [Online]. Available: https://www.eurocontrol.int/sites/default/files/2019-08/e-ocvm-version-3.0-volume-1.pdf.

[3] L. Beller, M. Pfahler, J. Hartl, P. Kurth, S. Rangger, P. Hernandez und C. Abate, „SafeOPS - Development of Use Cases, User Stories and Requirements," 2021. [Online]. Available: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5e0f1c687&appId=PPGMS. [Zugriff am 14 02 2022].

[4] C. Abate und E. Humm, „SafeOPS - Integrated Risk Framework," 15 07 2022. [Online]. Available: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5eedd8d00&appId=PPGMS. [Zugriff am 30 09 2022].

[5] E. Humm und C. Abate, „SafeOPS - Human Factors Analyses of the Impact of Providing Probabilistic Risk Information in Real Time," 27 05 2022. [Online]. Available: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5ecb7a660&appId=PPGMS. [Zugriff am 2022 09 30].

[6] P. Hernandez, L. Beller, P. Koppitz und C. Argerich, „SafeOPS - Complete Data Pipeline Description and Machine Learning Solution," 18 05 2022. [Online]. Available: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5ec5dac75&appId=PPGMS. [Zugriff am 30 09 2022].

[7] P. Hernandez, C. Argerich und L. Beller, „SafeOPS - Human Interpretability Framework for the Selected User Stories," 10 08 2022. [Online]. Available: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5efe602ee&appId=PPGMS. [Zugriff am 30 09 2022].

[8] J. Sun, „The 1090 Megahertz Riddle: A Guide to Decoding Mode S and ADS-B Signals," 2021. [Online]. Available: https://mode-s.org/decode/book-the_1090mhz_riddle-junzi_sun.pdf. [Zugriff am 30 09 2022].

[9] B. Rabiller, N. Fota und L. Carbo, „SESAR Safety Reference Material," SESAR Joint Undertaking, 2018.

[10] B. Rabiller, N. Fota und L. Carbo, „Guidance to Apply SESAR Safety Reference Material," SESAR Joint Undertaking, 2018.

[11] SESAR, „SESAR 2020 Experimental Approach Guidance ER," 2020.

[12] E. P. Chauvin, B. Josefsson, M. Branlat, M. Everdij, S. Stroeve und T. Laursen, „Resilience Engineering Guidance," SESAR Joint Undertaking, 2016.

[13] EASA, „EASA Concept Paper: First Usable Guidance for Level 1 Machine Learning Applications," 15 2021. [Online]. Available: https://www.easa.europa.eu/en/downloads/134357/en. [Zugriff am 30 09 2022].

[14] J.-M. Cordero, I. Garcia-Ovies, C. Verdonk-Gallego, L. Sanchez-Palomo und A. Bujor, „Performance Framework," SESAR Joint Undertaking, 2019.

[15] Wikimedia Commons, *Shows the ECEF coordinates (x, y, z) of a point on the surface of a spheroid.*

[16] P. H. Zipfel, Modeling and simulation of aerospace vehicle dynamics, Third edition Hrsg., Reston Virginia: American Institute of Aeronautics and Astronautics Inc, 2014, pp. xxviii, 661 pages.

[17] André Deperrois, *XFLR5,* 2003.

[18] M. Drela, „XFOIL: An Analysis and Design System for Low Reynolds Number Airfoils," in *Low Reynolds Number Aerodynamics*, Springer, Berlin, Heidelberg, 1989, p. 1–12.

[19] M. Ahmad, Z. L. Hussain, S. I. A. Shah und T. A. Shams, „Estimation of Stability Parameters for Wide Body Aircraft Using Computational Techniques," *Applied Sciences,* Bd. 11, Nr. 5, p. 2087, 2021.

[20] AIRBUS S.A.S., „A318/A319/A320/A321 AIRCRAFT RECOVERY MANUAL," 2018. [Online]. Available: https://caisatech.net/uploads/XXI_3_AIRBUS_H51_A320_O_ARM_R2_1JUL2009.pdf. [Zugriff am 16 9 2022].

[21] AIRBUS S.A.S., „A320 AIRCRAFT CHARACTERISTICS AIRPORT AND MAINTENANCE PLANNING," 1985. [Online]. Available: https://www.airbus.com/sites/g/files/jlcbta136/files/2021-11/Airbus-Commercial-Aircraft-AC-A320.pdf. [Zugriff am 16 9 2022].

[22] E. Coetzee, „Modelling and nonlinear analysis of aircraft ground manoeuvres [electronic resource]," University of Bristol, 2011.

[23] E. Obert und R. Slingerland, Aerodynamic design of transport aircraft, Amsterdam; [Delft]: Ios Press;Delft University of Technology, Faculty of Aerospace Engineering, Section Design of Aircraft and Rotorcraft, 2009, p. 638.

[24] S. Gudmundsson, General aviation aircraft design, 1st ed. Hrsg., Amsterdam: Elsevier, Butterworth-Heinemann, 2014, p. 1 online resource.

[25] J. Roskam, Airplane design, Lawrence, Kan.: DARcorporation, 2018, p. 550.

[26] McDonnell Douglas Corporation und Wright-Patterson Air Force Base, „USAF (United States Air Force) Stability and Control DATCOM (Data Compendium),“ 1978. [Online]. Available: https://archive.org/details/DTIC_ADB072483/page/n9/mode/2up. [Zugriff am 16 9 2022].

[27] C. E. Lan und J. Roskam, Airplane aerodynamics and performance, Revised edition Hrsg., Lawrence, Kan.: DARcorporation, 1997, p. 711.

[28] P. M. Sforza, Commercial airplane design principles, First edition Hrsg., Amsterdam;Butterworth-Heinemann is an imprint of Elsevier, 2014, p. 598.

[29] EUROCONTROL, „Aircraft Noise and Performance (ANP) Database,“ 2006. [Online]. Available: https://www.aircraftnoisemodel.org/.

[30] Google Bilder © 2022 GeoBasis-DE/BKG,GeoContent,Maxar Technologies,Kartendaten © 2022 GeoBasis-DE/BKG (©2009), „Google Maps,“ [Online]. Available: https://www.google.de/maps/@48.3454869,11.77168,2940m/data=!3m1!1e3. [Zugriff am 30 09 2022].

[31] DFS Deutsche Flugsicherung GmbH, „DFS AIP,“ [Online]. Available: https://aip.dfs.de/BasicIFR/pages/C004BD.html. [Zugriff am 30 09 2022].

Appendix A Validation Exercise #01 Report

A.1 Summary of the Validation Exercise #01 Plan

SafeOPS has no contractual Experimental Plan deliverable. An Experimental Plan has been submitted to the SJU in T0+14 but was not published until now. We therefore provide an extensive summary in the following, to make sense of this deliverable.

A.1.1 Validation Exercise description

In D2.1 [3], 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 [3] are, that a solution, as now further defined in section 3.1.1 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 [4], an operational risk assessment is presented for the solution described in section 3.1.3. Section 2.2 of D3.2 [4] 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 [4] 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 [4] 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 [4], 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 [4] and the expectations of D2.1 [3] with quantitative metrics. Therefore, based on the use case described in section 3.1.1 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.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

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 B.

Execution of the Exercise

From the initial situation, illustrated in Figure 10, 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 B.1.3 and B.2.3.

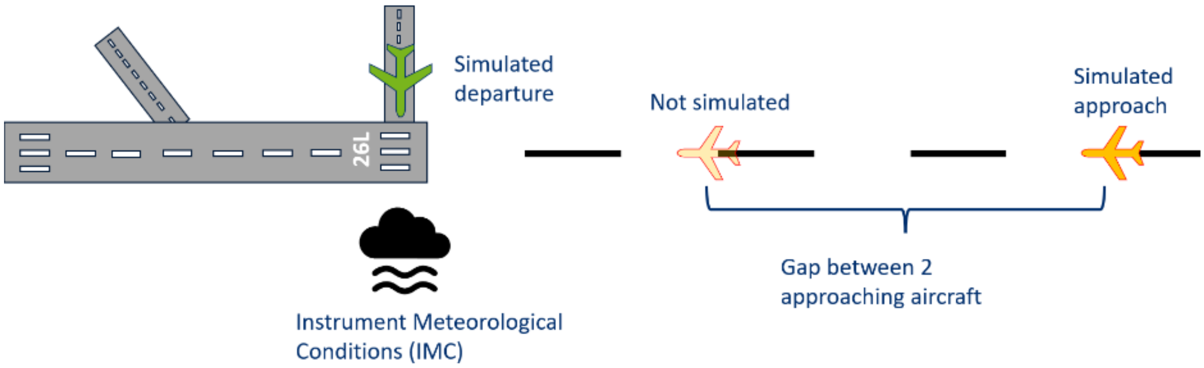


Figure 10: Initial conditions of the simulation

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 B.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 11.

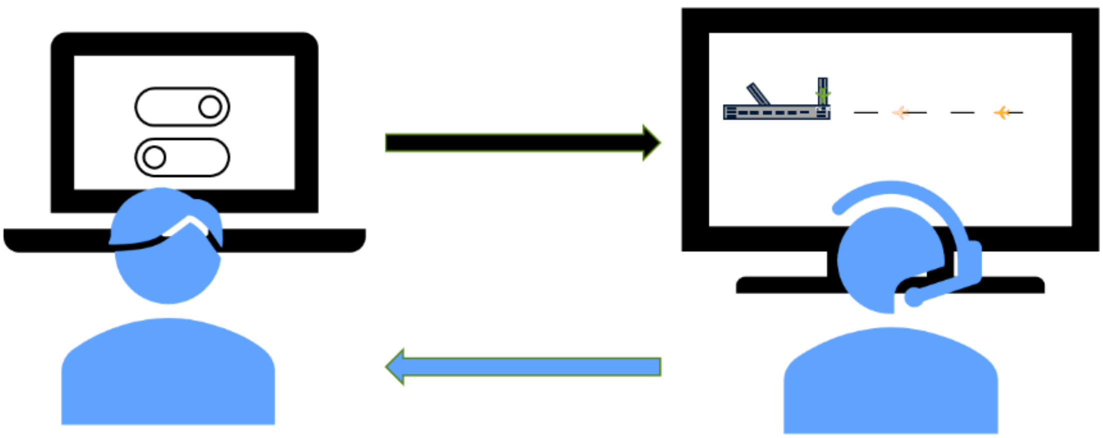


Figure 11: Illustration of simulation setup, simulation operator and Tower Controller

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 59 illustrates an excerpt of a data set.

Table 59: 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 [3] . A toy example is provided in Figure 12.

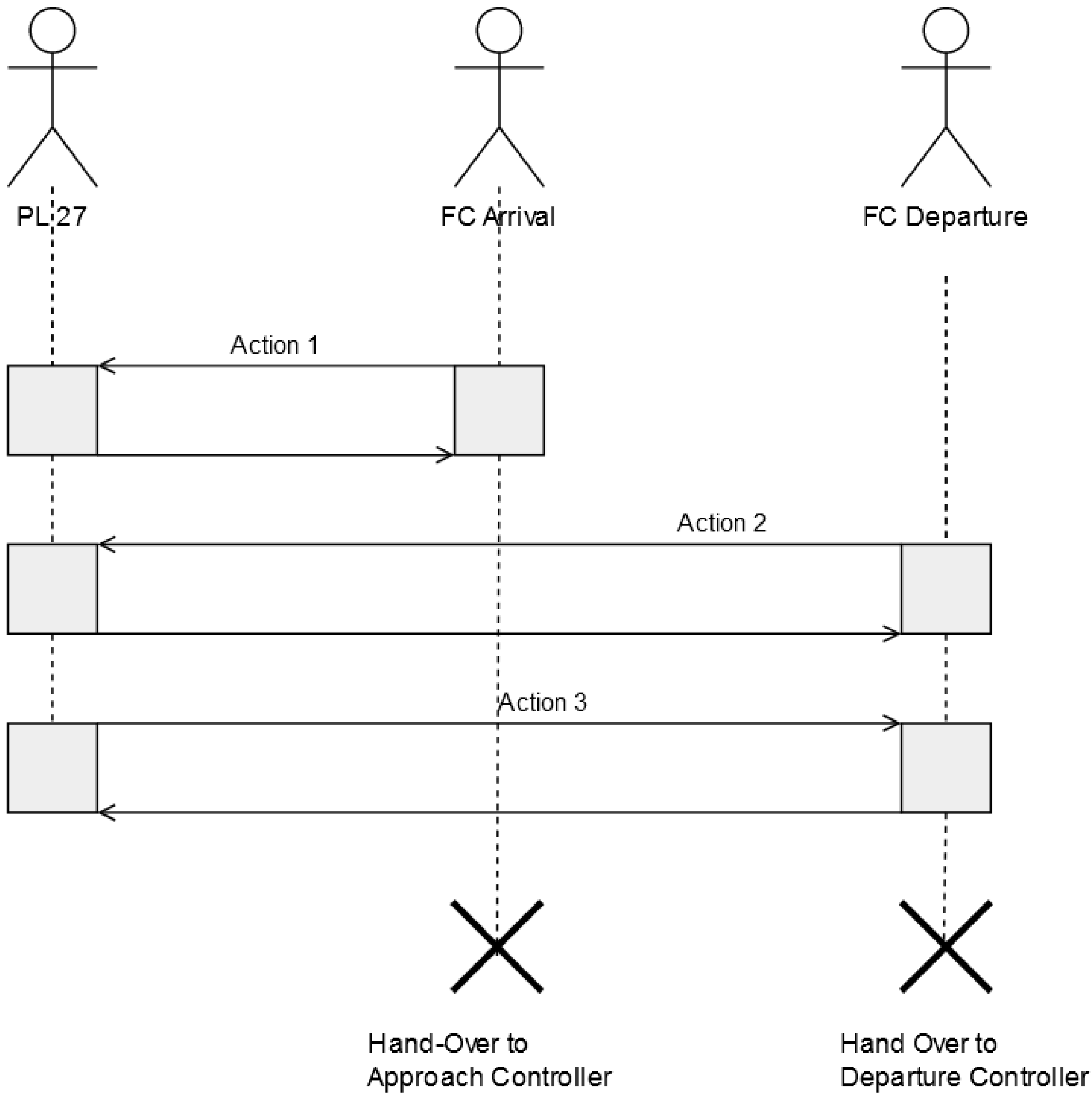


Figure 12: Illustration of a sequence diagram, used to visualize the actions of the Tower Controller during the simulation

A.1.2 Summary of Validation Exercise #01 Validation Objectives and success criteria

The high-level research questions for the SafeOPS concept are described in Table 2 in the main document. 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 [14]:

- **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 60: 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 61: 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 62: 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 13 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 63: 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.

