# D2.1 Project Scope

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# FARO

SAFETY AND RESILIENCE GUIDELINES FOR AVIATON

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## Abstract

The Deliverable "D2.1: Project Scope" is the first of the deliverables planned within WP2 "Safety and Resilience Conceptual Framework". This document establishes the theoretical basis of the work to be performed within FARO project. It presents the main objectives of the project as well as a summary of the work to be conducted after alignment of the interests of all stakeholders involved, including the SJU, in the form of entry and exit criteria for each of the Work Packages of the project. Additionally, it provides a review of the State of the Art in Safety and Resilience domains and in other transportation modes (such as train, maritime and road), as well as the complete list of other SESAR projects that are related to FARO.

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# 1 Introduction

FARO stands for "saFety And Resilience guidelines for aviatiOn". In a glance, the project addresses the evaluation of the impact of new automation solutions on safety and resilience. This evaluation is conducted by applying knowledge and data-driven approaches.

The aim of FARO is to bring a new light about how safety and resilience are addressed in ATM through four objectives:

- **Capitalisation of the existing knowledge of safety**. This objective is focused on the systematic extraction of the extant safety knowledge through data-driven techniques and a knowledge-based approach. The final goal is to define a conceptual framework which enables the evaluation of safety and resilient performance in terms of the technical, organisational, human and procedural characteristics of the ATM system.
- **Quantification of the impact of increasing the level of automation on ATM safety levels**. This objective pursues the generation of predictive models of safety events as a way to quantify the likelihood of these events and a measure of the safety level. This approach allows moving to a predictive perspective where safety is understood as the ability to succeed under varying conditions.
- **Analysis of the impact of higher levels of automation on ATM resilient performance**. The aim of this objective is to analyse the impact on resilient performance of the system, by characterising it as a function of performance variability and adaptive capacity. Its goal is to define a resilience baseline of the current system for the quantification of the system in terms of resilient performance and adaptive capacity.
- **Provision of design guidelines and identification of future research needs**. Through this objective, FARO project pursues the development of a set of guidelines to facilitate the definition and evaluation of the safety and resilience criteria associated to a new automated solution, as well as the identification of research gaps.

## 1.1 Purpose of the Document and relation to WP2

The Deliverable "D2.1: Project Scope" is a report covering the project scope and general approach of the FARO project. It includes a summary of the project scope, aligned with the interests of all internal stakeholders involved in the project, including the SJU, as well as a review of the State of the Art in Safety and Resilience domains in aviation and in other transportation modes (such as train, maritime and road).

The Deliverable "D2.1: Project Scope" is framed in WP2 "Safety and Resilience Conceptual Framework" whose objective is to collect all relevant inputs from the project team to define the scope, make an extensive literature review of the safety and resilience and transfer knowledge from other transportation domains. These activities will be translated into a set of use cases to be evaluated and later validated, as well as in a set of information management requirements.

The five tasks included in WP2 are:

- **T2.1 Project Scope and Alignment**. It summarises the project approach and scope, aligned with the interests of all stakeholders involved.

- **T2.2 State of the Art Review**. It reviews the State of the Art of the safety and resilience domains, with special focus on recent achievements brought by SESAR, to bring the most up-to date knowledge to the project.
- **T2.3 Knowledge Transfer from other Transportation Domains**. It reviews the work already done in other domains such as the railway and maritime trying to identify synergies between those domains and aviation for the subsequent safety and resilience analysis.
- **T2.4 Case Study Selection**. It implies the selection of the use cases to validate the safety and resilience models to be developed throughout the project.
- **T2.5 Information Management Requirements**. It is devoted to the derivation of information management requirements for identifying and assessing the data acquisition and management requirements for the project.

The first three tasks are the ones covered in the D2.1 report and will be further completed with future activities including the translation of this initial material into a set of use cases to be evaluated and later validated (to be covered by “D2.2: Case Studies”) and in a set of information management requirements (to be covered in “D2.3: Data, Computing and Visualisation Requirements”).

## 1.2 Document Structure

This document is structured as follows:

- Section 1 introduces the project objectives and the purpose of this document.
- Section 2 analyses the outcomes of task “T2.1: Project Scope and Alignment”
- Section 3 covers the task “T2.2: State of the Art Review”
- Section 4 presents a summary of the activities in task “T2.3: Knowledge Transference from other transportation domains”
- Finally, Section 5 shows the main conclusion of these 3 tasks.

## 1.3 Acronyms

| Term | Definition |
|---|---|
| AcciMAP | AccciMap systems based accident method |
| ADREP | Accident/Incident Data Reporting |
| ANSP | Air Navigation Service Providers |
| ATC | Air Traffic Control |
| ATCO | Air traffic controller |
| ATM | Air Traffic Management |
| AU | Airspace User |
| BAFO | Best And Final Offer |
| CEANITA | Comisión de Estudio y Análisis de Notificaciones de Incidentes de Trafico Aéreo |
| EASA | European Aviation Safety Agency |
| EB | Empirical Bayes |

| | |
|---|---|
| ECCAIRS | European Co-ordination Centre for Accident and Incident Reporting System |
| EOFDM | European Operators Flight Data Monitoring |
| ERTMS | European Railway Traffic Management System |
| EU | European Union |
| FARO | saFety And Resilience guidelines for aviatiOn |
| FMEA | Failure Mode and Effects Analyses |
| FP7 | Framework Programme |
| FRAM | Functional Resonance Analysis Method |
| HAZOP | Hazard and Operability Analysis |
| HERA | Human Error Reduction in Air Traffic Management |
| HP | Human Performance |
| ICAO | International Civil Aviation Organization |
| LoS | Loss of Separation |
| MAC | Mid Air Collision |
| MF | Modification Factor |
| ML | Machine Learning |
| NLP | Natural Language Processing |
| OFA | Operation Focus Area |
| PRA | Probabilistic Risk Assessment |
| RPAS | Remotely Piloted Aircraft Systems |
| RTM | Regression To The Mean |
| S&R | Safety and Resilience |
| SAF | Safety |
| SES | Single European Sky |
| SESAR | Single European Sky ATM Research Programme |
| SJU | SESAR Joint Undertaking (Agency of the European Commission) |
| SMS | Safety Management System |
| SOAM | Systemic Occurrence Analysis Methodology |
| SPFs | Safety Performance Functions |
| STAMP | System-Theoretic Accident Model and Processes |
| VT | Validation Target |
| WP | Work Package |

# 2 T2.1 FARO Scope and Alignment

## 2.1 Introduction

Task T2.1 aimed at summarising the project approach and scope to align them with the interests of all stakeholders in the ATM system, including an interaction with the SJU to agree on a common view of the Project. To do this, the consortium carried out an introspective process to determine the range of subjects each WP was going to cover, through the identification of the entry and exit criteria for each of these WPs, i.e. their required inputs and expected outputs.

This section presents a summary of the findings of this task: main inputs required by the different WPs to conduct their activities, as well as an overview of their expected outputs. This task sets the basis for the work to be developed throughout the project, and allows the identification of gaps, overlaps and dependencies across WPs. Figure 1 illustrates the content of the project, which is further discussed in the remainder of the section, including detailed explanations of the inputs and outputs to be produced by each WP.

The entry and exit criteria for each WPs shall be understood to be commensurate to the developments of T2.4, devoted to the modelling of the Use Cases.

