Final Project Report

Document information	
Project Title	COMPASS
Project Number	E.02.12
Project Manager	[redacted], THALES
Deliverable Name	Final Technical Report
Deliverable ID	D0.9
Edition	01.02.00
Template Version	03.00.00
Task contributors	
RWTH Aachen University	
University of York	

Abstract

The final report of the COMPASS WP-E project provides a publishable summary of the results. In addition it lists all deliverables, dissemination activities, eligible costs, deviations, bills and lessons learned.

Authoring & Approval

Prepared by - *Authors of the document.*		
Name & Company	Position & Title	Date
[redacted] / THALES	Coordinator	03/12/2013
[redacted] / York	Technical Coordinator	03/12/2013
[redacted]/ Innaxis	WP1 Leader	03/12/2013
[redacted] / RWTH Aachen	WP2 Leader	03/12/2013

Reviewed by - *Reviewers internal to the project.*		
Name & Company	Position & Title	Date
[redacted] / York	Project Quality Manager	04/12/2013

Approved for submission to the SJU by - *Representatives of the company involved in the project.*		
Name & Company	Position & Title	Date
[redacted] / THALES	Coordinator	04/12/2013
[redacted] / York	Project Quality Manager	04/12/2013

Document History

Edition	Date	Status	Author	Justification
01.00.00	03/12/2013	Available for internal review	ALL	New Document
01.01.00	05/12/2013	Release	[redacted] / [redacted]	Submitted to ECTL
01.02.00	17/12/2013	Final version	[redacted] / [redacted]	Addresses feedback from SJU

Intellectual Property Rights (foreground)

All foreground IPR belong to SJU.

Table of Contents

List of tables

Publishable Summary

Context

ATC is a service provided by ground-based controllers to direct and monitor aircraft through controlled airspace (and on the ground). The primary purpose of ATC systems is to prevent aircraft collisions, and this is achieved by having aircraft maintain a lateral and/or vertical minimum distance (separation minima). Maintaining separation minima requires ATCo to have access to, and interpret, aircraft position data. This data can be obtained through a number of mechanisms, with radar and aircraft position reports being most common.

Oftentimes, ATC are seamlessly able to maintain separation between aircraft. However, because of increasing levels of air traffic and increasing pressure to optimise the use of airspace for economic and environmental reasons, airspace is becoming increasingly difficult to manage and occasionally a loss of separation (conflict) between aircraft may occur. Moreover, upon detecting a conflict, the process of finding a solution may be complex because of the impact that ATC instructions may have on other aircraft not actively involved in the conflict. Early safety warnings, with regard to conflicts, are therefore particularly desirable in the ATC domain. In recognition of this, a number of technologies have been introduced into the ATC domain in an attempt to improve air traffic safety.

Airborne Collision Avoidance Systems (ACAS) are systems deployed within aircraft to warn pilots of the presence of nearby aircraft, which may present a threat of collision. These systems are therefore designed to augment the activities of ATC, and according to the literature, improve safety in the airspace by a factor of between 3 and 5. Short Term Conflict Alert (STCA) is a ground-based safety net operated directly by ATC. It checks possible conflicting aircraft trajectories in a time horizon of about 2 or 3 minutes and alerts the ATCo prior to a conflict. Finally, Medium Term Conflict Detection (MTCD) is a supporting technology in ATC, which identifies potential conflicts in a horizon of up to 20 mins. The benefit of this proposed technology is that ATCo would be able to plan solutions to conflicts, which minimises the likelihood of causing further conflicts between either the aircraft involved in the conflict at some future point, or to other independent aircraft. Such scenarios are frequent with STCA since the 2 or 3 minute look-ahead leaves ATCo a very short window of opportunity to analyse the impact of the possible solutions.

Hypothesis and Objectives

The research hypothesis of COMPASS was that safety patterns extracted from historical data can be used to classify and prioritise future safety-related events (e.g. conflicts). The objectives of COMPASS was to extract such safety patterns by mining historical data, to provide an environment that can visualise the traffic crossing ATM en-route sectors and detect instances of these patterns in this traffic, to provide a toolkit for defining artificial operational scenarios, and to provide a distributed environment for assessing the precision of mined safety patterns.