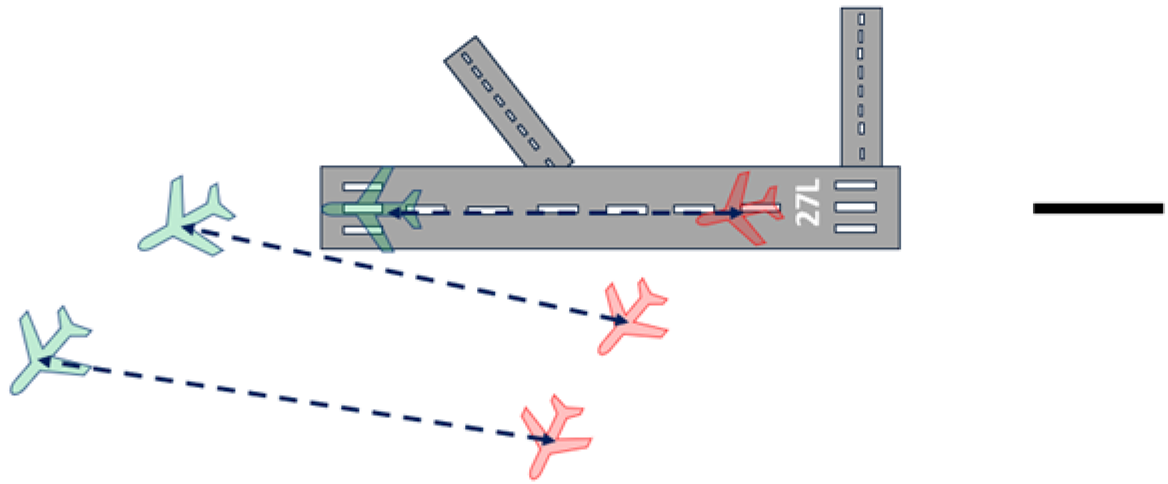


Figure 13: Illustration of the horizontal radar separation metric

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 14 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 64 and Table 65 document the two metrics regarding wake separation.

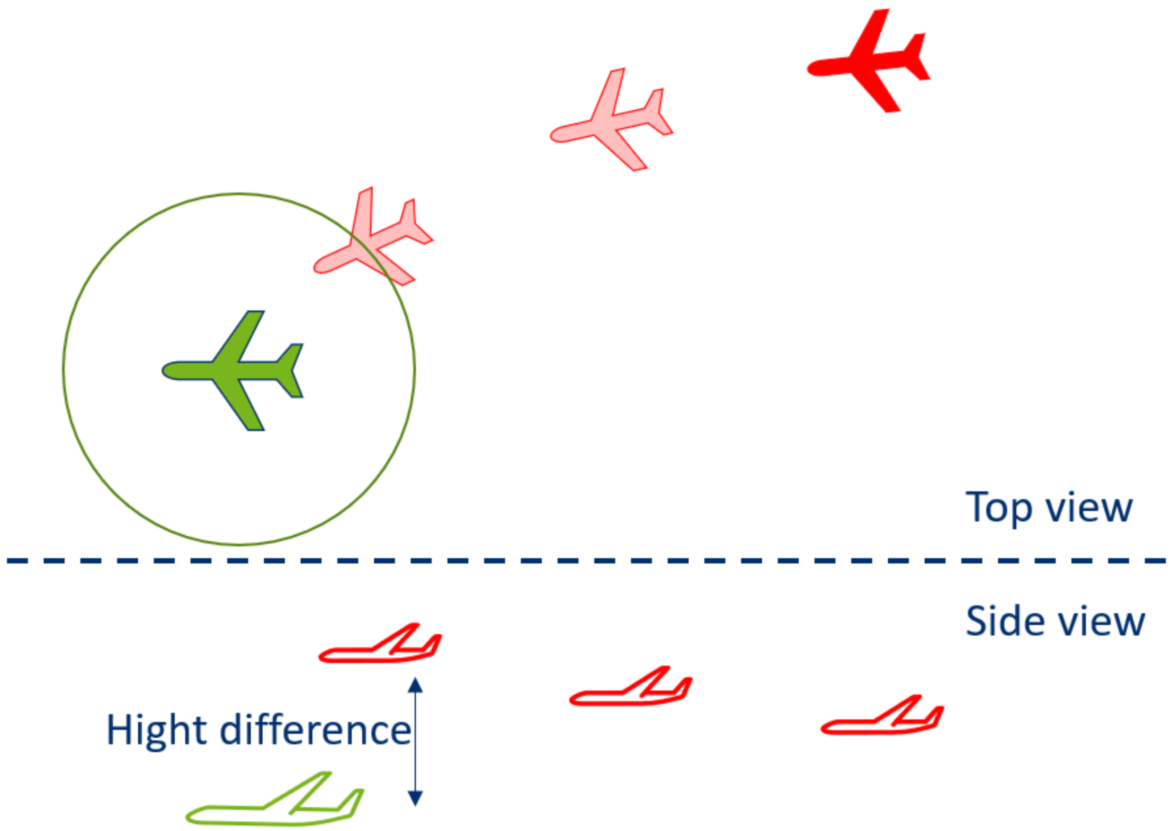


Figure 14: Illustration of the Wake Separation Metric

Table 64: 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 65: 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 66: 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 [3]and are considered a resilience metric, following the arguments from D2.1 [3] - 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 67: 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 68: 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 69: 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 70: 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 71: 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 72: 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.

A.1.3 Summary of Validation Exercise #01 Validation scenarios

Based on the generalized scenario, presented in the solution description in section 3.1.1 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 15. As was discussed in 3.1.1, 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.

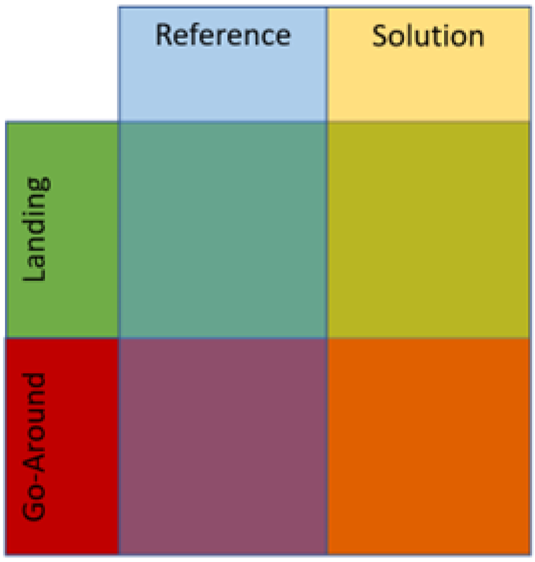


Figure 15: Illustration of different sub-scenarios for the validation exercise

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 10 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 73. 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 73: 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 74: 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 75 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 75: 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

A.1.4 Summary of Validation Exercise #01 Validation Assumptions

These are defined in section 3.2.3 in the main document.

A.2 Validation Exercise #01 Results

A.2.1 Summary of Validation Exercise #01 Results

The summary is presented in the main document in section 4.1, and is not repeated in the appendix.

A.2.2 Detailed Simulation Results for Exercise #01

This section provides details for every performed simulation. Therefore, we list the simulation configuration that defines the initial conditions for the simulation, the sequence of actions of the ATCO which defines the evolution of the simulation, the resulting visualization of the trajectories of the simulated aircraft and the evaluated metrics for the simulation.

1. Reference Scenarios Landing

a. RS.Landing.1

Simulation Configurations

In this scenario, the departure aircraft is configured according to Table 76.

Table 76: 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 77, indicating that no prediction tool is available and the aircraft is performing a landing.

Table 77: 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 requested from ATCO earlier.**	**Missed approach predicted at xxNM 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.

Sequence of Actions

The sequence of actions, the controller took during the simulation of RS.Landing.1 are documented in a sequence diagram, illustrated in Figure 17.

Visualization

Figure 16 visualizes the trajectories of the two aircraft in the simulation. The approaching aircraft is illustrated by the yellow line, the departing aircraft is illustrated by the dark blue line. Additionally, the relative positions of the approaching aircraft, when the departing aircraft gets cleared for line-up and take-off, as well as when the departure actually takes off, are illustrated by the cyan colored vertical lines.

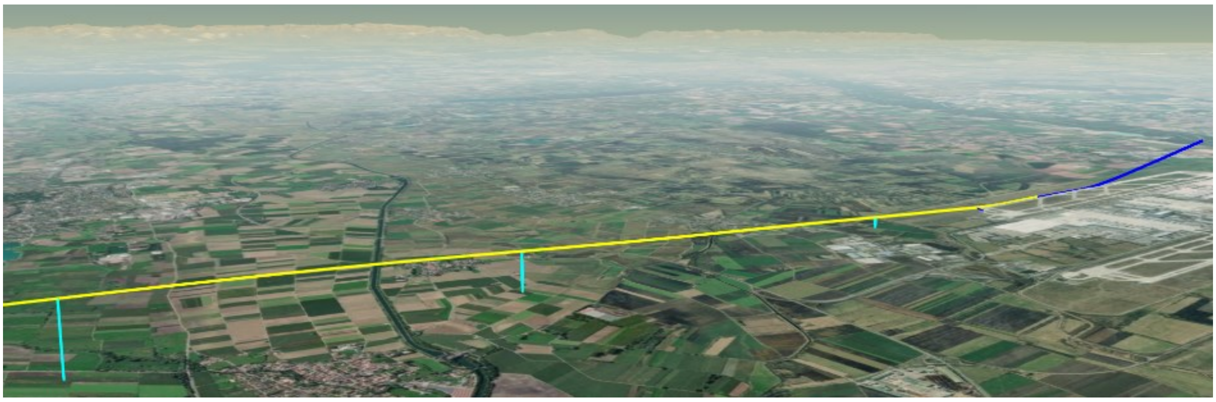


Figure 16: Visualization of RS.Landing.1

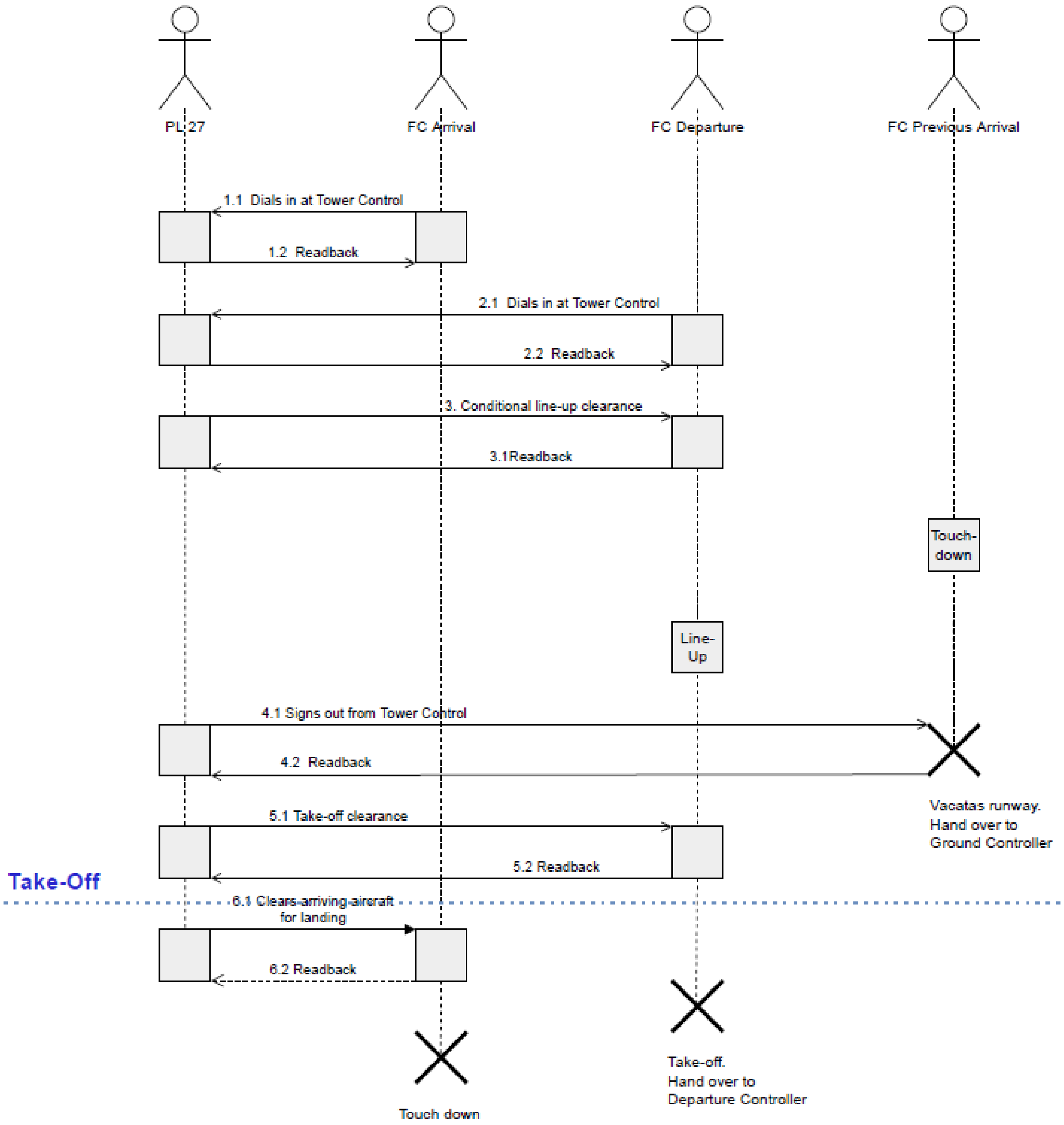


Figure 17: Sequence Diagram RS.Landing.1

Metrics

The defined metrics are summarized in Table 78.