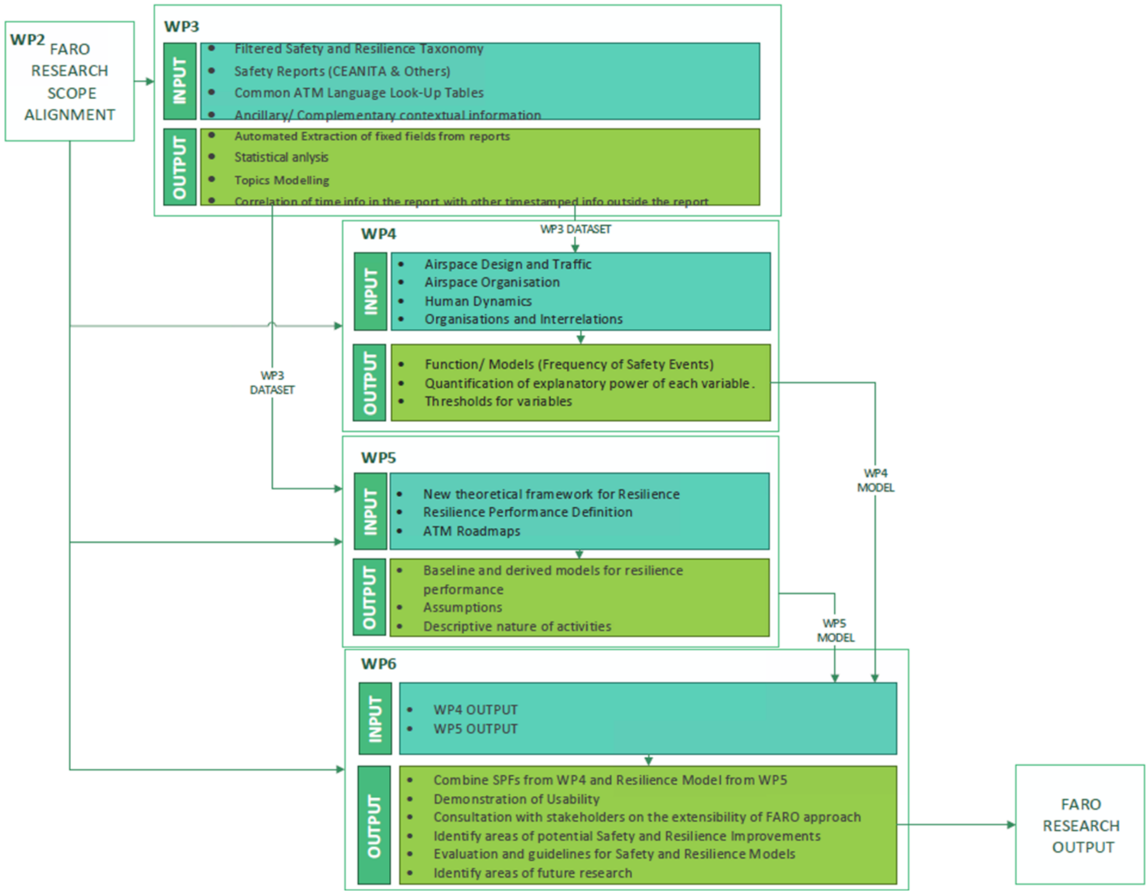


**Figure 1: Overview of the inputs required, and outputs expected by each WP in FARO Project.**

## 2.2 WP3 “Data Management and Engineering”: Entry and Exit Criteria

The entry and exit criteria are summarised in the following sections 2.2.1 and 2.2.2. These criteria are based on the initial thoughts and discussions with the partners in WP2, and these might be modified during the execution of WP3, that has not started at the time of writing this document.

### 2.2.1 WP3 entry criteria

The WP3 entry criteria are based on the input expected from WP2:

- A sufficient number[1] of safety reports to be analysed, currently limited to those published by CEANITA (*Comisión de Estudio y Análisis de Notificaciones de Incidentes de Trafico Aéreo*), in Spanish. It is expected to receive, if confidentiality issues allow it, additional safety reports in English and Spanish. These safety reports will correspond to the reportable safety-related occurrences, commensurate to the Use Cases to be defined in T2.4.
- The availability of:
    - Existing taxonomies of ATM in Spanish and English languages;
    - Look-up tables with the most common acronyms, abbreviations and sectorial expressions in Spanish and English.
    - Any other available ancillary/ complementary/ contextual information related to each individual safety report (e.g. the trajectories of the involved aircraft).

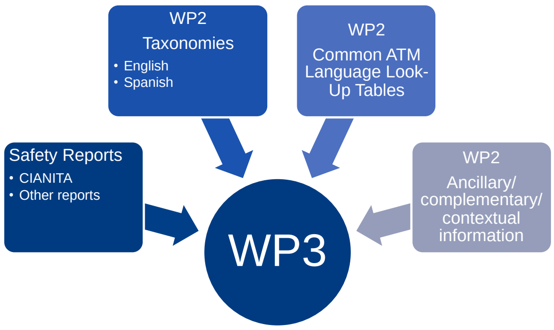


**Figure 2: The current WP3 entry criteria**

### 2.2.2 WP3 exit criteria

On the basis of the analysis of the state of the art of Natural Language Processing (NLP) and Machine Learning (ML) in aviation and other transport domains, carried out in WP2 T2.3 (see Section 4) at the

[1] From the statistical point of view to be able to apply Natural Language Processing (NLP) and Machine Learning (ML) techniques

time of writing this deliverable, it is possible to hypothesize as WP3 exit criteria a set of both qualitative and quantitative information and the corresponding tools and models to generate them.

Qualitative information will be extracted via these tools/models:

- Automated extraction of fixed fields from reports;
- Statistical analysis of safety reports including:
    - (Combination of) words count across reports;
    - Prevalence of keywords (e.g. causal factors like “wrong authorization”, “level bust” or “adverse weather”, or names of ATS units frequently involved);
- Topics modelling, i.e. extraction of abstract “topics” occurring in a collection of documents, potentially correlated with existing taxonomies and ancillary/complementary/contextual information;
- Correlation of time information in the reports with other timestamped information (e.g. trajectories) in ancillary/complementary/contextual data sets, commensurate to comply with the data management plan provisions in D1.2;
- Sentiment in reports, i.e. exploiting the NLP capabilities to extract sentiment from text;
- Identifying similarities between safety reports;
- Network visual representations of keywords in reports.

In addition, WP3 will transform the available data, in line with the conceptual framework and use cases defined in WP2, in order to cover the needs of WP4, WP5, WP6 and WP3 itself. In this sense, the expected quantitative WP3 outputs are:

- Training and testing datasets, containing highly integrated data covering WP4 and WP5 data requirements for safety and resilient performance dimensions and metrics.
- The datasets will include raw data and transformed information tailored to the use cases. As an example of raw data, these will include radar tracks, ATCo actions and events, sector entry and exit times, flight plans, information about the airspace structure (sectorisation, sector geometries), safety nets information (STCA alerts) or Mode-S information such as the Indicated Airspeed (IAS) for one of the use cases. As an example of transformed information, the datasets will include aggregated figures such as occupancies or hourly entry counts, commensurate to each use case.

## 2.3 WP4 “Safety Analysis: Identification of Safety Performance Functions”: Entry and Exit Criteria

The development of the conceptual framework (WP2) and the data engineering process (WP3) will underpin the identification of the Safety Performance Functions. Figure 3 illustrates the methodology, which is decomposed in two main blocks.

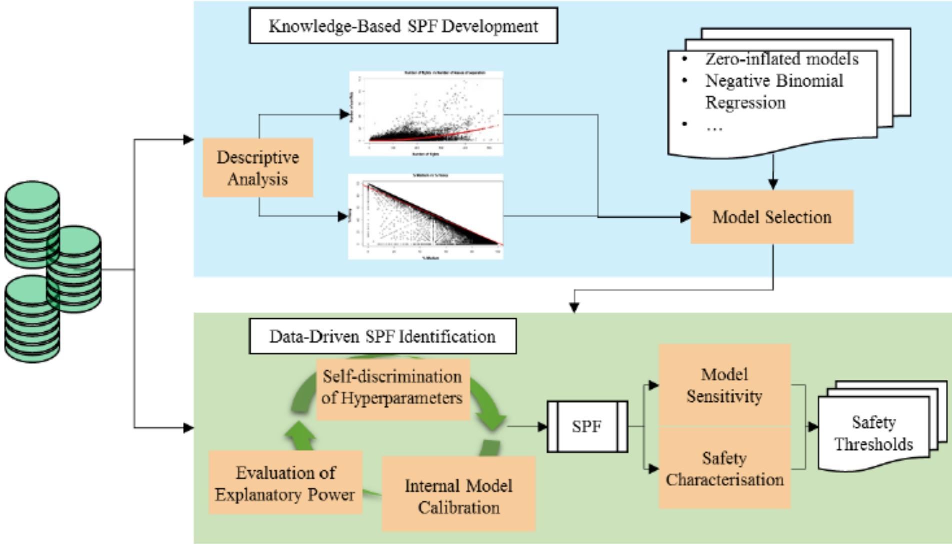


**Figure 3: Overall process in WP4.**

### 2.3.1 WP4 Inputs

The development of the SPFs will start with a characterisation of the safety events in terms of the safety dimensions and their aggregations. The safety events addressed by WP4 would be those related to the Use Cases to be defined in T2.4. Dimensions are expected to be defined in the framework of T2.4. The required data is expected to come from the outputs of WP3.

The outcome of this descriptive analysis together with prior statistical knowledge will serve to select potential models (zero-inflated models, negative binomial regressions, etc.) that could provide statistical representations of the frequency and severity of the safety events. Figure 4 represents this process within the top blue box.

The next step of the methodology is the identification of the SPFs themselves after the descriptive analysis and the selection of the potential statistical models in an automated manner. For doing so, it is envisaged to conduct a self-learning process in which the models are trained depending on different independent variables (dimensions), considering mixed effects and regularisation strategies to prevent overfitting.

The explanatory power of each independent variable and the mixed effects will be quantified as well in order to feed a self-discriminating method that selects via comparison of internal metrics, such as the Akaike Information Criterion (AIC) or the Bayesian Information Criterion (BIC), the ensemble of models and dimensions that have provided a larger predictive power.

In addition, the analyses conducted within T2.1 have shown that there is room for mutual collaboration between WP4 and WP5. For example, interim outputs that may be directed from WP5 to WP4 are:

- The identification of new processed dimensions by means of the characterisation of the system "work as done"[2], that may be suitable to be included as factors in the generation of the SPFs.
- The identification of prominent organisational and distal factors that may be fed to the process of generating the SPFs.

### 2.3.2 WP4 Outputs

The outcome of the previous process are the SFPs. The methodology will derive independently the sensitivity to the selected dimensions. The sensitivity analysis to the independent variables, considering also mixed effects, will enable to characterise safety not only in terms of the independent dimensions but also their combinations, identifying prior thresholds of those dimensions that could reduce the frequency of the addressed type of safety events. This process is expected to be a pure data-driven process.