Methodology

To this end, historical records of the planned and actual trajectory of flights across Europe (ALL_FT) were made available by Eurocontrol. This data was analysed in order to identify trajectories where the flight plan inferred a potential future conflict between aircraft. Furthermore, the data was analysed to identify the actual outcome of any detected potential conflict. In essence, the outcome will either be an actual occurrence of a conflict (either because of inadequate ATC or flight crew action), or no conflict (e.g. because of intervention by the ATC or the flight crew). The former potential conflicts are important to identify for the safe operation of the system, whereas the latter are the “nuisance” false positive potential conflicts.

To identify interesting safety-related events (iEvents) that are more likely to materialise COMPASS employed data mining techniques to construct safety patterns. While mining safety patterns, one of the main ideas that emerged was that the history of flights should somehow be considered in the analysis. In other words, the behaviour of the same flight across different days should provide some useful information, and whenever a repetitive pattern is found, deviations from that pattern are expected to significantly impact the ATC operation. In support of this, COMPASS defined Trajectory Synchronisation Likelihood (TSL) – a measure of the synchronization of the trajectories of two aircraft. Generally speaking, we define that two aircraft are synchronized when both of them present significant deviations from their usual trajectories at the same time. Therefore, and as a first step, it is necessary to define what the usual trajectory of an aircraft is, and how to measure whether a deviation is statistically significant. Suppose that we have identified a safety related event on a given day, in which two flights were involved: AIR0001 and AIR0002. The same two flights may have been operated in previous days, and this can be easily checked by examining flights with the same code, operating between the same pair of airports and with the same planned departure time. These other historical flights are then used to compute the expected position of each aircraft at the time of the considered event. The historical flight analysis associated with the TSL presents several major challenges. First of all, one must face the very large quantity of data to be analysed, which requires highly optimized algorithms; this is especially true if a real-time implementation is sought, and therefore results have to be obtained as soon as aircraft make their appearance. Second, it is important to include in the analysis the interactions between different aircraft, and not just consider each trajectory as independent. This, in turn, further aggravates the problem of the computational cost.

Given the high computational cost associated with the initial safety pattern, a reduced safety pattern was mined, which avoids the use of the TSL. As expected, the efficiency of the reduced safety pattern is lower than the one corresponding to the complete pattern, as important factors, like, for example, the ones related with the TSL, have been discarded. In any case, the maximum value of this proportion for the reduced safety pattern is still three times higher than the one observed in the case of random classification, indicating that relevant knowledge is still extracted from the system and that the reduced pattern is still of utility.

To enable domain experts to visualise planned and executed trajectories and classify conflicts using automatically-mined or otherwise constructed safety patterns, the Early Safety Warning System (ESWS) was developed to provide a GUI workbench that allows geographical data to be plotted onto an interactive map (selectable, allowing navigation and resizing of the map). This allows the visualisation of the ESWS model, which provides a representation of objects, which play a prominent part in air traffic management. Examples of objects of the ESWS model include airspaces, airways, and flight trajectories. To build this model, the ESWS reads data from a database pre-populated with a sample of the ALL_FT dataset. The significance of the ESWS is that it enables Air Traffic Control (ATC) to perform various types of analyses of airspace such as occupation analysis, important point analysis, air fragment analysis and conflict analysis and classification. Multiple panels in the ESWS GUI workbench allow easy access and viewing of the results of these analyses. This enables the intuitive presentation of relevant information and analysis results to ATM experts. Conflict analysis and classification capabilities give ATC an early indication of potentially conflicting aircraft trajectories, which may result in the aircraft crossing a point with inadequate separation. To enable domain experts to experiment with artificial operational scenarios, COMPASS defined an Operational Scenario Language (OSL) and supporting tools (editors, support from initialising scenarios from real data) integrated with the ESWS.

As discussed above, ESWS was developed as a desktop-based application with a rich user interface. While a user interface is necessary in scenarios that involve user interaction, it is unnecessary – and arguably detrimental from a performance and automation perspective – when batch analysis needs to be performed to evaluate the accuracy (precision and recall) of safety patterns across a large number of days and airspaces (sectors). To enable the ESWS to evaluate the reduced safety pattern against such large datasets, it was necessary to re-engineer the system into a scalable form that could operate on a distributed computing environment without user interaction. After re-engineering the system as a distributed service-oriented architecture, the reduced safety pattern was evaluated against a subset of the ALL_FT dataset. The approach that was taken in selecting data samples was to randomly select dates from each month of the aforementioned data range thus providing a certain level of even coverage. This strategy was chosen since seasonal variations in air traffic occur and it is important that the ESWS is evaluated in the context of such variations. Eventually, 44 dates were selected, representing nearly 15% of the complete dataset.