Table 78: Metric Evaluation for RS.Landing.1

Metric	Description	Evaluation

S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable, since in case of successful landing separation is based on runway separation
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable, since in case of successful landing separation is based on runway separation
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category
C1	Planned Gap used for departure	1
C2	Approach landed successfully	1
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	6
R3	Number unbriefed missed approaches during simulation.	0

b. RS.Landing.2

Simulation Configurations

In this scenario, the departure aircraft is configured according to Table 79

Table 79: 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 77 (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.

Sequence of Actions

The sequence of actions in this scenario is identical to the sequence diagram from RS.Landing.1, depicted in Figure 17.

Visualization

Figure 18 visualizes the trajectories of the two aircraft in the simulation. The approaching aircraft is illustrated by the yellow line, the departing aircraft is illustrated by the dark blue line. Additionally, the relative positions of the approaching aircraft, when the departing aircraft gets cleared for line-up and take-off, as well as when the departure actually takes off, are illustrated by the cyan colored vertical lines.

Figure 18: Visualization of RS.Landing.2

Metrics

Table 80: Metric Evaluation for RS.Landing.2

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable, since in case of successful landing separation is based on runway separation
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable, since in case of successful landing separation is based on runway separation
S3	Situation which requires immediate action by Tower Controller to ensure separation	0

S4	Minimum height difference of missed approach and departure	not applicable, since in case of successful landing separation is based on runway separation
S5	Wake Separation Infringement	not applicable, since in case of successful landing separation is based on runway separation
C1	Planned Gap used for departure	1
C2	Approach landed successfully	1
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	6
R3	Number unbriefed missed approaches during simulation.	0

2. Reference Scenarios Go-around

a. 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 76 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 81: 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			

Sequence of Actions

Figure 19 depicts the sequence diagram, documenting the actions of the controller, taken in the simulation.

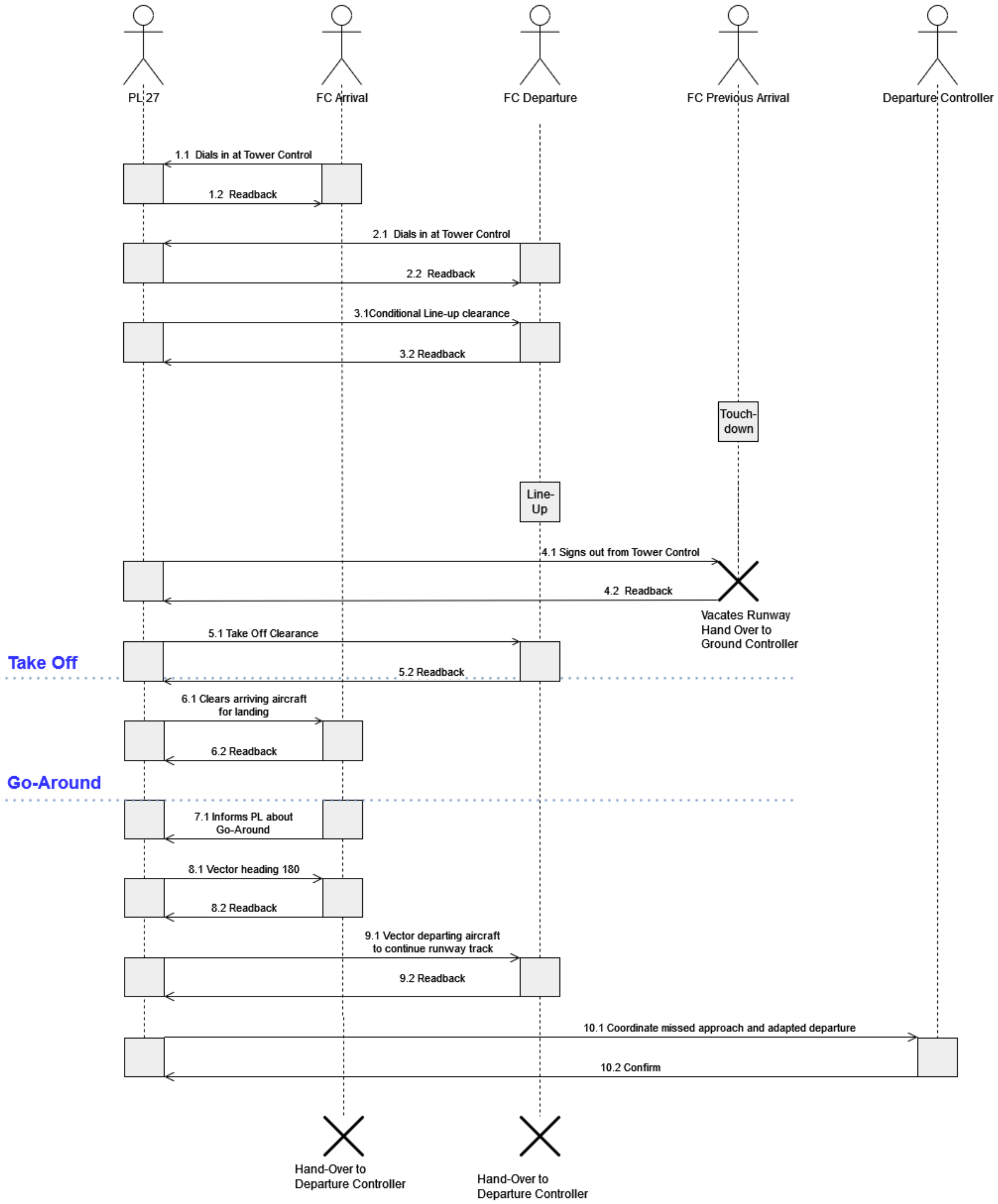


Figure 19: Sequence Diagram for RS.GoAround.1

Visualization

Figure 20 illustrates the trajectory the approaching aircraft as yellow line, the trajectory of the departing aircraft as blue line and the referencing positions of the approach where the line-up and take-off clearance was given and the actual take-off was performed by the departure as vertical cyan colored lines. The black line indicates the point of closest horizontal distance.

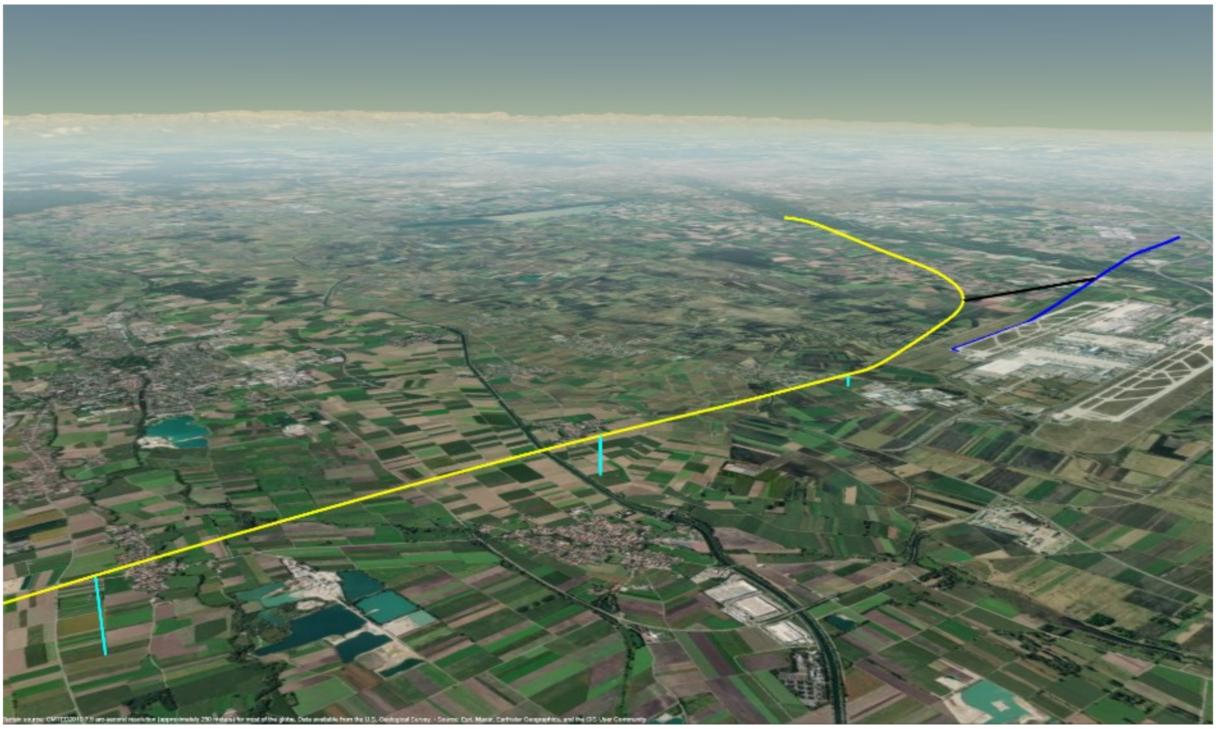


Figure 20: Visualization of RS.GoAround.1

Metrics

Table 82: Metric evaluation for RS.GoAround.1

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	0m
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	2.1 NM
S3	Situation which requires immediate action by Tower Controller to ensure separation	1
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category

C1	Planned Gap used for departure	1
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	3
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	9
R3	Number unbriefed missed approaches during simulation.	1

b. 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 79. The configuration for the approach is similar to RS.GoAround.1, specified in Table 81. 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.

Sequence of Actions

The sequence of actions is similar to RS.Goaround.1, depicted in Figure 19.

Visualization

Figure 21 illustrates the trajectories the approaching aircraft as yellow line, the trajectory of the departing aircraft as blue line and the referencing positions of the approach where the line-up and take-off clearance was given and the actual take-off was performed by the departure as vertical cyan colored lines. The black line indicates the point of closest horizontal distance.

Figure 21: Visualization of RS.GoAround.2

Metrics

Table 83: Metrics evaluation for RS.GoAround.2

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	78m

S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	2.6 NM
S3	Situation which requires immediate action by Tower Controller to ensure separation	1
S4	Minimum height difference of missed approach and departure	221m
S5	Wake Separation Infringement	0
C1	Planned Gap used for departure	1
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	3
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	9
R3	Number unbriefed missed approaches during simulation.	1

3. Solution Scenario False Positive Predictions

a. 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 76. The approach configuration is specified in Table 84, 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 84: 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 requested from ATCO earlier.**	**Missed approach predicted at xxNM from RWY Threshold**
	ILS 26L	yes	N.a.	2
WX	IMC Conditions, no wind, ISA standard			
Aircraft Type		**VAPP**		

Medium twin engine	135 kt

Sequence of Actions

The sequence diagram in Figure 22 documents the ATCOs action during the simulation.