## 2.4 WP5 "Resilience Analysis": Entry and Exit Criteria

WP5 is the work package that contributes to FARO the scientific discipline of Resilience Engineering. The WP itself involves three methodological steps that create a view of the socio-technical system through three different perspectives. Each of these perspectives provides an input to the other work packages.

The first step is to derive and develop a base case for resilient performance of the ATM system as it is in its current, but pre-COVID19, system state[3]. Eliciting the characteristics of the ATM system that drive resilient performance is one aspect that characterises the system's ability to adapt and manage and deal with the inevitable performance variability that the ATM system confronts and responds to as part of the everyday *'work'* that the system undertakes. Here, *work* can be considered as the purposeful activity that the system is designed to support and enable.

The strategies that are used by the system actors are one object that will shape the outputs from WP5 for these provide insight into how the system adapts, the costs in terms of coordination with others to exploit adaptive capacity and sustain the operation of the system in both effective and safe operation in terms of resilient performance.

At the centre of FARO is to explore the resilient performance of a future ATM system state or states. The changes that this induces in resilient performance – the nature of adaptive capacity, the sources of resilience, the characteristics of patterns of adaptation, the new boundary conditions – all contribute to the outputs to other work packages directly (WP6) as well as indirectly (WP3 & WP4).

### 2.4.1 Inputs to WP5

The inputs into this work package are anticipated to be:

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[2] See Sections 3.2.3 and 3.2.4

[3] Resilient performance has as its unit of analysis the system itself and defined as the system of interest. See Section 2.4.3

- The WP2 characterisation of the socio-technical aspects and system facets
- Processed data from WP3 needed to develop WP2's Use Cases in terms of resilient performance.

The analyses conducted within T2.1 have shown that there is room for mutual collaboration between WP4 and WP5. For example, the interim outputs that may be directed from WP4 to WP5 are:

- The secondary analysis of the SPF that is the primary object of interest in WP4.
- Characterisation of organisational and distal factors as well as thresholds identified through the derivation of SPFs

### 2.4.2 Outputs from WP5

The outputs from this work package are primarily in the service of WP6. Currently, these have been defined as:

- The baseline and derived model of resilient performance for both the current and envisaged ATM system designs.
- The assumptions that are embedded in the resilience model and the changes assumed in the evolution of the work system.
- Structural characteristics of the systems in terms of adaptive capacity.
- Some description of the nature of the activities of the work system, especially in relation to performance variability.
- The characteristics and artefacts of resilient performance.
- A proposed system of resilient indicators and metrics at the Meso, Micro, Macro levels.
- Some indications of the conditions or patterns of activity that may generate brittleness in the work system as well as the assumptions around how these patterns influence resilient performance.

### 2.4.3 WP5 Processes and Methods

Methodologies that are commonly used in the research and study of resilient performance are typically multi- and inter-disciplinary. Drawing most upon social science as well as, for example, complexity science, general systems theory and systems thinking [1] and cognitive systems engineering [2] including Cognitive Work Analysis [3].

The theoretical framework that underpins the methodology, from which will frame the epistemological position, in the case of Resilience Engineering, will be one that is inherently practice-based. The object is the *work system* itself, where the *work system* is assumed to be characterised as a socio-technical system [4]. In such a *'system'* the human work, the human actor, is situated within a social context as well as a technical context. Human actors in socio-technical systems rarely work independently, but work situated in some socially organised group or formal organisation. The unit of analysis in studying socio-technical systems therefore is the *work system* that is constructed to achieve the panoply of design objectives and its goals. It is through this that the joint optimisation of human and technology can be explored.

The *work system* in socio-technical theory is considered to be complex and adaptive, and that has been taken into resilience engineering. Complexity, as an emergent property of the system, is a resultant of the system goals and demands upon it not being constant as well as the variability in performance that flows from changes in the operating environment. These lead to the juxtaposition of variance in the couplings and interactions between system artefacts, actors, practitioners as a well as the organisation itself.

Agents within the *work system* can be human actors or technical artefacts. The research inquiry is one that pursues the relationships between these through analysis and synthesis of the *work system.* At one level of system abstraction, the interaction or dependencies that emerge from the co-agency of machine artefacts and human actors and also the criticalities that emerge from the interaction of the co-agents. Questions that can be posed are how they work together and how they evolve and intertwine into tangle layered networks of social agency and praxis. Especially, resilience engineering recognises that socio-technical systems are characterised by complexity. How this complexity is understood, perceived and accounted for in the purposeful activity that the work system undertakes is a principal element of understanding resilient performance.

Resilience engineering has as its unit of analysis, not the explicitly micro level of work system activity but the meso and macro level as well. A principle of Joint cognitive systems is that it moves beyond the traditional view of cognitive science to a much larger system of interest. So, in conjunction with resilience engineering, here the discipline has as its object of interest the socio-technical system potentially through some of its characteristics – coordination, adaptive capacity through the sources of resilience, and the pattern of activities and interactions as the *work system* adapts to both complexity and variability. At the micro level of abstraction, a suitable empirical analytical frame is that of the archetypes of work [5].

Resilience engineering assumes that socio-technical systems are complex and non-linear. This has implications for the methods and methodologies that are used hence the use of the previously referred practice based and naturalistic approaches that explore situated action [6].

The FARO methodology will use a systems theory to develop a broad understanding of the ATM system as it is currently established. What will be derived is the 'system of interest' from which a series of workshops can derive a view of the nature of performance variability. Through these outcomes particular episodes can be developed and explored with actors and the strategies that are typically used, which can be elicited as well as the boundary conditions.

The data from these data gathering exercises will be subject to synthesis that leads to a system model which will be the basis for understanding the social-technical systems characteristics and properties, such as the sources of resilience as well as propagators of complexity and the nature of emergent system behaviour.

This will be qualitative and narrative results, from which further synthesis can be used to deduce the nature of resilient performance. Especially its nature, adaptive capacities as well as the assumptions that are made that sustain resilient performance of the ATM system.

A number of models are available for use that are effective in synthesising the goal conflicts and trade-offs that characterise safe production of the ATM system. Rasmussen [7] introduced what is known as the *'gradient model'* which has been used to explore resilient performance in aviation and non-aviation contexts.

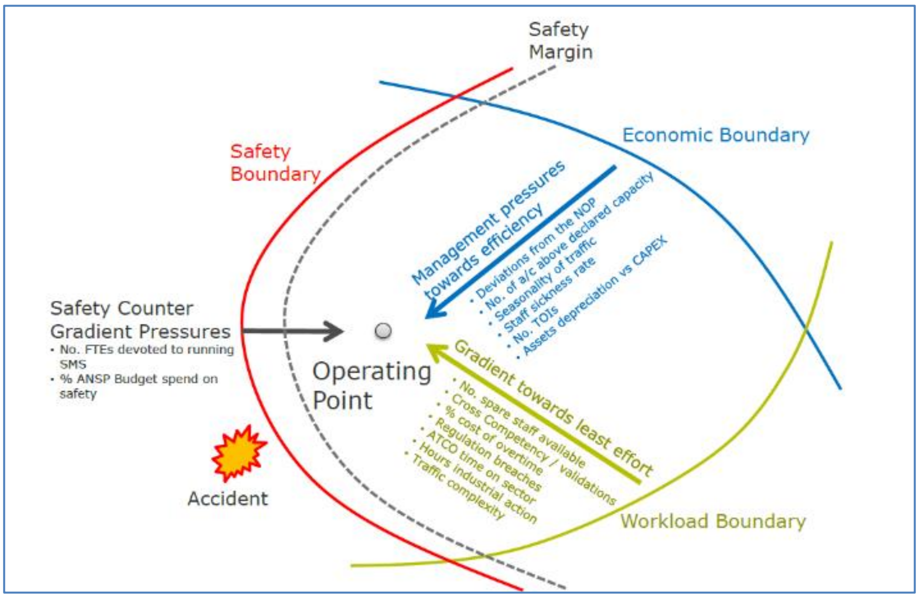


**Figure 4: Rasmussen Gradient model as applied in an ATM context**

The Rasmussen gradient model is one that provides a frame for a narrative description of the nature of operations, the operating point as well as the organisational factors that push the operating point in a direction and helps to establish the presence or otherwise of counter gradients.

Other structural models that have been used in the analysis of resilient performance include ACCIMAP, STAMP and FRAM. In the latter case, FRAM has been used to examine the operational impact of automation in ATM [8], a mid-air collision in Brazil [9] and in the flight deck in the instance of a runway overrun [10].

## 2.5 WP6 "Safety and Resilience Guidelines": Entry and Exit Criteria

### 2.5.1 WP6 Inputs

The objective of WP6 "Safety and Resilience Guidelines" is to validate the safety and resilience performance analysis together with the data ecosystem within the context of the current and future ATM concepts, by demonstrating the usability of the safety and resilience performance models to enable:

- the generation of design guidelines, and
- identification of future research needs.

Having in mind that WP6 is located at the end of the project, **explicit inputs** are expected from WP4 "Safety Analysis" and WP5 "Resilience Analysis". **Implicit inputs** are expected from WP2 "Safety and Resilience Conceptual Framework" (see Figure 5).

Apart from these two input categories, there is another called **Internal inputs**, generated within WP6, during execution of T6.2 – Consultation with Stakeholders (See Figure 5).