Results

The prediction outcome results show that the reduced safety pattern has an average correct prediction accuracy rate of 86%, a false positive rate of 5% and a 9% false negative rate. Moreover, these values only deviate by 4% across all of the dates that the pattern was evaluated with. The results from the experiments suggest that the reduced safety pattern is consistently accurate. The high number of correct predictions outcomes, low number of false positives outcomes, and low average deviation of predicted conflict occurrence time across different airspaces, different dates of the year and even different times of day demonstrates the relevance of the mined safety pattern. The unanticipated number of false negative prediction outcome results and the fairly high maximum deviation of predicted conflict occurrence time are not believed to pose a threat to the safety of airspace. Systems such as ESWS are in use to help ATM experts to plan their actions well in advance of the predicted iEvents. Data from a multitude of systems and procedures is used to shape the final decisions and actions of ATCo. Clearly it is inevitable that looking ahead and predicting aircraft trajectories and conflicts by 60 minutes or so will have a certain level of uncertainty attached to it. Given that the ESWS will be allowed to refine its results as conflicts approach, and given that the ESWS is designed not to replace STCA or other systems but instead to augment them, the false negative rate is not deemed to be an obstacle in the adoption of the ESWS to the ATC domain.

Future Long Term Research

Future research directions include investigating the value of sector-specific patterns, integrating additional sources of information in the pattern mining process, and applying the data-driven approach followed in COMPASS for the detection of patterns in other types of sectors (e.g. Terminal Sectors). Exploring the particular phases of the ATM process (e.g. capacity management, traffic complexity management) in which an early safety warning system such as the one proposed by COMPASS could realistically fit in is also an area for further exploration.

1 Introduction

1.1 Purpose of the document

The purpose of this document is to:

- Summarise the technical results and conclusions of the project (Publishable Summary);
- Provide a complete overview of all deliverables;
- Provide a complete overview of all dissemination activities (past and in progress). Where appropriate, provide feedback from presentations. Describe exploitation plans.
- Provide a complete overview of the billing status, eligible costs, planned and actual effort (incl. an explanation of the discrepancies).
- Analyse the lessons learnt at project level.

1.2 Intended readership

The intended readership of this document is primarily Eurocontrol and the SJU. The publishable summary is intended for the wider ATM and ICT ATM communities.

1.3 Inputs from other projects

There was no specific input from other projects.

1.4 Glossary of terms

ATCO: Air Traffic Controller

ATM: Air Traffic Management

CEP: Complex Event Processing

DSL: Domain Specific Language

Correct Prediction: Conflict that was either not predicted by the system as likely to materialise and did not materialise, or was predicted by the system as likely to materialise and did materialise

ESWS: Early Safety Warning System

False Negative (Nuisance) Prediction: Conflict that was not predicted by the system as likely to materialise but did materialise

False Positive Prediction: Conflict that was predicted by the system as likely to materialise but did not materialise

MTCD: Medium Term Conflict Detection

RCA: Root Cause Analysis

Resolved Conflict: Conflict that the system predicts as unlikely to materialise

SOA: Service-Oriented Architecture

Unresolved Conflict: Conflict that the system predicts as likely to materialise

2 Technical Project Deliverables

Management deliverables such as progress reports, gate report or this final report need not be included.