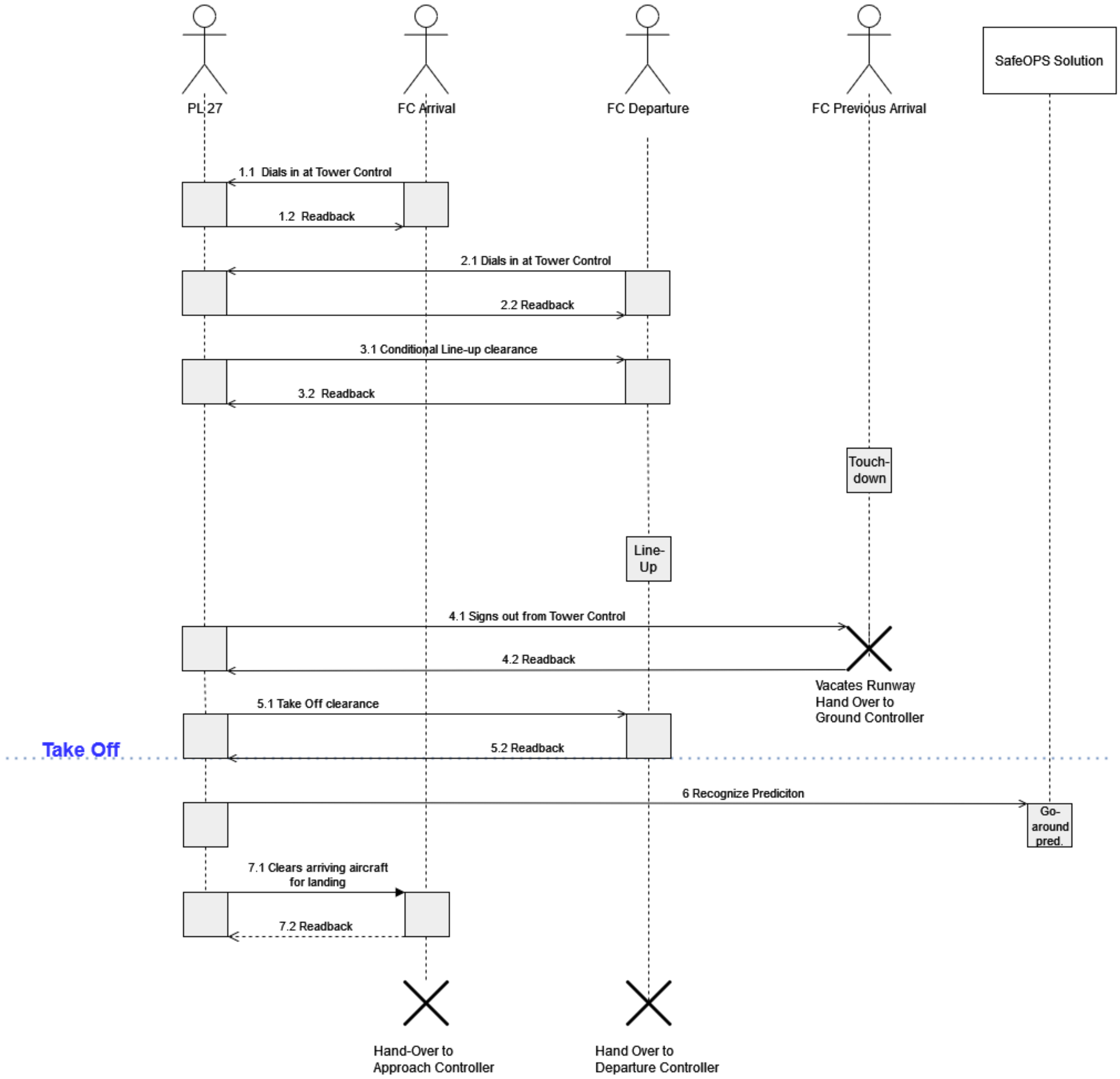


Figure 22: Sequence Diagram for SS.FalsePositive.1

Visualization

Figure 23 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and the actual take-off was performed, are illustrated as cyan colored vertical lines.

Figure 23: Visualization of SS.FalsePositive.1

Metrics

The following Table 85 summarizes the metric evaluations for SS.FalsePositive.1.

Table 85: Metric evaluation for SS.FalsePositive.1

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable, since in case of successful landing separation is based on runway separation
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable, since in case of successful landing separation is based on runway separation
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category
C1	Planned Gap used for departure	1
C2	Approach landed successfully	1
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	6

R3	Number unbriefed missed approaches during simulation.	0

b. 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 76. The approach configuration is specified in Table 86, 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 86: 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.2 is similar to SS.TruePositive.2, therefore, the sequence diagram is depicted in Figure 30 , the visualization is illustrated in Figure 31 and the metric evaluation is summarized in Table 94: Metric evaluation for SS.TruePositive.2.

c. 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 76. The approach configuration is specified in Table 87, 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 87: 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		

Sequence of Actions

The sequence diagram in Figure 24 documents the ATCOs action during the simulation.

Co-funded by the European Union

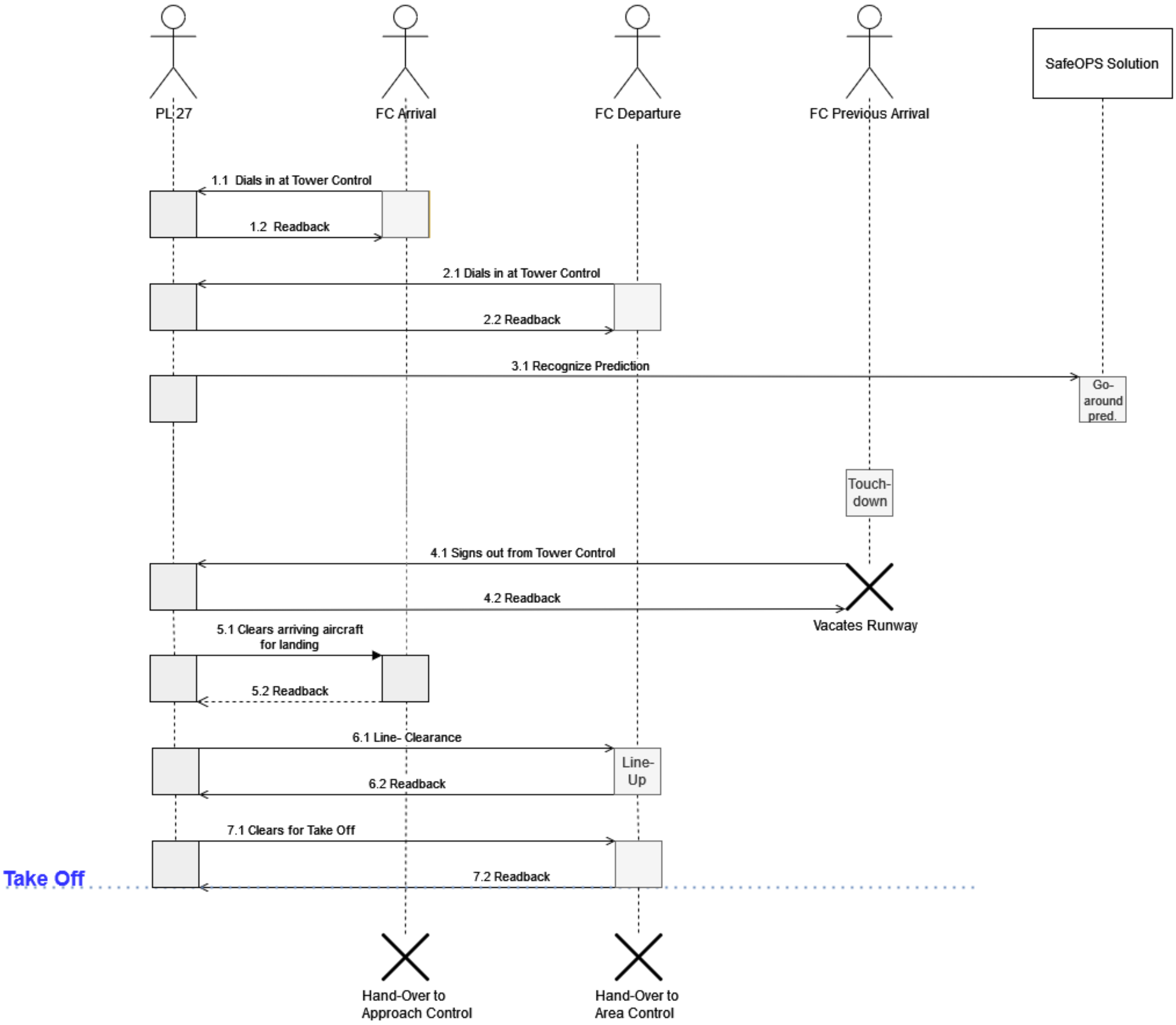


Figure 24: Sequence Diagram for SS.FalsePositive.3

Visualization

Figure 25 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Since the line-up clearance is given, after the approach lands, the departure is only visible at the holding point of the taxi way.

Figure 25: Visualization of SS.FalsePositive.3

Metrics

The following Table 88 summarizes the metric evaluations for SS.FalsePositive.3.

Table 88: Metric evaluation for SS.FalsePositive.3

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable, since in case of successful landing separation is based on runway separation
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable, since in case of successful landing separation is based on runway separation
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category
C1	Planned Gap used for departure	0
C2	Approach landed successfully	1

R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	6
R3	Number unbriefed missed approaches during simulation.	0

d. 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 79. The approach configuration is specified in Table 84, indicating a prediction to take place after the take-off clearance has been given to the preceding departure aircraft, similar to SS.FalsePositive.1

Sequence of Actions

The sequence diagram in Figure 22 documents the ATCOs action during the simulation. These are similar to SS.FalsePositive.1.

Visualization

Figure 26 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and the actual take-off was performed, are illustrated as cyan colored vertical lines.

Figure 26: Visualization of SS.FalsePositive.4

Metrics

The following Table 89 summarizes the metric evaluations for SS.FalsePositive.4.

Table 89: Metric evaluation for SS.FalsePositive.4

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable, since in case of successful landing separation is based on runway separation
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable, since in case of successful landing separation is based on runway separation
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	Not applicable, since runway separation exists throughout the scenario
S5	Wake Separation Infringement	Not applicable, since runway separation exists throughout the scenario
C1	Planned Gap used for departure	1
C2	Approach landed successfully	1
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	6
R3	Number unbriefed missed approaches during simulation.	0

e. 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 79. The approach configuration is specified in Table 86 Table 86, 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.5 is similar to SS.TruePositive.5, therefore, the sequence diagram is depicted in Figure 30, the visualization is illustrated in Figure 36Figure 31 and the metric evaluation is summarized in Table 98.

f. SS.FalsePositive.6

Simulation Configuration

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 79Table 76. The approach configuration is specified in Table 87, indicating a prediction to take place before the line-up clearance has been given to the preceding departure aircraft, similar to SS.FalsePositive.3.

Sequence of Actions

The sequence diagram in Figure 24 documents the ATCOs action during the simulation. It is similar to the one from SS.FalsePositive.3

Visualization

Figure 27 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Since the line-up clearance is given, after the approach lands, the departure is only visible at the holding point of the taxi way.

Figure 27: Visualization of SS.FalsePositive.6

Metrics

The following Table 90 summarizes the metric evaluations for SS.FalsePositive.6.

Table 90: Metric evaluation for SS.FalsePositive.6

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable, since in case of successful landing separation is based on runway separation
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable, since in case of successful landing separation is based on runway separation

S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	Not applicable since approach is landed before departure takes-off
S5	Wake Separation Infringement	Not applicable since approach is landed before departure takes-off
C1	Planned Gap used for departure	0
C2	Approach landed successfully	1
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	6
R3	Number unbriefed missed approaches during simulation.	0

4. Solution Scenario True Positive Predictions

a. 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 76. The approach configuration is specified in Table 91, 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 91: 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

Sequence of Actions

The sequence diagram in Figure 28 documents the ATCOs action during the simulation.

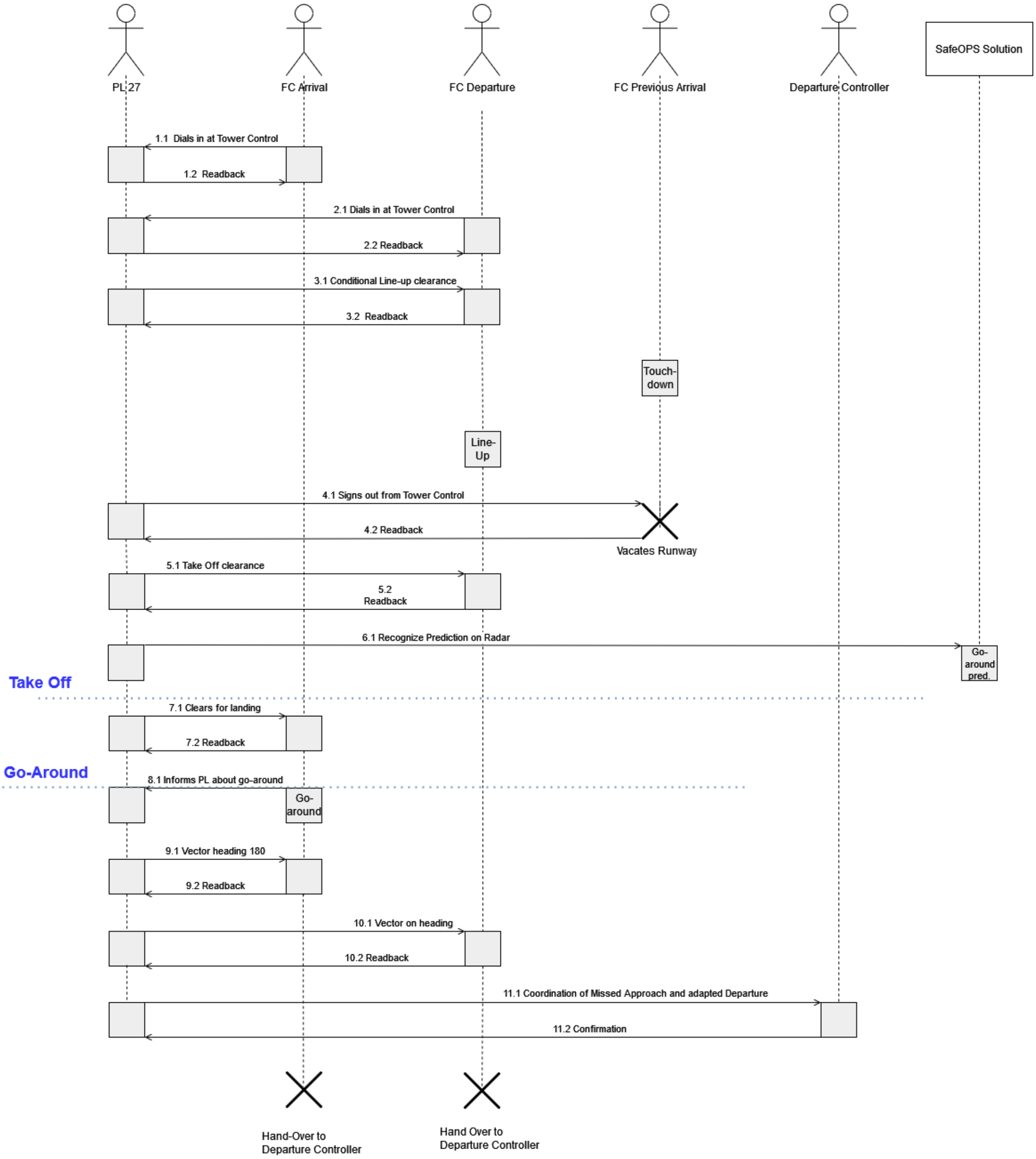


Figure 28: Sequence Diagram for SS.TruePositive.1

Visualization

Figure 29 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and the actual take-off was performed, are illustrated as cyan colored vertical lines. The black line indicates the point of closes horizontal proximity (S2 metric).