Following inputs will be required from WP4:

- The assumptions that are embedded in the safety model.

- Functions/models that would provide statistical representations of the frequency of the safety events as function of different independent variables (dimensions) that will consider technical, organizational, human and procedural characteristics of an ATM system.
- Sensitivity analysis that will quantify the explanatory power of each independent variable and the mixed effects when possible.
- Identification of possible thresholds for the independent variables (dimensions) that would help to reduce the frequency of a safety event.

Following inputs will be required from WP5:

- A baseline and derived model of resilient performance.
- The assumptions that are embedded in the resilience model.
- Some description of the nature of the activities of the work system.
- The characteristics and artefacts of resilient performance.
- A proposed system of resilient indicators and metrics: Meso, Micro, Macro.

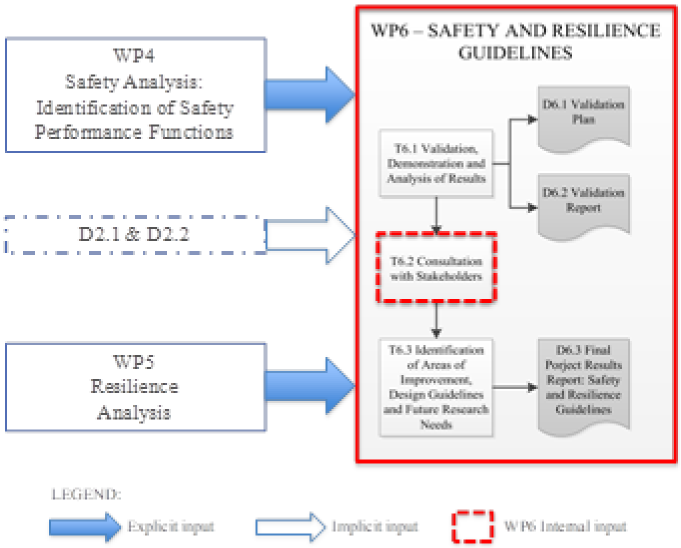


**Figure 5: Inputs for WP6**

## 2.5.2 WP6 Outputs

The outputs from this WP will serve as a general output from the project.

A specific output from Task 6.1 will be the D6.1 “Generic Validation Plan”. D6.1 will be created explaining how to perform analysis combining safety and resilience models both in case of current and future ATM Concept (see Figure 6).

There are some challenges foreseen related to this output Figure 6: first - How to combine safety and resilience models having in mind their different nature (quantitative vs. qualitative)?, but also - what other analysis should be undertaken in D6.1? and what does it consist of?

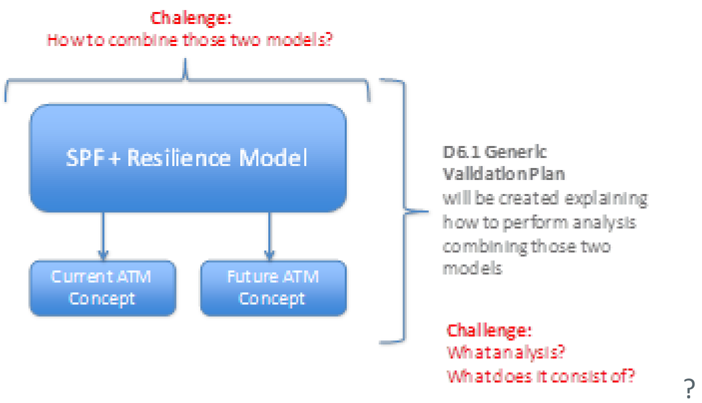


**Figure 6: Output from Task 6.1**

A specific output from Task 6.2 will be the D6.2 Validation Report. This deliverable should combine following: a) Consultations with stakeholders with the aim to evaluate current and future ATM concepts from a safety perspective, and b) Consultations with experts from other domains related to extensibility of the FARO approaches to their domains. Findings from those two consultations will be summarised in D6.2 (See Figure 7).

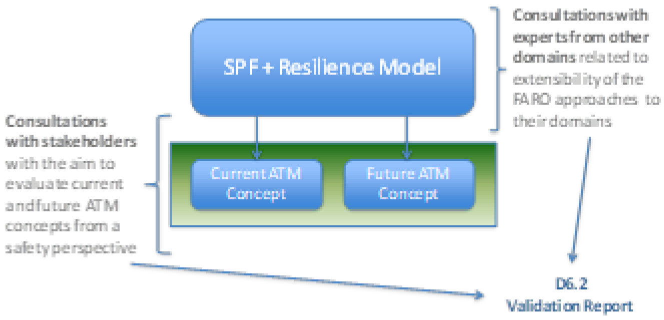


**Figure 7: Output from Task 6.2**

Task 6.3 should provide the D6.3 Final Project Results Report: Safety and Resilience Guidelines in which findings from D6.1 and D6.2 will be combined resulting in the following outputs (See Figure 8):

- Identification of areas of potential safety and improvements in resilient performance (challenge here is what improvement to cover: improvements of safety or resilience, or improvement of safety/resilience models?);
- Evaluation of the developed S&R models; and
- Definition of the design guidelines on how to use the SPF and resilience methodologies.

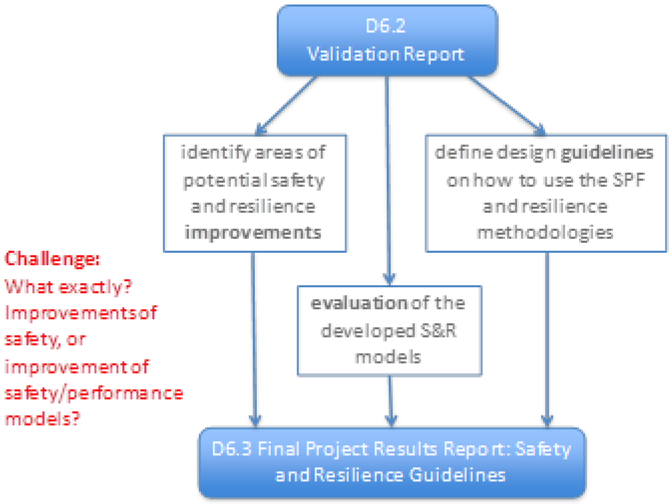


**Figure 8: Output from Task 6.3**

# 3 T2.2 State of the Art Review: An Overview

This section presents an overview of the state-of-the-art in safety data analysis, Safety Performance Functions and resilience, covering the most important topics and the relationship to other SESAR projects.

## 3.1 Safety Data Analysis

Current knowledge of the determining factors of the occurrence of LoS incidents between aircraft is limited as is the current industry's ability to predict them. Studies and models that analyse or determine the safety of aircraft operations in the airspace, and the loss of separation between them, have so far focused on intervention and human error as the main cause of unsafe situations as a result of loss of separation between aircraft [11] [12] [13].

Incidents of loss of separation between aircraft, generally respond to very low frequencies of occurrence, making it very difficult to have a sufficient volume of data to allow relevant statistical analyses. As the SESAR Safety Reference Material [14] points out:

> *"Due to the high level of safety reached in ATM, relatively little data is available on negative safety outcomes; as a consequence, it is increasingly difficult to deliver further safety benefits using standard approaches to safety"*

Due to this, most of the work have been devoted to ex post analysis, and to the reconstruction of the events that have led to a loss of separation between aircraft in the air [12]. Some work has created analytical models, in which the probability of incidents is predicted based on the expected trajectories of future aircraft, calculated based on the respective flight plans [13]. However, there are very few references that exploit operational data in a massive way, that is, the large volume of data on all those operations in airspace that have not resulted in separation losses [15] [16]; nor that allow incorporating information from experts into predictive models, or using data from scenarios or situations with similar characteristics [17]. It is important to report and evaluate those safety events that are less serious. Data and statistics on less serious incidents can provide extensive and valuable information, considering that this type of data is more frequent, and that the reports generated are simpler and more accessible.

To address all of these shortcomings, a combination of reactive, proactive, and predictive analysis is required to exploit the potential of safety-related data and provide feedback on potential hazards and operational risks. In this context, the statistical models used, and the safety analysis carried out must evolve from the analysis of reactive methods towards a more predictive perspective, which allows predicting the likelihood of future safety events.

In recent decades, relevant research has been conducted on the use of modern statistical techniques to predict safety incidents and precursors in other modes of transport, specifically road transport. These tools are increasingly being used for predictive applications in areas such as microbiology, sociology, psychology, econometrics, structural engineering, nuclear physics, etc. Two of the most widely used ones are hierarchical and Bayesian models. The relevant academic literature give interesting examples of the types of aviation-related issues to which Bayesian techniques can be applied. Examples include [18] [19] [20].

The most commonly used statistical models, within the framework of Bayesian inference, include Binomial models (used to model the number of successful/failed events of a total number of operations); Poisson (which models the number of occurrences of a certain event in a predetermined time interval); and Gamma-Poisson (or negative binomial, which determines the probability of having a certain number of successful events before a certain number of failures occur), among others [21]. Tools used to develop predictive models include random effects models [22], generalized estimation equations (GEE) [23], and Markov Monte Carlo chain methods (MCMC).

Within the aviation context, there is little research available that compares different predictive modelling approaches, or that identifies the most appropriate statistical models for predicting safety events, or furthermore, that helps to predict safety performance. Some recent studies that offer relevant results are [24], [25], [26], [27], [28] and [29].