Number	Title	Short Description	Approval status
1.1	Data Management Report	Deliverable reporting on the ATM historical data that have been collected by the partners of the consortium, and that have been the inputs of subsequent data-mining processes; for each dataset, it is included a description of its main characteristics, descriptive statistics about its content, and, whenever necessary, the pre-processing tasks executed on it.	Approved
1.2	COMPASS Scenario Definition Report	This document reports on the definition of specific interesting events related to safety situations, called iEvents. Different types of events, or scenarios, are described, and the specific detection algorithms required for their assessment are discussed. Finally, a descriptive analysis of a specific type of iEvents, namely established FL crossings, is presented.	Approved
1.3	Safety Patterns Report	This document reports on the identification and definition of safety patterns, i.e. combinations of factors that are associated to safety-related scenarios. Different aspects of the operation have been extracted from available operational data, by means of complex systems and data mining techniques. Results indicate that safety-related events could be forecasted with high confidence.	Approved
1.4	Global Patterns Report	This document reports on the use of data-driven strategies to improve the effectiveness of factors that are used to forecast safety-related events. Building on results obtained in D1.3, the effects of changes in the parameters used to construct these factors are assessed though different data mining techniques, improving their capacity in making correct predictions.	Approved
2.1	Domain Analysis	Deliverable 2.1 of the WP-E project COMPASS consists of a domain analysis of the Air Traffic Management (ATM) domain, particularly the Air Traffic Control (ATC) part. The entities being in focus of the further research of the COMPASS project are described along with their attributes and relations between them using UML modelling techniques.	Approved
2.2	Data Analysis	Deliverable 2.2 of the WP-E project COMPASS consists of an analysis of the structure of available ATM data. Also an outline of the relationship between the available ATM data and the abstract domain model of Deliverable 2.1 is presented. Additionally a description of a transformation from ATM data into instances of the domain model is given.	Approved
2.3	Safety Pattern Language and Tool	Deliverable 2.3 of the WP-E project COMPASS reports on the development process and concrete realization of a Domain Specific Language (DSL) for the specification of safety relevant operational scenarios of air traffic and weather. Additionally, the respective airspace	Approved

		configurations can be specified with a dedicated airspace configuration DSL also developed in this deliverable. The report also gives a brief overview of the deployed generative DSL development framework MontiCore.	
2.4	Expert Interface	Deliverable 2.4 of the WP-E project COMPASS documents the extensions to the Early Safety Warning System (ESWS) which form the expert interface for the management and configuration of Safety Patterns. The aforementioned extensions allow Air Traffic Control (ATC) experts to create, update, and select safety patterns to be executed in order to early on detect situations which are considered to be of major importance for safe operation. This report describes these new features and how domain expert users of the ESWS can use them.	Approved
3.1	Integrating Complex Event Processing and Root Cause Analysis	Deliverable 3.1 of the WP-E project COMPASS investigates the integration of Complex Event Processing (CEP) and Root Cause Analysis (RCA) techniques. The background and application of these techniques are studied and their relevance in the ATM domain discussed. This report also presents an approach describing how the integration may be achieved and discusses some example of scenarios highlighting the potential contribution of the integration in the safety management of ATM systems.	Approved
3.2	Integration with Safety Language	In this deliverable D3.2 we report on the development of the mechanism, which allows the integration of the Safety Pattern Language with the Early Safety Warning System. An overview of the Early Safety Warning System is presented to give a better understanding of its internal model, and the architecture and functionalities of the transformation mechanism with the Safety Pattern Language are discussed.	Approved
3.3	Early Safety Warning System Architecture	In this deliverable D3.3 we report on the development of the Early Safety Warning System. An overview of the Early Safety Warning System architecture, and the design and implementation of the database, which is currently used to construct the models are presented. ESWS models, which underpin the system, its analysis mechanism, as well as the ESWS GUI Workbench are discussed.	Approved
3.4	Operation with Live Data	Up to D3.3, the Early Safety Warning System (ESWS) provided planning-based tools, which could help maintain safety in the airspace by - for example - using flight plans to predict potential conflicts between flight trajectories and to predict traffic congestion throughout the day. Whilst such flight-plan-based tools are undoubtedly useful, it is also essential that Air Traffic Controllers constantly monitor the positions of aircraft rather than rely solely on flight plans. This is most commonly achieved with the use of “live” (radar) data. In D3.4, we document the extensions to, and modifications of, the ESWS, which enable it to utilise “live” radar data while also preserving the flight-plan-based functionality of the system. More specifically, the extensions and	Approved