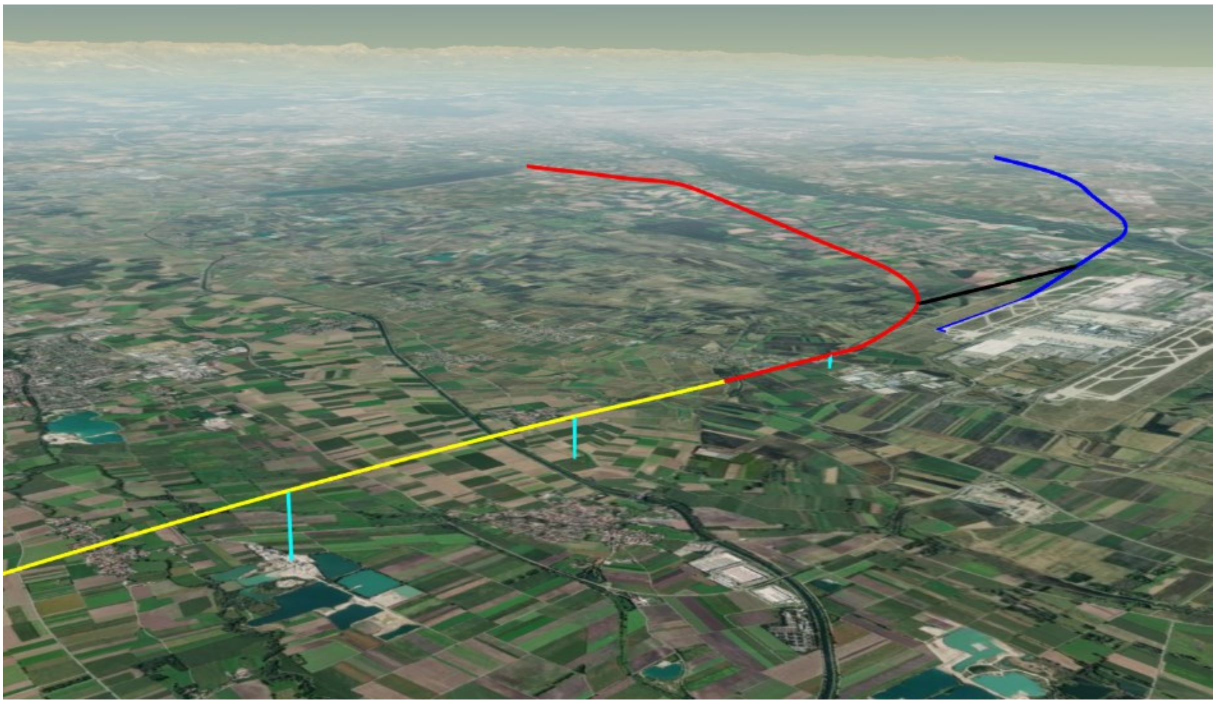


Figure 29: Visualization of SS.TruePositive.1

Metrics

The following Table 92 summarizes the metric evaluations for SS.TruePositive.1.

Table 92: Metric evaluation for SS.TruePositive.1

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	0ft
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	2.1 NM
S3	Situation which requires immediate action by Tower Controller to ensure separation	1
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category

C1	Planned Gap used for departure	1
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	3
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	9
R3	Number unbriefed missed approaches during simulation.	0

b. 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 76. The approach configuration is specified in Table 93 , 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 93: 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		

Sequence of Actions

The sequence diagram in Figure 30 documents the ATCOs action during the simulation.

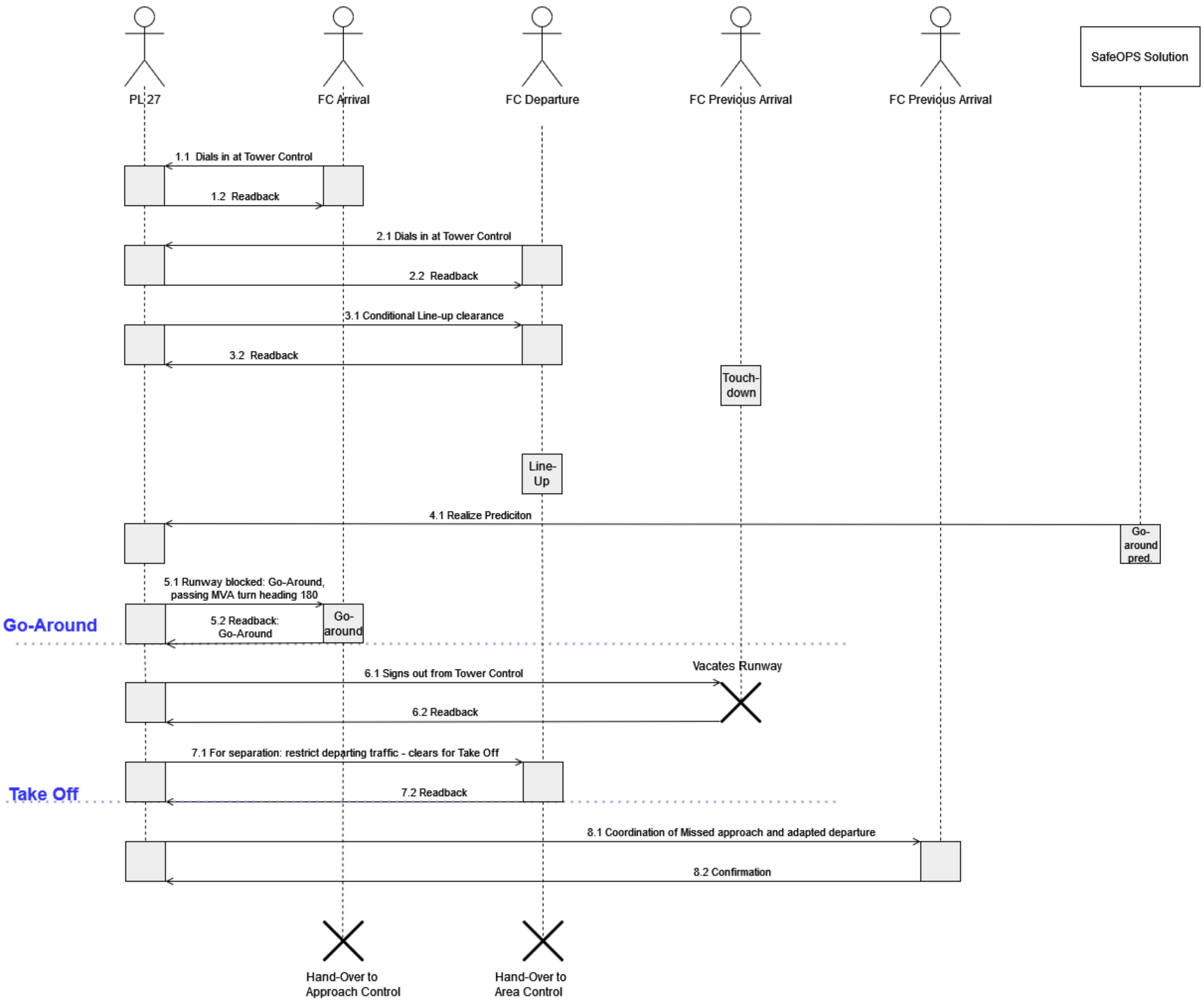


Figure 30: Sequence Diagram for SS.TruePositive.2

Visualization

Figure 31 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the actual take-off was performed, are illustrated as cyan colored vertical lines.

Figure 31: Visualization of SS.TruePositive.2

Metrics

The following Table 94 summarizes the metric evaluations for SS.TruePositive.2.

Table 94: Metric evaluation for SS.TruePositive.2

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	1042m
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	n.a. since vertical separation always kept
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category
C1	Planned Gap used for departure	1
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	2
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	7
R3	Number unbriefed missed approaches during simulation.	0

c. 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 76. The approach configuration is specified in Table 95, 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 95: 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		

Sequence of Actions

The sequence diagram in Figure 32 documents the ATCOs action during the simulation.

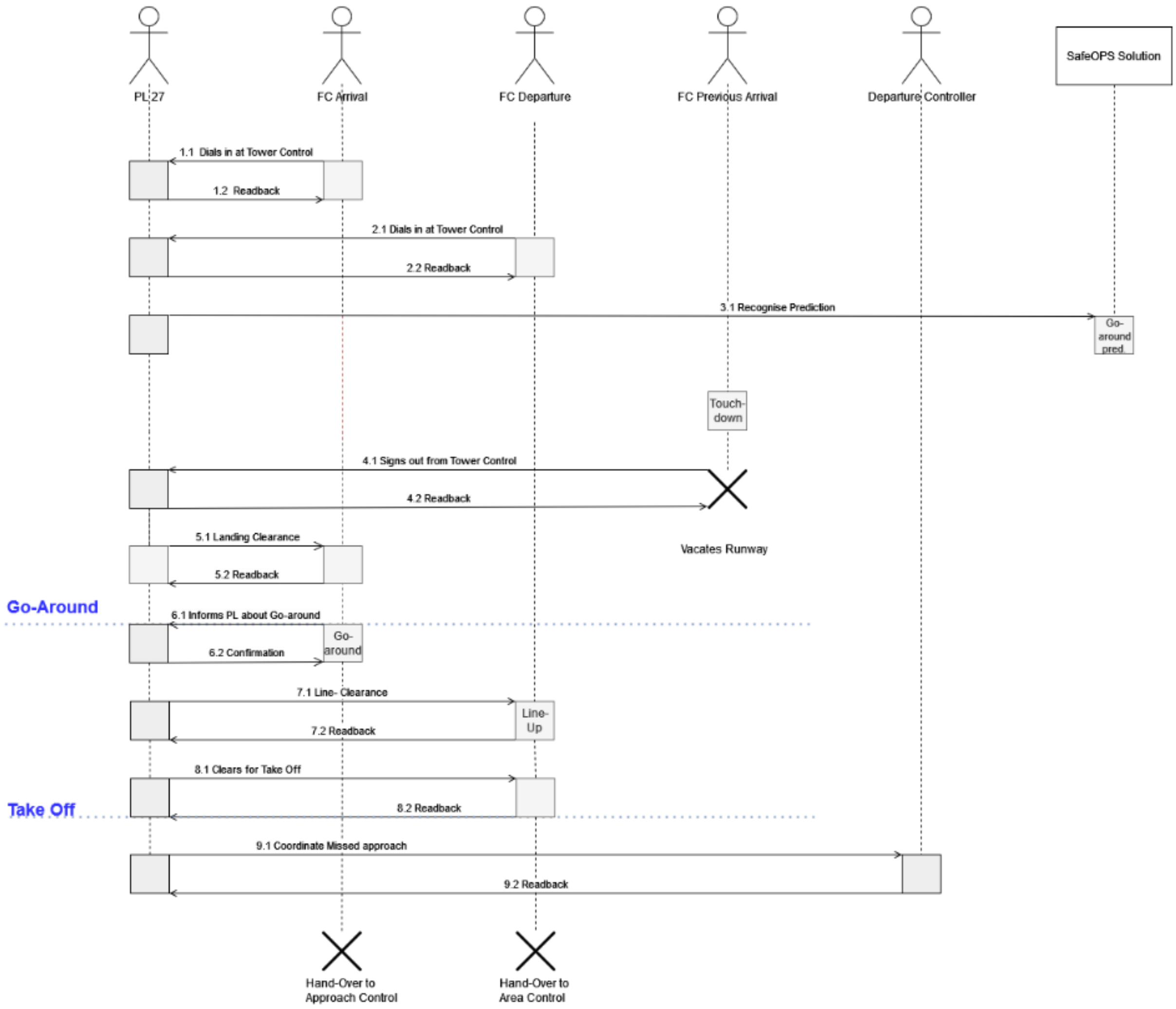


Figure 32: Sequence Diagram for SS.TruePositive.3

Visualization

Figure 33 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and actual take-off was performed, are illustrated as cyan colored vertical lines.

Figure 33: Visualization of SS.TruePositive.3

Metrics

The following Table 96Table 94 summarizes the metric evaluations for SS.TruePositive.3.

Table 96: Metric evaluation for SS.TruePositive.3

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	1057m
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	n.a. since vertical separation always kept
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	not applicable, since no difference in wake turbulence category
S5	Wake Separation Infringement	not applicable, since no difference in wake turbulence category
C1	Planned Gap used for departure	0
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0, since the departure is not cleared for take-off in the initially planned gap but cleared for take-off, once the go-around has been performed.

R2	Number of overall coordinative actions of the ATCO from the sequence of action.	8
R3	Number unbriefed missed approaches during simulation.	0

d. 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 79. The approach configuration is specified in Table 91, 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.

Sequence of Actions

The sequence diagram in Figure 34 documents the ATCOs action during the simulation.