All of these examples of methodological advances in research take an innovative statistical approach. They use Bayesian inference to develop statistical models for estimating and predicting the loss of separation between aircraft in airspace, depending on the scenario (intrinsic characteristics of the scenario of routes and sectors, traffic and its evolution, and airspace management). These functions allow evaluating, determining and predicting the results of a given airspace in terms of safety. These models are known as **Predictive Safety Functions or Safety Performance Functions (SPF)**. These types of models, once developed, calibrated and validated, could be extended to other key performance areas in air traffic management such as capacity, efficiency, etc.

This distinctive approach involves the use of advanced methods to be able to incorporate statistical estimation and prediction models with different complexities and objectives. One of the most outstanding characteristics of Bayesian inference is that it allows hierarchical models to be easily developed, with different orders of complexity, which, in addition, may have different objectives. It also allows evaluating the accuracy and precision of the models and comparing them with each other. In a discipline such as aviation safety, this type of hierarchical structure is extremely useful, as it is conceptually consistent with techniques already in use in the sector, such as Bayesian networks or fault trees.

### 3.1.1 Safety Performance Functions (SPF) in other domains

Safety Performance Functions have been used in many fields, as references through the following paragraphs illustrate. The reason lies in the fact that these are predictive models with a great potential of an overall safety improvement.

First, these models have been used to determine road transport occurrences, but over the years, their applications have expanded into new fields such as railway or aviation. SPFs may be used to identify locations which may benefit the most from a safety treatment, or to use SPFs as part of a broader network screening to identify sections that may have the best potential for improvements. Other applications propose to use SPFs to determine the safety impacts of design changes at the project level, or to determine the safety effects of engineering treatments.

Road crashes can occur as a consequence of several factors such as: human behaviour, environment, vehicle and road characteristics. Khair [30] establishes a mathematical relationship between explanatory variables and collision frequency among sections of roadways that share similar features. In these cases, a Multivariate Analysis Model is used, using a variety of variables such as weather, road geometry, traffic volume and human factors.

In other cases, it may be of interest to analyse the influence of the infrastructure geometry on the road accident rate. In [31], a SPF is used to analyse rural motorways. As a result, this application shows that the geometric design consistency has a significant effect on rural motorways' safety and highlights that the geometric design of both new motorways and improvements of existing motorways should consider the safety effects of consistency in driving dynamics, operating speed and inertial speed. In particular, this study has used Pearson's correlation in order to reflect the degree of linear relationship between two variables. In this context, empirical Bayesian models that consider negative Poisson and binomial functions have been developed and validated, as well as hierarchical Bayesian models. In these works, the use of more elaborated hierarchical models is also suggested to identify segments of the road network where accidents or collisions occur most frequently, which, therefore, requires the implementation of safety measures.

In ground transportation, the problem of motorcycle accidents has also been addressed [32]. Motorcycle crashes constitute about 36% of total road traffic crashes. A number of researchers have attempted to qualify the effects of roadway, traffic, environmental, human and vehicle factors on motorcyclist. The application of SPF aims in this case at studying motorcycles safety taking into account factors such as intersection geometries and traffic characteristics at signalised intersections. For this purpose, four mathematical models were used: Poisson Gamma model, Hierarchical Poisson Gamma model, Hierarchical Poisson Lognormal model, and finally, the Hierarchical Poisson (AR-1) model. With this application, actions and recommendations are identified that allow reducing the accident rate in this mode of transport.

Some applications of the SPFs were used to estimate train driver errors and conduct safety assessments of the whole ERTMS (European Railway Traffic Management System) [33]. In this application two complex Bayesian Network were developed taking into account variables such as tiredness, fatigue, training, familiarity policies of organization and so on. The difference between these two networks lies in the equipment needed for ERTMS/ECTS operation. They consider two levels. Level 1 fitted with balises, loops, lineside electronic units, lineside signals and track circuits and level 2 fitted with balises and radio track circuits and radio block.

The results of this analysis show that ERTMS level 2 is safer and less prone to driver errors than ERTMS level 1; however, it also contains more critical elements, such as GSMR-Global *System* for Mobile Communications Railway- system and RBC- Radio Block Center- that have a significant impact on the continuity of ERTMS functioning, such that any failure in one of these components will stop the whole ERTMS system.

### 3.1.2 Safety Performance Functions in Aviation

These SPFs can be conceptually extrapolated to the airspace considering different characteristics: the geometry of the routes followed by the aircraft, the volume of traffic, the mix of traffic and its dynamic variables, the geometries of the encounters between aircraft, the severity or magnitude loss of separation between aircraft, the complexity of the airspace structures, the size and characteristics of the sectors where the aircraft are flying, the complexity of the organization and management of the airspace, etc.

One of the main potential applications focuses on the analysis of Loss Of Separation. A first attempt is presented at [34] to predict the occurrence of losses of separation. In this work a data-driven approach is used to characterise the LoSs between aircraft as count data with an excess of zeros and over dispersion. Subsequently, the relationships between the number of aircraft LoSs in a particular route segment and the airspace design and traffic flow characteristics are modelled using Zero-inflated models. Based on the characteristics of the route segment, the distribution that most closely matches observations of the number of LoS in airspace segments is a Zero-inflated negative binomial probability distribution. It also takes account of the large amount of null values that characterise safety-related occurrences in aviation.

In the simplest case, SPFs belong to the exponential family and are capable of predicting the number of LoS based on simple and general parameters, such as, for example, the length of the section of airway considered and the annual average of daily traffic. These models predict the number of occurrences or loss of separation in an airway segment or at intersections, as well as their severity. These models only consider exposure data (traffic volume and segment length) and are validated or applicable to those segments that meet specific conditions [35].

There are several ways to consider the effect of deviation of the characteristics of the scenario from the standard, or basic ones as considered in the primary model. A simple way is to define Modification Factors (MF), which multiply the base prediction value (*Nspf*), to adjust the predicted frequency of separation losses to that of actual conditions. Thus, a MF greater than 1 indicates an increase in expected incidents due to the non-basic condition, while a MF less than 1 represents a reduction in incidents.

A more complete alternative will be to use empirical Bayesian models (Empirical Bayes, EB). These models allow us to address two common problems associated with prediction safety models: (1) on the one hand, the consideration of regression to the mean (RTM); and, on the other, (2) the lack of data when there is an insufficient historical period or with a very low number of occurrences [36]. Regression to the mean is a common bias when evaluating a network in terms of accident rate or safety, since a point or element in the network can have high number of occurrences in a year and, nevertheless, be compatible with an admissible probability distribution for the occurrences. The EB method will allow a better estimation of the safety of a part of the air transport system, taking into account not only the number of safety-related occurrences at that location, but also the occurrences observed in similar environments, naturally incorporating the knowledge of the experts on the causes that could have produced them [36].

Stakeholders have to monitor, gather and analyse safety-related data and information in order to anticipate and predict actual and emerging safety risks. In this context safety analytics and statistics need to evolve to forecast future safety performances and risks. At [37] authors adopt an innovative statistical approach involving the use of Bayesian inference and Hierarchical structures to develop statistical estimation and prediction models with different complexities and objectives. The study develops and analyses five Bayesian models of increasing complexity, two basic and three Hierarchical models, which allowed us to explore safety incident data, efficiently identify anomalies, assess the level of risk, define an objective framework for comparing air carriers, and finally predict and anticipate incidents.

Bayesian Inference is also applicable to aviation Safety-Compliance Assessment. In [35], authors develop an integrated methodology, based on Bayesian inference, for assessing and evaluating compliance with system safety requirements when there is uncertainty regarding the safety performance of ATM systems. The study constructs a Bayesian framework that reformulates the Safety Compliance Assessment as decision-making under uncertainty. This framework addresses the main limitations of the System Safety Assessment carried out by Air Navigation Service Providers (ANSPs). In particular, the features and advantages of this approach are demonstrated via a case study which assesses whether an Air Navigation Service Provider (ANSP), which had begun to provide services at a new airport with new systems and technology, was compliant with the safety objectives.

In all the cases analysed, the behaviour of the air operator is difficult to predict or model. In fact, almost all accidents are the result of human error caused by impaired performance or distraction. Since these factors and their effects can be very diverse depending on the different areas considered, it is recommended to calibrate the existing models for each local airspace as well as to develop specific models for each environment, with the aim of developing new more precise tools, that predict the safety levels of the airspace considered with greater reliability. The calibration of the models is carried out by applying a multiplicative factor to the considered SPF, so that it maintains its original shape [38]

### 3.1.3 FARO contributions on Safety Performance Functions

One of FARO's objectives is to verify that all the models discussed above can be applied to the study of available safety data on the evolution of aircraft in airspace. By using these functions, we aim to be able to extract information about the magnitude of the risk involved and to make predictions about future safety-related occurrences. **The main contribution of the development of such SPFs in ATM will be the use of modern statistical techniques and models to predict safety incidents by means of precursors**. Thus, SPFs can be used in preventive and predictive methodologies to improve the safety conditions in ATM operation, thus minimising the level of risk. These safety SPFs will allow to:

- Explore safety incident data and effectively identify anomalies;
- Assess the level of risk;
- Define an objective framework for the comparison between different airspaces, including their design and the way in which they are managed, and lastly;
- Predict and anticipate incidents and estimate its probability of occurrence in a given scenario and context.