		modifications pertain to three fundamental areas: radar-driven flight position estimation, incremental conflict detection, and incremental safety pattern analysis. An outline of newly introduced ESWS classes and modification to existing ESWS classes is given.	
3.5	Early Safety Warning System Experiment	The Early Safety Warning System (ESWS) provides tools which aim to help maintain safety in the airspace, by using flight plans and radar data to predict potential conflicts between flight trajectories, and by using safety pattern analysis to allow predicted conflicts to be prioritised by ATCo. In this document, we discuss how we re-engineered the ESWS from a desktop-based application into a scalable distributed service-oriented architecture (SOA) that enables the system to evaluate the accuracy of safety patterns against large datasets. We also report on evaluating the reduced safety pattern produced in WP1 against 44 days worth of ALL_FT data using the SOA. The results of this experiment provide confidence on the usefulness of the SOA for evaluating the accuracy of safety patterns, and demonstrate the high accuracy of the safety pattern produced in WP1. We also report on the outcome of a validation meeting with ATM domain experts from THALES Air Systems, during which the experts unanimously expressed their support for the approach followed in COMPASS and a strong interest in the findings of the project.	Submitted

Table 1 - List of Project Deliverables

3 Dissemination Activities

3.1 Presentations/publications at ATM conferences/journals

Provide one paragraph per presentation, mentioning the name of the event, date and place, the title and a short description of the presentation. Add the full reference of the associated paper in 0. Provide an additional paragraph on the feedback, where appropriate.

Title: On Demand Data Analysis and Filtering for Inaccurate Flight Trajectories [1]

Event: SESAR Innovation Days (SID) 2011 (29/11/2011 - 01/12/2011)

Description: The submitted and presented paper reports on work performed in the context of the COMPASS SESAR-JU WP-E project, on developing an approach for identifying and filtering inaccurate trajectories (ghost flights) in historical data originating from the EUROCONTROL operated Demand Data Repository (DDR).

Title: Synchronization Likelihood in Aircraft Trajectories [2]

Event: Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago, 2013

Description: The metric specifically developed inside D1.3 for detecting synchronization between aircraft trajectories, which has been called Trajectory Synchronization Likelihood, has been presented at the 10th USA/Europe Air Traffic Management Research and Development Seminar, Chicago, June 10-13, 2013. The presentation included an overview of the problem, i.e. the detection of factors describing the future appearance of safety events; a description of the metric, as an evolution of the Synchronization Likelihood metric used to evaluate brain dynamics; and a demonstration of its predictive power. Several people asked for more information, including people from ICAO, FAA, and Crown Consulting Inc.

3.2 Presentations/publications at other conferences/journals

Provide one paragraph per presentation, mentioning the name of the event, date and place, the title and a short description of the presentation. Add the full reference of the associated paper in 0. Provide an additional paragraph on the feedback, where appropriate.

Title: The COMPASS Early Safety Warning System

Event: Dagstuhl Seminar on Software Certification (27/1/2013-1/2/2013)

Description: An overview of COMPASS results was given at the recent (27 Jan-1 Feb) Dagstuhl Seminar on Software Certification. The audience of 60 attendees was drawn from US industry (e.g., FDA, avionics, aerospace, nuclear), US/Canadian academia, European academia/industry (aerospace, avionics, cloud computing). The results were very well received with opportunities for new collaboration with the Software Certification Consortium (based out of UPenn) and the US Office of Naval Research identified.

3.3 Demonstrations

Provide one paragraph per demonstration (excluding demonstrations part of validation exercises or acceptance tests), explaining what was demonstrated and to whom. Provide an additional paragraph on the feedback.

Title: The COMPASS Early Safety Warning System

Event: SESAR Innovation Days (SID) 2012 (27/11/2012 - 29/11/2012)

Description: A live demonstration of the ESWS was performed in the context of the SESAR Innovation Days 2012 to ATM experts and scientists.

Title: The COMPASS Early Safety Warning System

Event: SESAR Innovation Days (SID) 2013 (26/11/2013 - 28/11/2013)

Description: A live demonstration of the ESWS was performed in the context of the SESAR Innovation Days 2013 to ATM experts and scientists.

3.4 Exploitation plans

Describe, per project participant, how the results or lessons learnt from this project will benefit the company or the research community in the future.

RWTH Aachen University

For the Software Engineering group of the RWTH Aachen University the project embodies a highly interesting field of application for our domain specific modelling methods and technologies. The investigated approaches for the reasonable custom-tailored specification of potentially complex operational scenarios helped us to understand general requirements for such Domain Specific Languages (DSL). We expect the resulting knowledge to be useful in various domains and consider the deployment of domain specific modelling techniques to be a valuable benefit for the ATM research domain.