EUROPEAN PARTNERSHIP

Co-funded by the European Union

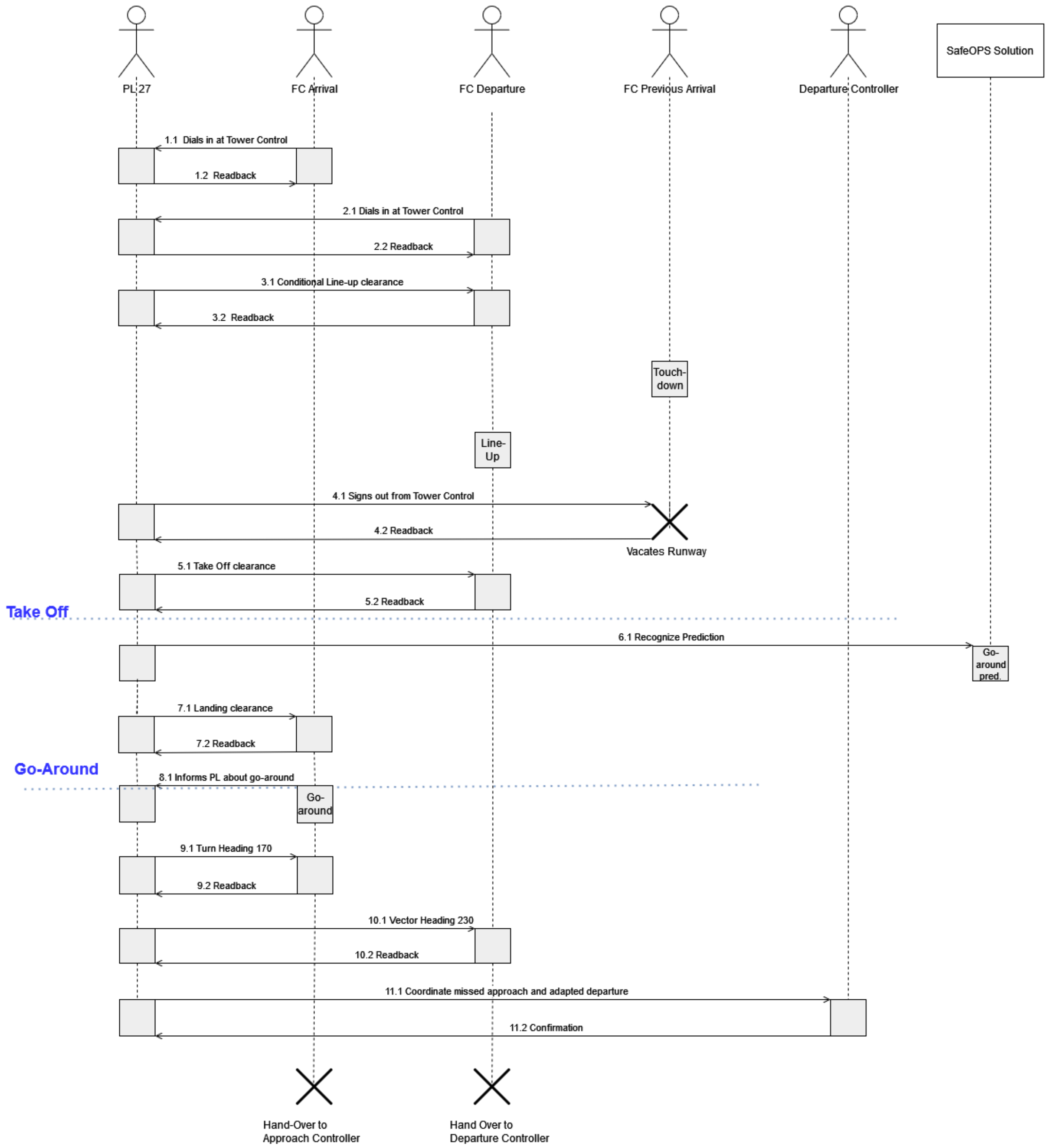


Figure 34: Sequence Diagram for SS.TruePositive.4

Visualization

Figure 35 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and the actual take-off was performed, are illustrated as cyan colored vertical lines. The black line indicates the point of closes horizontal proximity (S2 metric).

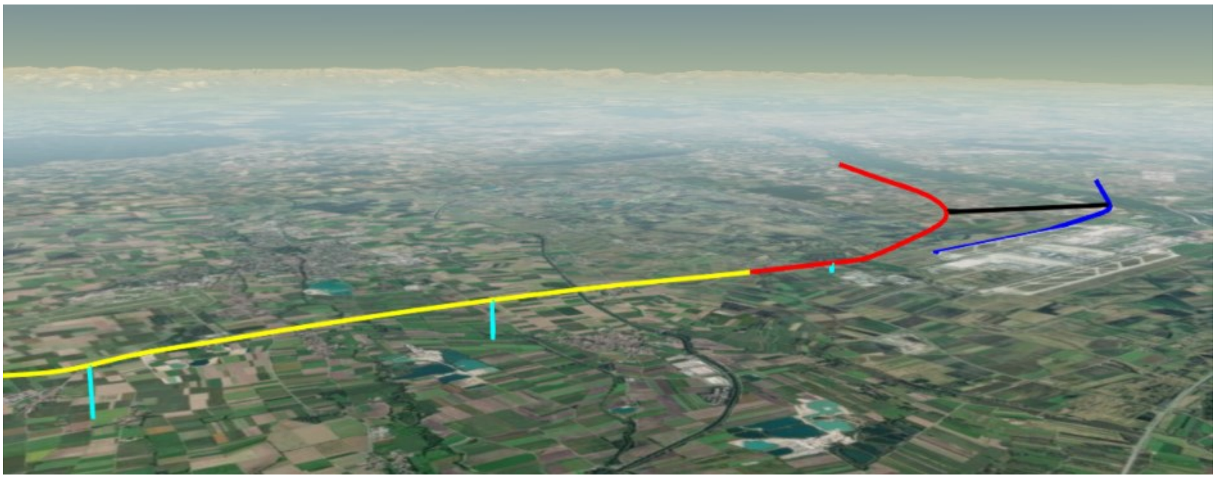


Figure 35: Visualization of SS.TruePositive.4

Metrics

The following Table 97 summarizes the metric evaluations for SS.TruePositive.4.

Table 97: Metric evaluation for SS.TruePositive.4

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	85m
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	2.6NM
S3	Situation which requires immediate action by Tower Controller to ensure separation	1
S4	Minimum height difference of missed approach and departure	232.9m
S5	Wake Separation Infringement	0
C1	Planned Gap used for departure	1
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	3
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	9
R3	Number unbriefed missed approaches during simulation.	0

e. 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 79Table 76. The approach configuration is specified in Table 93, 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.

Sequence of Actions

The sequence diagram in Figure 30 documents the ATCOs action during the simulation. It is similar to SS.TurePositive.2.

Visualization

Figure 36 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and actual take-off was performed, are illustrated as cyan colored vertical lines.

Figure 36: Visualization of SS.TruePositive.5

Metrics

The following Table 98 summarizes the metric evaluations for SS.TruePositive.5.

Table 98: Metric evaluation for SS.TruePositive.5

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable since radar separation is always given, when both aircraft airborne
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable since vertical separation is always given, when both aircraft airborne
S3	Situation which requires immediate action by Tower Controller to ensure separation	0

S4	Minimum height difference of missed approach and departure	not applicable since trajectories never come close
S5	Wake Separation Infringement	0
C1	Planned Gap used for departure	1
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	2
R2	Number of overall coordinative actions of the ATCO from the sequence of action.	7
R3	Number unbriefed missed approaches during simulation.	0

a. 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 79. The approach configuration is specified in Table 95, 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.

Sequence of Actions

The sequence diagram in Figure 32 documents the ATCOs action during the simulation, similar to SS.TruePositive.3.

Visualization

Figure 37Figure 33 illustrates the trajectories of both simulated aircraft in yellow and blue. At the point where the SafeOPS solution predicted a go-around, the trajectory of the approach is colored red. Furthermore, the referencing positions of the approach where the line-up and take-off clearance was given and actual take-off was performed, are illustrated as cyan colored vertical lines.

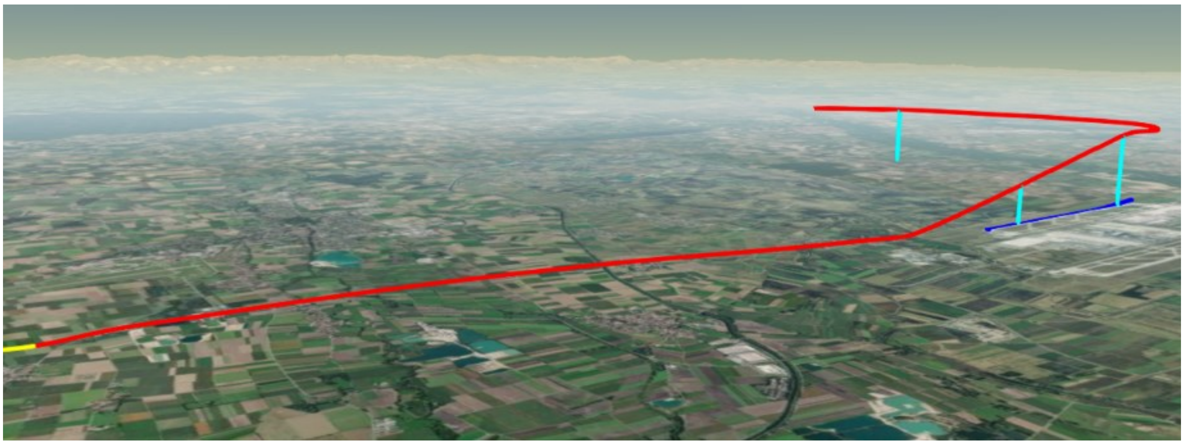


Figure 37: Visualization of SS.TruePositive.6

Metrics

The following Table 99 summarizes the metric evaluations for SS.TruePositive.6.

Table 99: Metric evaluation for SS.TruePositive.6

Metric	Description	Evaluation
S1	Minimum vertical distance between Aircraft, when horizontal distance below 3NM	not applicable since radar separation is always given, when both aircraft airborne
S2	Minimum horizontal distance between Aircraft, when vertical distance below 300m	not applicable since vertical separation is always given, when both aircraft airborne
S3	Situation which requires immediate action by Tower Controller to ensure separation	0
S4	Minimum height difference of missed approach and departure	not applicable since take-off clearance of departure is given after missed approach is turned from runway heading
S5	Wake Separation Infringement	0
C1	Planned Gap used for departure	0
C2	Approach landed successfully	0
R1	Number of coordinative actions of the ATCOs after the initiation of a go-around.	0

R2	Number of overall coordinative actions of the ATCO from the sequence of action.	8
R3	Number unbriefed missed approaches during simulation.	0

A.2.3 Analysis of Exercise 1 Results per Validation objective

This is documented in the main document in section 4.2 and is not repeated in the appendix.

Appendix B Simulation Environment

B.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.

B.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.

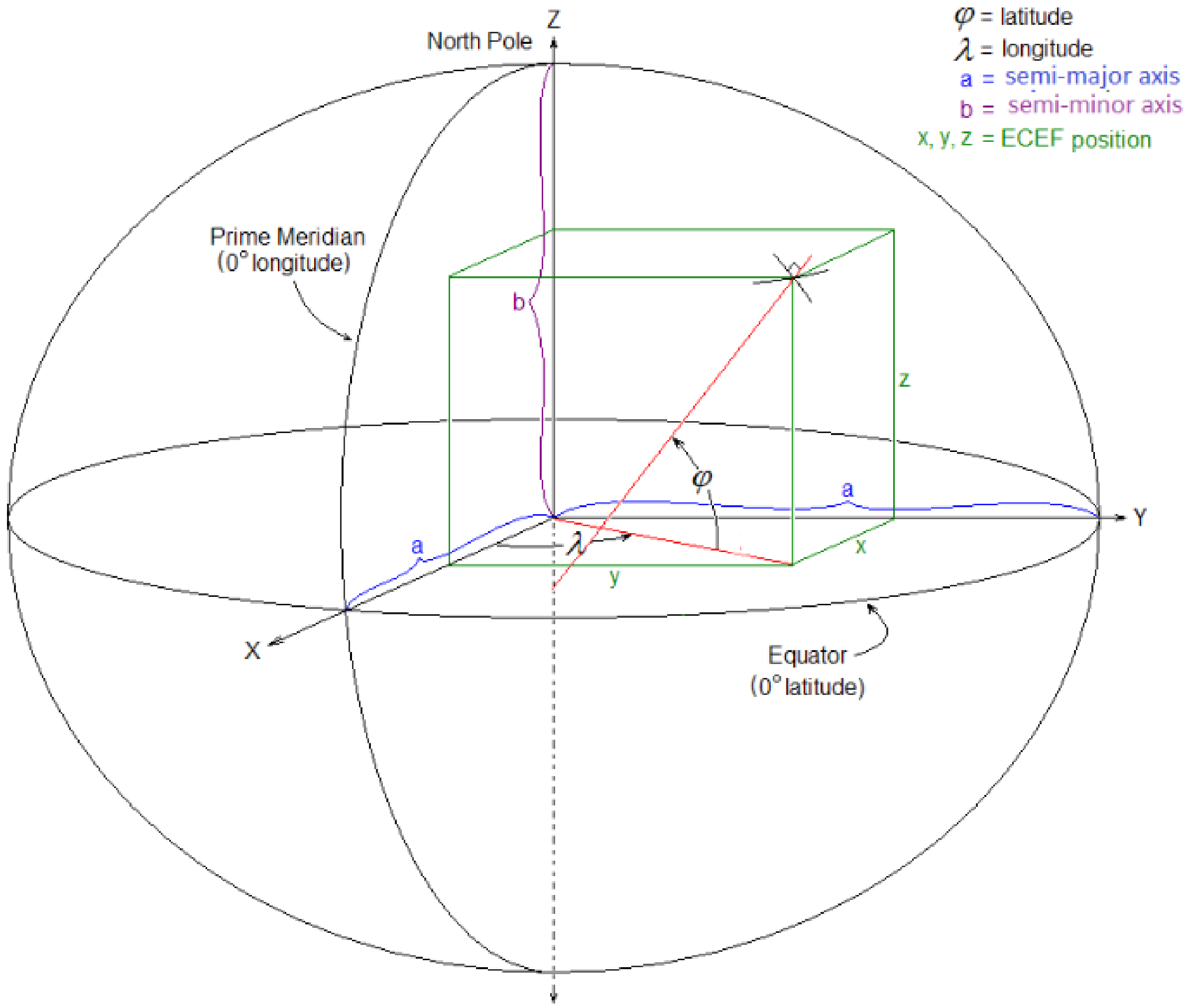


Figure 38: Definition of Coordinate Frames and Coordinates [15]

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.