These models (SPFs) could be used, fundamentally, in two ways. On the one hand, they are used to predict the safety of an airspace for a future period of time (for example, after a modification, or after an increase in traffic). On the other hand, it can also be used to identify scenarios that experience abnormal high numbers of LoS occurrences (based upon statistical principles but also taken into consideration the context of the operation), where the observed frequency is much higher than the predicted value; as well as identifying the possible causes. Understanding the factors that affect the number of separation losses in a given context can help ATM system planners make decisions that improve safety.

## 3.2 Resilient Performance

### 3.2.1 Another way of conceiving producing services safely and effectively

By the middle 1990's, there was growing frustration with the classic safety paradigm. Compounded with a series of high-profile events and accidents that challenged the received wisdom of this classic safety paradigm. Especially its ability to provide effective understanding of what happened in events and episodes that can lead to meaningful safety interventions that lead to structural change. In part, this was perceived as the inability to reflect the reality of operational practice and the organisational aspects of accidents and events as well as a lack of appreciation of the complex nature of late twentieth century socio-technical systems [39].

In October 2004, a group of international safety experts met in Söderköping in Sweden, to discuss 'resilience'. The outcomes were published in the first of several tomes, as *Resilience Engineering: Concepts and Precepts*. Much more has been published since then, such as seminars and symposiums held, and research undertaken and published. However, it is the case that despite this, this nascent discipline of safety science still remains nascent fifteen years later. Perhaps this is best illustrated by one development of resilience engineering – *Safety II* – which caught the imagination of many safety researchers, some safety professionals and many practitioners in aviation and healthcare. But it has failed to truly become integrated into mainstream safety management praxis.

In parallel, society was growing in its awareness of the events and the part that human practitioners had to play. One of the consequences of this perceived mismatch was the increase in the criminalisation of practitioners, in effect the criminalisation of human error.

The classic safety paradigm is one that is characterised by reductionism and deconstruction of a *'system'* to its constituent elements and where, as described by Woods et al [38] investigations effectively reach an end point when *'human's frailties are found'*, i.e. human error. Here *cause* can be ascribed typically directly as 'human error' or by causes that are manifestations of 'human error', for example: lack of situational awareness, poor CRM (crew resource management).

Organisational and system safety was, as it remains principally today, a series of processes that provides assurances around the nature of hazards that are transformed into risks, through causal taxonomies, that are used as causal factors and that subsequently drives safety interventions. Such events are characterised as unwanted or adverse outcomes. These being assessed in terms of errors, accidents, manifestations of incident types such as loss of separation, level busts etc. By analysing these events, hazards can be identified which leads to risk mitigations to eliminate those hazards. This safety paradigm assumes that 'errors' were something that could be counted and categorised, that studies of human performance would lead to safety interventions that could 'manage or resolve the ways in which limited or erratic human performance could degrade an otherwise well designed and 'safe' system' [40]. Safety, safe operation, safe production is what a system *has*. But, as Weick asserts '*safety'* is a dynamic non-event [41].

As a consequence, a narrative in human factors and safety science emerged that was largely the antithesis of this view. For example, with regards to the safety investigation activity, event analysis and learning form experience has not been as successful as predicted. This narrative in the safety science and human factors discourse arguably reached maturity in Söderköping in 2004 as a new discipline in safety science, i.e. **Resilience Engineering**. This narrative asserts that:

> *'In a world of finite resources, of irreducible uncertainty, and of multiple conflicting goals, safety is created through proactive resilient processes rather than through barriers and defences'* [40].

Intrinsic to this safety narrative is that safety is not what an organisation *has* but what it *does*. Today, safety is measured by what has failed as opposed to how safe production has been sustained when confronted by surprises and challenges. There are many more examples in day to day operation of the operation being sustained in contrast to what has failed. By emphasising safety management activities in terms of failure, there is no account of how the system has adapted to a situation and sustained performance. This is exemplified in Figure 9 and Figure 10:


**Figure 9: The imbalance between things that go wrong and things that go 'right'**


**Figure 10: The focus of safety**

In ATM, for example, the frequency and population of such adverse events is low, almost rare. Amalberti [42] coined the term *Ultra safe organisations* embracing aviation with this class of organisations. This recognises a particular safety concern, *reinforcing the limitations of the classic safety paradigm that with so few safety events,* **is there any learning potential at all?**

Resilience Engineering is therefore a response to the diminishing returns perceived of the classic safety paradigm. It is a different vocabulary [40] and a different mindset [43].

### 3.2.2 What is Resilience Engineering?

The term 'Resilience' has become synonymous with an ability, be it individual, group or organisation to stand firm or to cope with adverse, traumatic or challenging events [44]. In other examples of the use of the term, it has been used to embrace how communities confront 'unforeseen challenges such as natural disasters such as Hurricane Katrina to tsunami's in the sea of Japan, to human made disasters' [44].

The term *resilience engineering* is more than just *resilience*, therefore.

In 2006, Woods and Hollnagel [40]:

> *'Resilience engineering is a paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success. It strongly contrasts with what is typical today a paradigm of tabulating error as if it were a thing, followed by interventions*

> *to reduce this count. A resilient organisation treats safety as a core value, not a commodity that can be counted. Indeed, safety shows itself only by events that do not happen!'* [40].

Woods (2015) [75] notes that there are four conceptual frameworks that the label resilience can be characterised by[4]. That is that 'affect the ability, to create, manage, and sustain resilience' [45]:

- Rebound = Resilience (resilience as a rebound to trauma and a return to a state of equilibrium)
- Robustness = Resilience
- Graceful extensibility = Resilience (resilience as the opposite of brittleness)
- Sustained adaptability = Resilience (resilience as network architectures that can sustain the ability to adapt to future surprises as conditions evolve)

In this section, resilience will refer to categories 3 and 4 as the essential categories of resilient engineering and thereby, resilient performance, especially of *social-technical systems that confront complexity*.

Relating to the 4th category, here these are referred to as *'complex adaptive systems'* recognising that **sustained adaptability** requires that the system itself, with its concomitant system dynamics, change and evolve over the system's lifecycle. Therefore, resilient performance changes over the system lifecycle too. There are opportunities that emerge which can enhance as well as erode an organisations competence which shapes resilient performance.

About the 3rd category, the resilience/brittleness of a system captures how well it can adapt too and handle events that challenge the boundary conditions for its operation. Such 'challenge' events do occur because:

- plans and procedures have fundamental limits,
- the environment changes over time and in surprising ways,
- the system itself adapts around successes given changing pressures and expectations for performance. In large part, the capacity to respond to challenge events resides in the expertise, strategies, tools, and plans that people in various roles can deploy to prepare for and respond to specific classes of challenge.

Here, brittleness and what was known as resilience, is concerned with understanding how the system adapts to challenges, disturbances and surprises.

The question about *how resilience in resilience engineering means has evolved since 2006*, is answered as a result of greater understanding of what resilience and robustness themselves mean, i.e. how resilience and brittleness is enacted in everyday operations. It somehow shows the differences between the two paths that the resilience engineering has taken – one the work of Erik Hollnagel, the second that of David Woods.

Since 2006, when the proceedings of the first gathering to discuss, what was then – *resilience* – various views of the meaning of the term *resilience* were aired. [40] described the essential characteristics of *resilience* as the '*ability to recognise and adapt to handle unanticipated perturbations that call into question the model of competence and demands a shift of processes, strategies and coordination*'.

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[4] For further discussion of these archetypes of resilience: *Four concepts of resilience and the future of resilience engineering*.

This leads to resilience of an organisation being related to the monitoring of the boundary conditions of the work system and adjusting the capability and competence accordingly (defined as how strategies are matched to demands by [40]). The 'focus is on *assessing* the organisations adaptive capacity'. This is very much a *Woodsian* view of resilience.

As an example of the competing narratives, from Hollnagel's perspective, *'Resilience is not a feature of an organisations life in avoiding failures or striving to deal with a 'lack of safety'*. Hollnagel [46] emphasises that *resilience* is a feature of production *per se*, the productive function of an organisation and not solely related to safety. A 2018 definition of resilience illustrates the change as well as introduces the rational for the expression resilient performance:

> 'Resilience is an expression of how people, alone or together, cope with everyday situations – large and small – by adjusting their performance to conditions. An organisation's performance is resilient if it can function as required under expected and unexpected conditions alike (changes/disturbances/opportunities)'.

This definition broadens the scope to a new focus of resilience engineering – *resilient performance*. It should be recognised that this means an organisation's performance in toto – not safety alone. **It is about how an organisation can effectively undertake its productive function safely.**

### 3.2.3 Unit of analysis of Resilience Engineering and resilient performance

The fundamental unit of analysis to understand and explore resilient performance, as referred to earlier, is the complex adaptive system [75]. In essence this is the *work system*, the socio-technical system that leads to the productive function of the organisation.

Within the *work system*, various different perspectives and dimensions need to be explored, in keeping with general system theory and systems thinking for example, to explore the properties of the system and, essentially the sources of resilience that the work system is able to exploit, to use to adapt, and thereby, the adaptive capacity of the system.