York

This project has helped us (York's Enterprise Systems group) build expertise in the ATM domain and identify interesting directions for future research, including distributed architectures for processing large spatiotemporal datasets, and hybrid data persistence back-ends for efficient storage and retrieval of such datasets. We anticipate that the experience gained by building the Early Safety Warning System will be highly valuable for future projects in the ATM domain.

Innaxis

This project has meant for Innaxis the proof of concept on the benefits of a Data Science approach for safety in ATM. Several ad-hoc techniques have been developed in the project, as for instance the automatic detection of factors related with the appearance of safety events, which could have a wider application scope in terms of scenarios to be considered. Innaxis is working on further developments, aimed both at improving safety monitoring systems and at tackling other open safety-related problems by means of a Data Science approach, like the development of KPIs for safety or the transitions over automated systems.

THALES

This project has helped us at THALES identify interesting directions for the feature roadmap for THALES products and research areas for THALES projects, including specifically, more accurate forms of MTCD. We anticipate that the advantages of COMPASS methodology and results as demonstrated by the Early Safety Warning System will be highly valuable for future projects and products.

4 Total Eligible Costs

This section is based on the Project Costs Breakdown Forms of the eligible costs incurred by project participants.

Date	Deliverables on Bill	Contribution for Effort	Contribution for Other Costs (specify)	Status
Date of invoice	*List of deliverable numbers*	*Requested contribution for effort*	*Requested contribution for travel, licences, logistics etc.*	*Billed or paid*
18/12/2012	D0.0, D0.1	25.706,50		Paid
18/12/2012	D0.1, D0.2, D1.2, D2.1, D2.2, D3.1, D4.1, D4.2	164.950,50	2300	Paid
05/12/2012	D0.3, D0.4, D2.3, D3.2, D3.3, D4.3, D4.4	130.739,50		Billed
05/12/2012	D0.5, D0.6, D1.3, D2.4, D3.4	158.863,75	9750,50	To Be Billed
05/12/2012	D0.7, D0.8, D0.9, D1.4, D3.5, D4.5, D4.6	119.652,00	9750,00	To Be Billed
GRAND TOTAL		599.911,25	27,944,00	

Table 2 Overview of Billing

Company	Planned man-days	Actual man-days	Total Cost	Total Contribution	Reason for Deviation
See Financial Tender	*See Financial Tender*	*TBD (pending final CBFs)*	*TBD (pending final CBFs)*	599.911,25	*TBD (pending final CBFs)*
GRAND TOTAL					

Table 3 Overview of Effort and Costs per project participant

5 Project Lessons Learnt

What worked well?
Give the Top-5 of positive aspects and explain why it allowed the project to achieve its objectives.
Close collaboration and regular face-to-face meetings
Good use of remote collaboration facilities (version control management systems, mailing lists)
Balanced expertise in the consortium between ATM and ICT
What should be improved?
Give the Top-5 of potential improvements / suggestions.
Identifying and gaining access to ATM data took longer than anticipated. For subsequent rounds of research project it may be beneficial to centrally identify and disseminate the available datasets, the owning organisations and the processes through which they can be acquired.
The progress report spreadsheet can become challenging to work with, particularly as the number of actions/deliverables/risks grows.
A stronger push for releasing the software products of research projects as open-source software – where applicable – could help improve reproducibility of results and reduce duplication of effort in subsequent projects.

Table 4 - Project Lessons Learnt

6 References

Reference to main documentation, delete if not required

[1] M. Zanin, D. Perez, K. Chatterjee, D. Kolovos, R. Paige, A. Horst and B. Rumpe. *On Demand Data Analysis and Filtering for Inaccurate Flight Trajectories*. In: Schaefer, Dirk (ed) Proceedings of the SESAR Innovation Days (2011) EUROCONTROL. ISBN 978-2-87497-024-5.

[2] M. Zanin, *Synchronization Likelihood in Aircraft Trajectories*, in Proceedings of the Tenth USA/Europe Air Traffic Management Research and Development Seminar (ATM2013), Chicago, 2013.