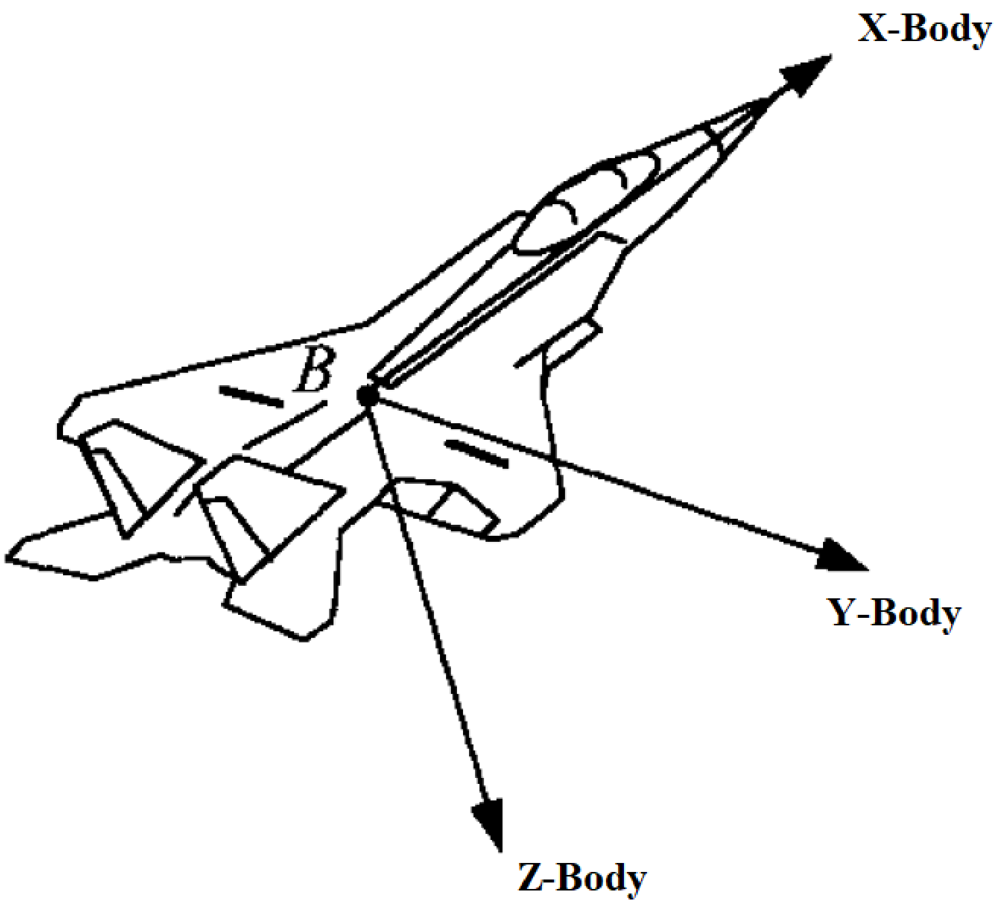


Figure 39: Body Fixed Coordinates [16]

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 100: 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)

B.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.

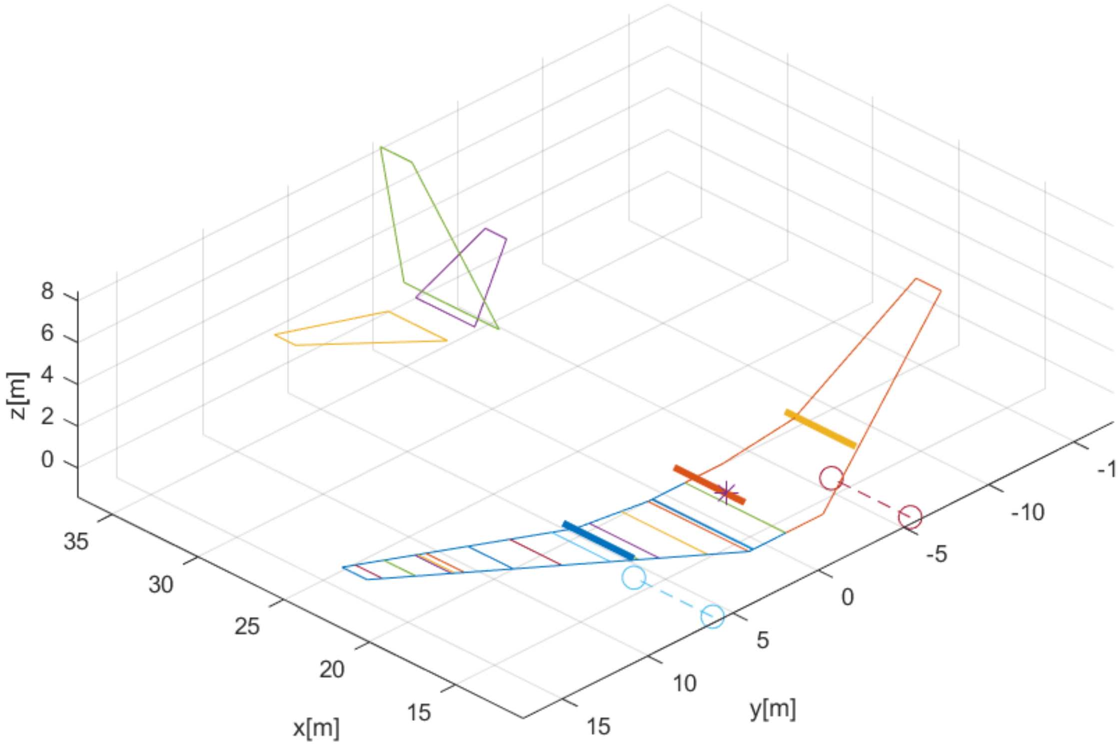


Figure 40: The aerodynamic surface sections of multi-point model representation. Only the right main wing is shown. Orthogonal view

The two-dimensional aerodynamic coefficients were computed using an open-source tool called XFLR5 [17] [18], 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 [19]. The airfoil geometry was taken from a weight-wise similar aircraft [20] [21] [22] [23], 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. [24] [25] [26] [27] [28]. 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) [29] 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 101: 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 102 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

B.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.

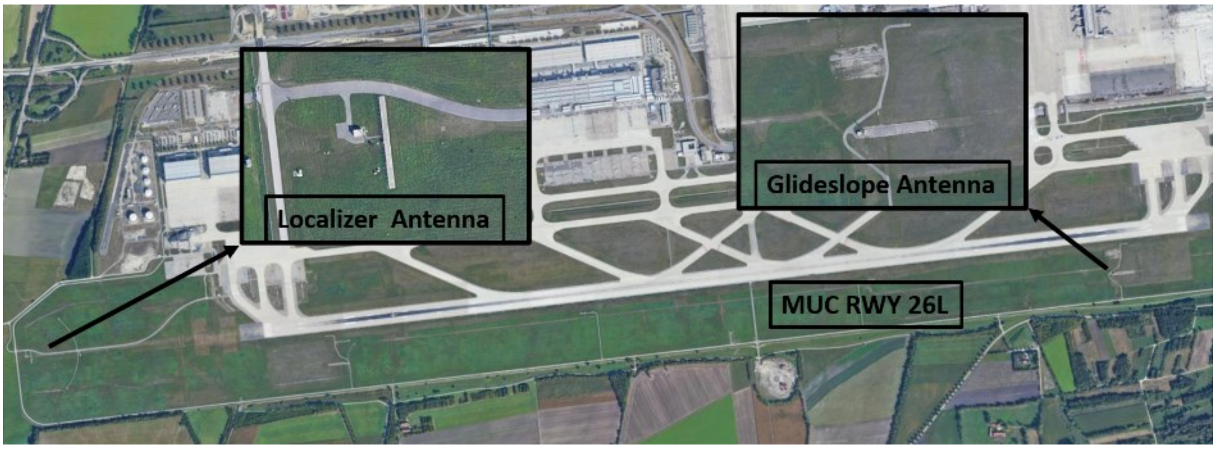


Figure 41: The locations of the ILS antennas of Runway 26L in Airport 2 on Google Maps. [30]

B.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 103: 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.

B.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 104: Possible Arrival Scenarios and inputs to the simulation model

<table>
<tr><th colspan="9">1. Standard Final Approach.</th></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><th colspan="3">2A. Standard landing procedure.</th><th colspan="3">2B. Standard missed approach procedure - Climb straight.</th><th colspan="3">2C. Non-standard missed approach procedure - Climb straight.</th></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.					

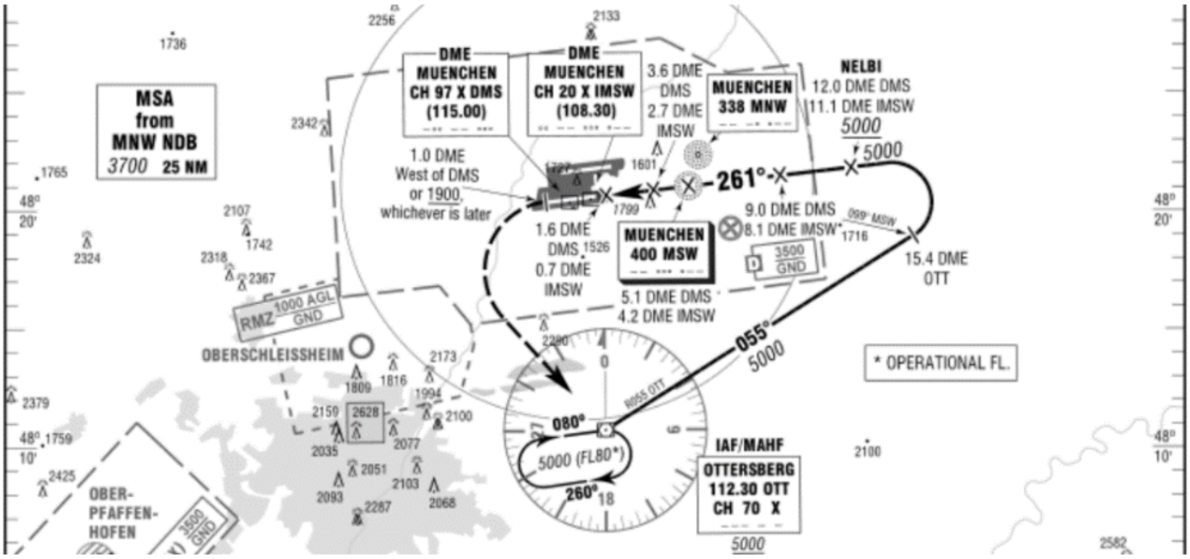


Figure 42 Airport 2 Runway 26L, instrument approach chart with the dashed line showing the standard missed approach route. [31]

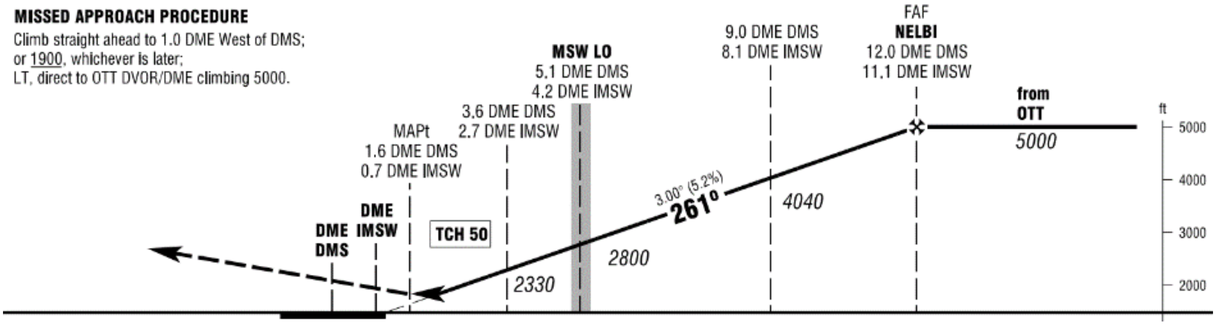


Figure 43: Airport 2 Runway 26L, the missed approach procedure on the top left. [31]

B.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 105: 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

B.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.

B.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.

B.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.

B.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).

B.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 106: 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.