To do so requires and understanding of how work is undertaken at different levels of the system hierarchy, functional roles and artefacts contribution. Coordination, common ground, dependencies (hidden or otherwise) and availability are all probes that enable an understanding of how the work system achieves resilient performance.

A concept that is associated today with resilience is that of 'work as done' and 'work as imagined'. This notion assumes that all procedures, rules, etc. that shape work are underspecified and require the human actors to adapt. It is the understanding that exploring the nature of work in this way that some sources of resilient performance can be revealed. Currently though, this is no longer seen through a lens of work as done or work as imagined. But a number of other phenotypes of work [43].

Multiple narratives and multiple perspectives provide the basis for a synthesis of data that provides an understanding of resilient performance. Knowledge that is gained from those who are undertaking the work in the work system. Exploring the *strategies*, *trade-offs* and *decisions* that influence resilient performance.

A focus of 'work as done' and 'work as imagined' was a feature of some resilience engineering narratives. Here the analytical emphasis is on the practitioner and the co-agency with artefacts in *enacting locally adaptive strategies* and the way that **performance variation is managed or coped with**. This emphasis however is upon the local and proximate facets of the work system. Resilient performance is a function of both proximal, near distal and distal elements of an organisation. These are also referred to as micro, meso and macro. Wears and Perry [47] note in research that 'local adaptations are often essential to maintain system function, *ad hoc* adaptations taken to the extreme might easily be locally useful, but globally maladaptive and might lead to an extreme casualness of operations.

Understanding the adaptiveness and why there is a need to adapt becomes a critical element of understanding resilient performance which can inform the design of cognitive artefacts as well as structural elements of the system design.

How are these 'underground adaptations' revealed and how is maladaptation and the consequent cascade effects found? Especially when the locally adaptive strategies are normative and unconsciously? Increasingly, the resilience engineering scientific community have evolved a number of methods and methodologies to elicit such knowledge [48], [49], [50], [51], and [52]. As well as several methods to visually model work systems [53].

SESAR WP 16.06.01b examined a resilience engineering approach to safety assessment of envisaged designs (up to and including V3) and tested the safety assessment on a number of SESAR projects [52]. This method, which whilst is resource intensive did reveal a number of new perspectives at the micro, meso and macro levels in the use trajectory date in the computation of 4D trajectories for use in AMAN calculations.

### 3.2.4 Measuring Resilient performance?

In the publication that brought together the deliberations of the Söderköping seminar [40] Hollnagel writes:

> *'Analysis of successes, incidents and breakdowns reveal the normal sources of resilience that allow systems to produce success when failure threatens. These events and other measures indicate the level and kinds of brittleness/resilience the system in question exhibits. Such indicators will allow organisations to develop the mechanisms to create foresight to recognise, anticipate and defend against paths to failure that arise as organisations and technology change'* [40].

From the outset what was once measuring resilience has evolved to the assessment of and measurement of resilient performance. Research has been carried out to derive the nature of safety performance indicators that assess proactive safety performance indicators (i.e. a resilience engineering perspective on safety management [54]).

SESAR project WP 16.06.01b included as an element of the Resilience Engineering assessment guidance on the development of safety key performance indicators. These focused-on system organisational factors that influenced the adaptive capacity of the organisation that impacted resilient performance and that influenced brittleness in some way. Indicators such as the buffers and margins of the work system were operationalised.

These approaches were also examined by Saurin [55] in the development of a framework that analyses slack in socio-technical systems by theorising about the mitigative effect that slack can bring to a complex social-technical systems ability to manage performance variability. The proposed theory was illustrated by a particular application for a maternity ward in a healthcare setting. Mixed methods were used including the use of FRAM to explore the instantiation of critical event, see Figure 11 below.

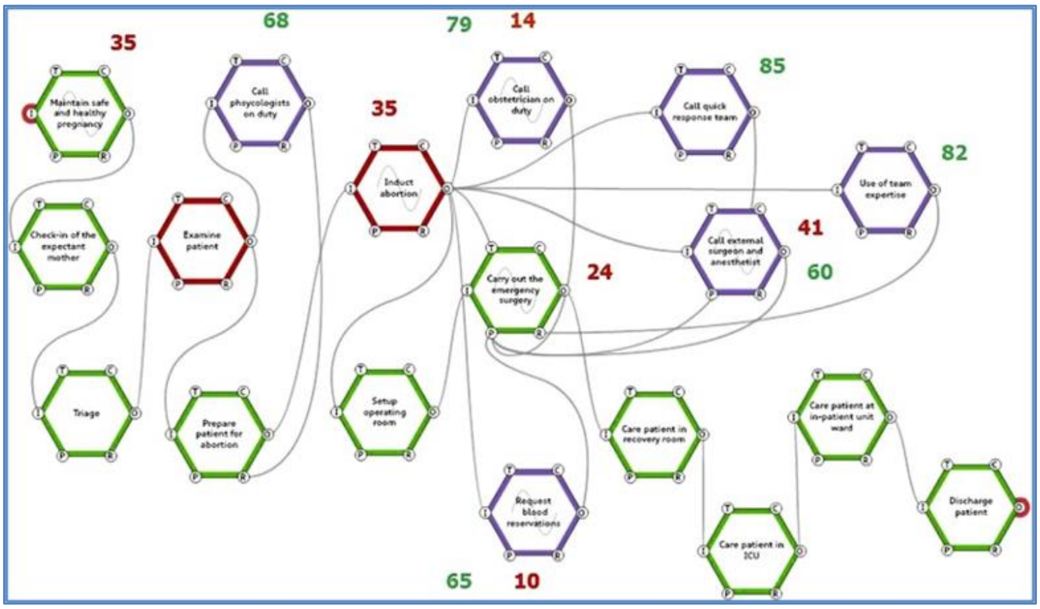


**Figure 11: Instantiation of a critical event (Saurin, 2017)**

Other ways to measure the resilience of an organisation have been proposed by Hollnagel, building on the four '*Resilience Potentials*' [46]. The four 'potentials' are the current basis of Hollnagel's development of resilience through Safety II.

These *Resilience Potentials* are shown through the Resilience Analysis Grid – or RAG. An essential assumption lays the foundation for the RAG, that '*neither resilience not resilient performance can be managed or controlled directly*' [46]. Hollnagel then continues:

> *'If on the other hand, resilient performance is accepted as an expression of an organisation's abilities or potentials, then resilient performance can be managed indirectly through the potentials for resilient performance'*

In Hollnagel's evolution of Resilience Engineering, the four potentials have been key to describe how resilient performance can be explored, being fundamentally what an organisation *does* rather than *has*.

It is possible to consider the extent to which each of the four *Resilience Potentials* are present in or supported by the system. The RAG uses four sets of questions to determine how well a system performs on each of the four basic potentials. An example of the application of the RAG to assess and ANSP can be found in [56].

The output of a RAG assessment can take the form of a radar or star plot as shown in Figure 12.

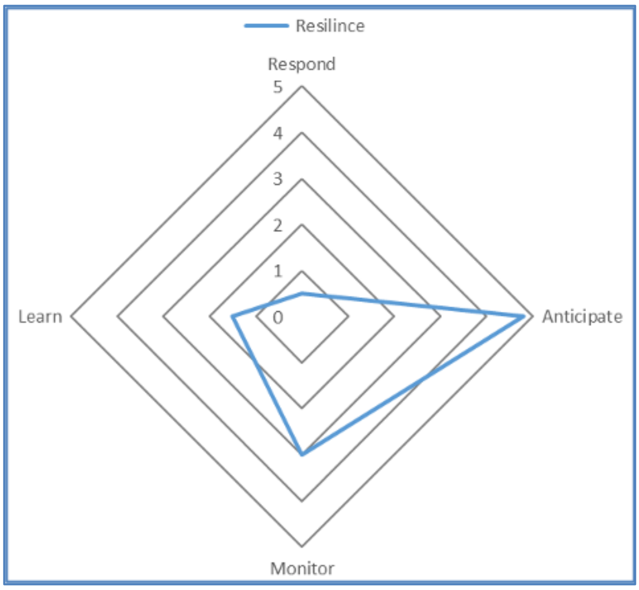


**Figure 12: Example of a RAG star chart**

Recent research has explored a different perspective of safety performance measurement systems, by explicitly addressing a safety performance measurement system from the theoretical framework of resilience engineering as opposed to the classical safety paradigm or a systems thinking/theory perspective.

The conclusions made are enlightening. Generally, it was found through a literature review that extant traditional safety performance measurement schemes had low or poor agreement with five RE guidelines. However, 'several studies moderately or strongly aligned with those guidelines' [57].

### 3.2.5 Resilience engineering in practice: Safety management

Recent research has explored the contribution that resilience engineering can make to safety management [58]. In this instance, using the French ANSP, DSNA, a field study was undertaken to 'contrast the classic safety management framework, the Safety Management system (SMS) which is the regulatory requirement for ATM with two other framework – RE and High Reliability Organisations (HROs).

A longstanding critique of resilience engineering has been that it mirrors or duplicates or is the same as HRT [59]. A more explicit approach was taken by Haavik et al. [60] by contrasting HROs and RE directly from safety science and the pragmatic implementation into practice of each.