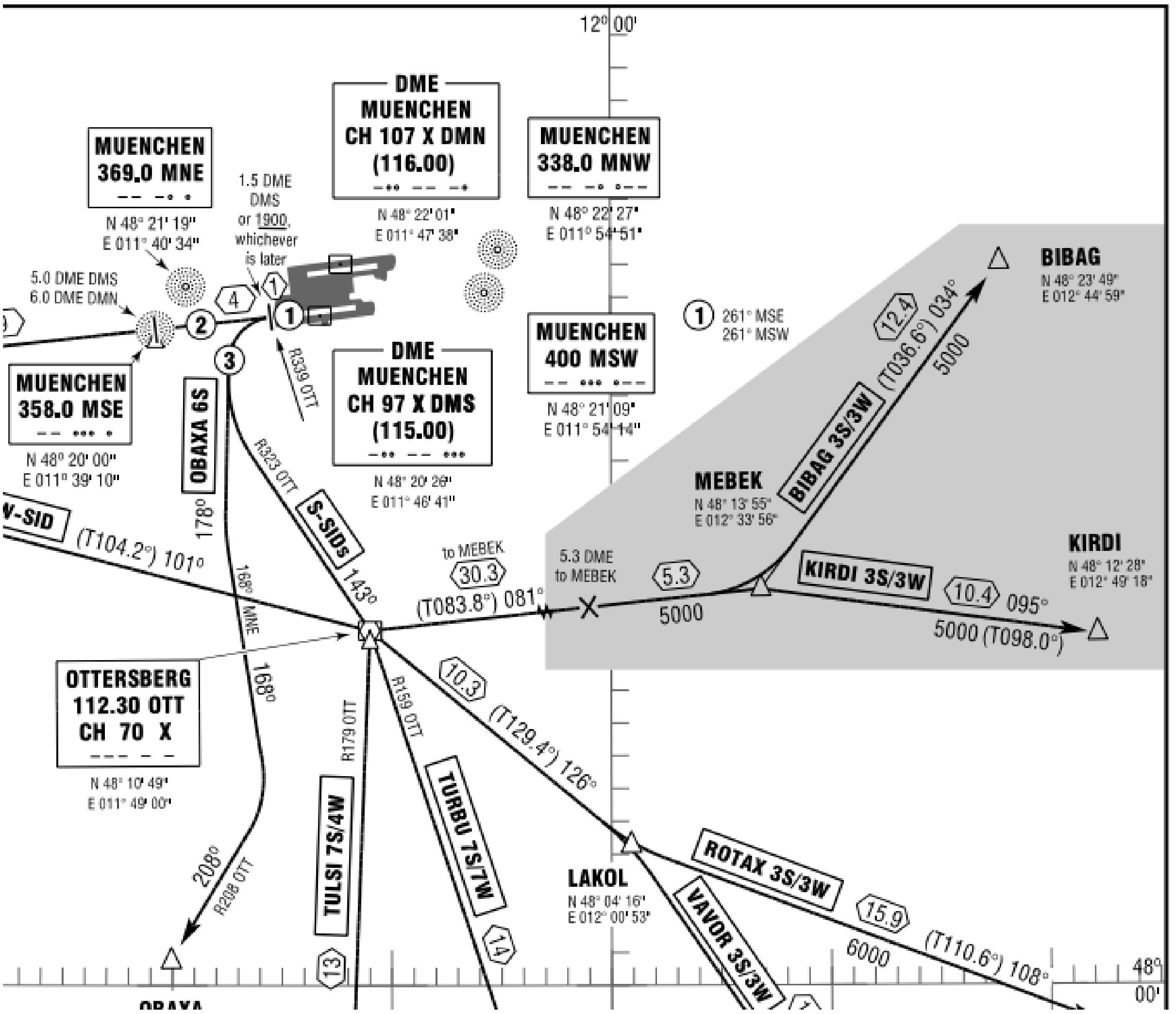


Figure 44: Standard Instrument Departure Airport 2 Runway 26L [31]

For the scenarios analyzed we chose the ROTAX 3S departure, see Figure 44, 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

Co-funded by the European Union

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 107 summarizes all available modes.

Table 107 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

B.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 108 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 108 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

B.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 [3] 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.

B.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

B.3.2 Resources

All resources required to setup a radar screen like plot are provided by DFS [31]. These are, namely

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

B.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.

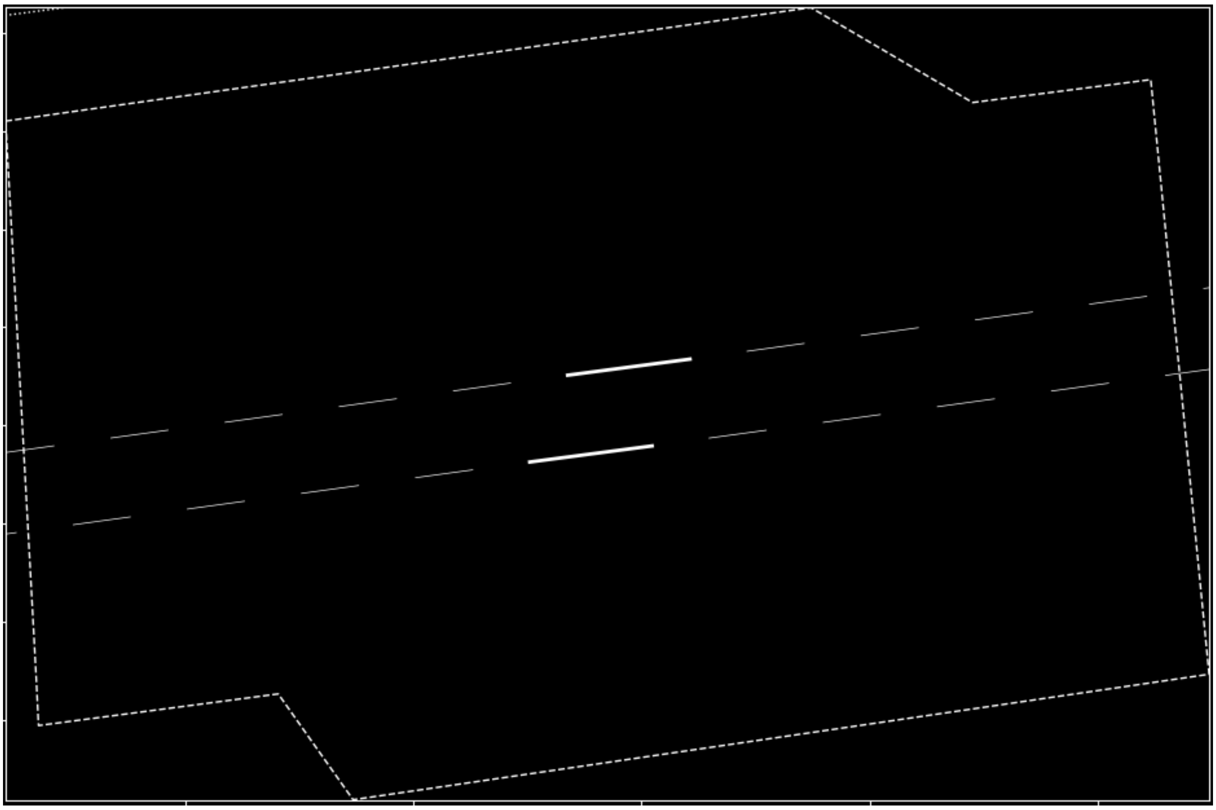


Figure 45: Illustrating an empty radar screen

Aircraft are symbolized by a square. Adjacent one finds the Callsign colorized according to Table 109.. Below the callsign, altitude in 100 ft and indicated airspeed in tens of kts are shown, as illustrated in Figure 46.

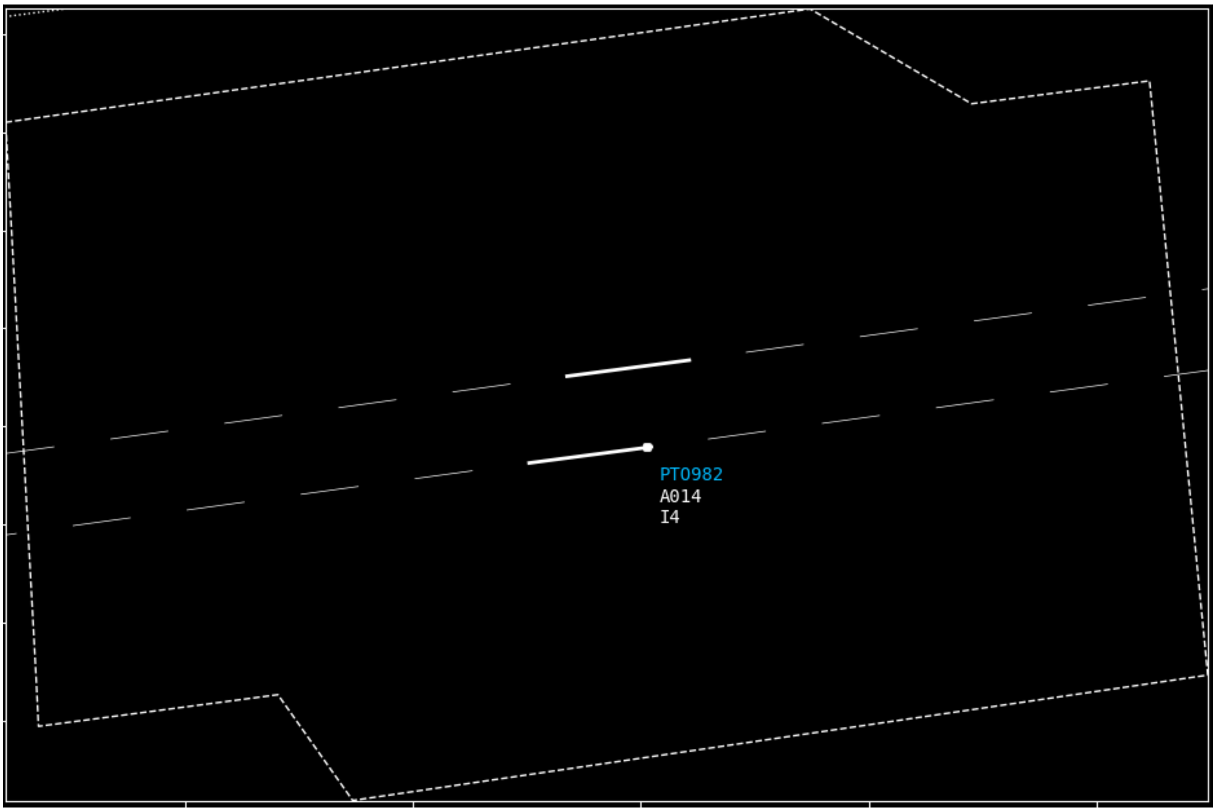


Figure 46: Illustrating an aircraft on the radar screen with callsign, altitude above ground and indicated airspeed.

The whole setup on a single pc is shown in the following Figure 47. 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.

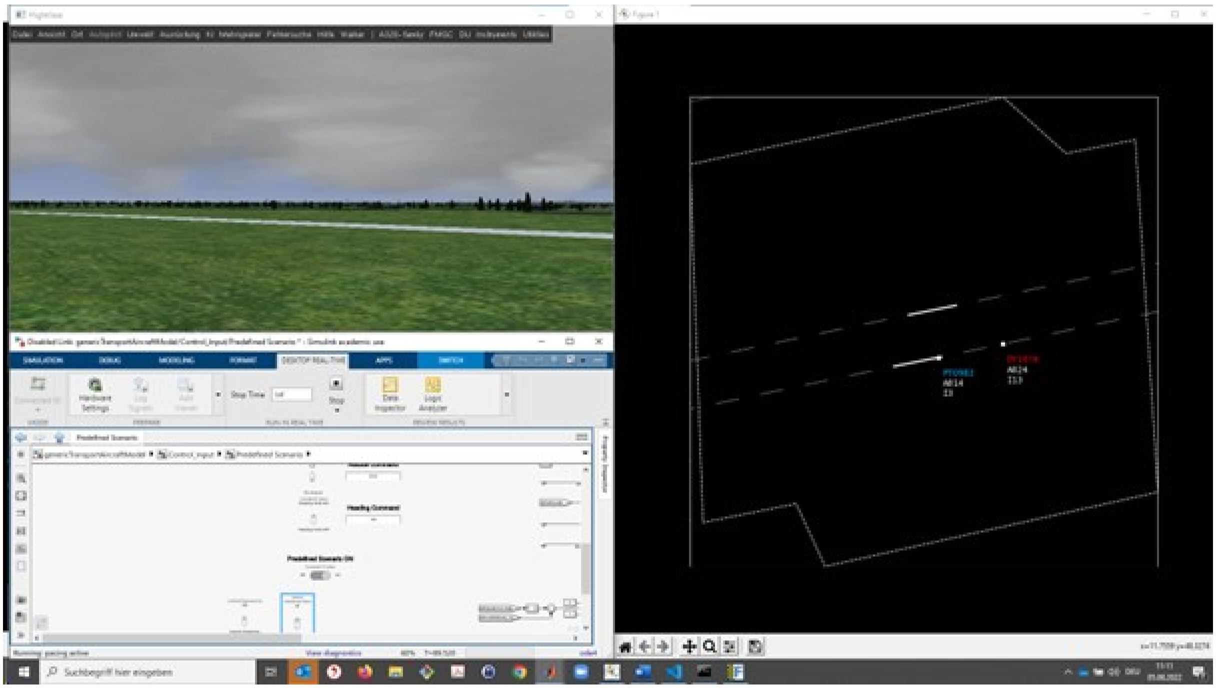


Figure 47: Simulation setup on a Laptop Screen with inputs and visualizations

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 109: 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.

-END OF DOCUMENT-

Insert beneficiary's logos below, if required