The transfer form research and scientific theory into implementation within organisational and safety praxis has been a constant criticism of Resilience Engineering. It is a new concept and has a fundamentally different theoretical framework and foundations. These being not just stemming from different ontologies and ontological positions. RE drawing from a broad range of social science as well as other scientific disciplines – Ashby's law of requisite variety from cybernetics, economics and Ostrom and the understanding of complexity through normative-polycentric system behaviour and governance and materials science in the conception of brittleness.

Both Haavik et al and Paries et al., make strong arguments that resilience is not irrelevant but appeals to different levels within organisations.

The contribution that resilience engineering can bring to safety management is one of different questions about organisational performance and the nature of safe production or production safely in complex socio technical and adaptive systems. In some cases, resilience engineering can provide a collaborative of complementary view to the view that the classic safety paradigm brings. Perhaps more prosaic, resilience engineering brings a different perspective of what safety means that is better adapted to the digitalised nature of ATM that the ATM roadmap aspires too.

### 3.2.6 The dark side of resilience

Resilience engineering is considered as an inherently 'optimistic' approach to safety and production. However, it is fundamentally different from other safety paradigms. Safety can take a different conception in resilient performance terms.

An example can be the assertion, as presented by Morel et al., that 'the best safety response may be to stop fishing in marginal or borderline conditions, the resilient response is to go on, and develop survival skills according to the situation' [61]. In this instance operating in boundary conditions can provide some extent of optimization or maximization of production but borrowing from safety? Or being resilient? Patterson and Wears refer to this as creating the possibility of the 'tragedy of adaptability' [62].

These may be normative behaviours that contribute to resilient performance but if this becomes an expectation in the sense of responsibilising practitioners to achieve resilient performance is this morally or ethically acceptable?

## 3.3 A Relationship with other SESAR Project

### 3.3.1 SESAR activities overview

The Single European Sky ATM Research (SESAR) programme is an initiative of the European Union (EU) formed with the aim of modernising and harmonising Air Traffic Management (ATM) in Europe. SESAR is the technological pillar of the Single European Sky (SES) [63]. Based on its predecessor, SESAR 1, SESAR 2020 is an innovative research programme aiming to deliver high-performing operational and technological solutions for understanding the future air traffic management in Europe. The SESAR 2020 programme is supporting projects in delivering diverse solution in four focus areas: **High-performing airport operations**, **Advanced air traffic services**, **Optimised ATM network services**, and **Enabling aviation infrastructure**. The research projects are categorised into three groups: **Exploratory research**, **Industrial research and validation** and **Very-large scale demonstration**. The main results of these projects are to define and develop actual solutions that meet what is needed [64] in order to improve overall ATM system. A Solution refers to new or improved operational procedures or technologies to improve the modernisation of the European and global ATM system. SESAR Solutions are presented in the **European ATM Master Plan** addressing all ATM parts including airports, air traffic services, networks as well as system architectures and technological enablers [65].

### 3.3.2 SESAR 1 and SESAR 2020 projects

There are two phases of the SESAR Joint Undertaken activity: SESAR 1, based on Framework Programme (FP7), was launched in 2009 and last until the end of 2016, while SESAR 2020, co-funded by the EU's Horizon 2020 Programme, beginning after SESAR1 and will last until 2024 [64]. Within

SESAR 1, the 322 Industrial research projects based on "Best and Final Offer" (BAFO) process were conducted by the Members. Due to the inability to manage such a large number of projects, the projects were grouped according to the Operation Focus Areas (OFA) delivering performance improvements in specific areas. There were organised two calls for Exploratory research projects resulting in two networks and a total of 40 research projects [66].

Within SESAR 2020, there were two waves of the Industrial research and validation calls (Wave 1 from 2016 to 2019 and Wave 2 from 2019 to 2021) that resulted in 20 projects. The first Exploratory Research (ER1) call within the SESAR 2020 Programme, fully funded under H2020 was launched in 2015, resulting in 28 ER1 projects which have been closed in 2018. In 2016, the second ER call was launched to address the domain of Remotely Piloted Aircraft Systems (RPAS) and unmanned vehicles. There were 9 ER2 projects that were launched at the beginning of 2018, delivering the results at the end of September 2019. A third ER call for proposal was launched at the end of 2016, resulting in 7 projects (closed by December 2019) and one Network (Engage Knowledge Transfer Network) still ongoing. The last ER call was launched in 2019 (ER4 call), beginning with execution in early 2020 with the plan of closing by the end of 2022 [67]. Currently, 28 ER4 projects are ongoing [68] [69].

### 3.3.3 Projects scope

The analysis of previous and ongoing projects provided in this document is based on a review of the following sources:

- 7$^{th}$ Framework Programme projects,
- SESAR WP-E (long-term and innovative research) projects following the first and second call,
- SESAR 2020 Exploratory Research projects following the ER1, ER2, ER3 and ER4 calls,
- SESAR 2020 Industrial Research projects,
- SESAR 2020 Very Large Demonstration projects,
- H2020 projects which are not SESAR projects but could be relevant to the given topic, and
- ENGAGE Knowledge Transfer Network, Deliverable 3.5: Opportunities for innovative ATM research.

**Note:** the projects information was retrieved from European Commission database named CORDIS database (https://cordis.europa.eu/), as well as from projects websites.

### 3.3.4 Projects classification

The selection of the projects was made based on the objectives of the FARO project. In order to present it as faithfully as possible, the connection between the already completed projects and those that are in progress, with objectives of FARO project, the evaluated projects were divided into four groups:

- Safety related projects,
- Air traffic control automation relation projects,
- ATM performance related projects, and
- Other projects related to the FARO scope of work.

A brief overview of the selected projects, classified by groups, is presented below, while full list of projects with their basic information can be found in Appendix A.

**Safety related projects** group include nine selected projects as follows: Future Sky Safety, OPTICS2 (Observation platform for technological and institutional consolidation of research in safety and security), Safe Cloud (Data-driven research addressing aviation safety intelligence), EUNADICS-AV

(European Natural Airborne Disaster Information and Coordination System for Aviation), EWIS SAT (Safety Analysis Tools for Electrical Wired Interconnected Systems), VISION (Validation of Integrated Safety-enhanced Intelligent flight control), SAFEMODE (Strengthening synergies between aviation and maritime in the area of human factors towards achieving more efficient and resilient mode of transportation), PJ19 Content Integration (D4.0.060 - SESAR Safety Reference Material and D4.0.050 - Guidance to Apply SESAR Safety Reference Material) and project SESAR 16.06.01b (D04: Resilience Engineering Guidance Final Deliverable). Seven projects are closed, while one is still ongoing. The main objectives and results of these projects are the following:

- to achieve the highest level of safety aiming to ensure the protection of overall air transport system and its infrastructure;
- to assess if Europe is performing the right safety and security research and if the research is delivering the expected benefits to society;
- to develop a set of algorithms, monitoring techniques and data-driven approaches in order to achieve a deeper understanding of the system dynamics where risk could be proactively identified and mitigated in continuous effort;
- to develop specific data sets for discovering unknown safety hazards, to provide real-time hazard measurement and to reduce the effects of external hazards in understanding and defining a performance-based system safety concept especially in unanticipated circumstances;
- to develop a new data platform that provides all necessary information as soon as possible, to ensure the closing the gap in data and information availability enabling to all stakeholders to obtain fast, coherent and consistent information;
- to apply artificial intelligence in improving the operational safety by providing predictive analytics of variety scenarios increasing awareness of hidden treats;
- to improve and provide data safety analysis through historical analysis, predictive analytics, automatic safety data monitoring and unknown hazard identification;
- to develop systematic approach in collecting and assessing Human Factors information to support Human Factor analysis in order to contribute to safeguarding human performance in flight upset conditions (increased levels of automation, remote operations etc),
- to apply Resilience Engineering Guidance to relevant operational environments as well as organizational contexts, and to propose improved Resilience Engineering Guidance integrated into the SESAR methodology for safety assessment as well as into Safety Management Systems;
- to present a clear, complete, coherent and integrated approach to safety assessment that meets the needs of the SESAR work programme (SESAR Safety Reference Material) and provide practical guidance to support the safety assessment activities as defined in the SESAR Safety Reference Material.

**Air Traffic Control Automation** group counts 17 projects (14 closed and three ongoing projects). These projects are: MINIMA (Mitigating negative impacts of monitoring high levels of automation), AUTOPACE (Automation pace), STRESS (Human performance neurometrics toolbox for highly automated systems design), TACO (Take control), SVETLANA (Safety (and maintenance) improvement through automated flight data analysis), COTTON (Capacity optimisation in trajectory-based operations), MALORCA (Machine learning of speech recognition models for controller assistance), SALSA (Satellite-based ADS-B for lower separationminima application), AGENT (Adaptive self-governed aerial ecosystem by negotiated traffic), COPTRA (Combining Probable Trajectories), EVOAtm (Evolutionary ATM: A modelling framework to assess the impact of ATM evolutions), ADAPT (Advanced prediction models for flexible trajectory-based operations), PARTAKE (Cooperative departures for a competitive ATM network service), MOTO (the embodied remote tower), AISA (AI situational awareness foundation for advancing automation), MAHALO (Modern ATM via human/automation learning optimisation) and TAPAS (Towards an Automated and exPlainable ATM System). The main objectives and results of these projects are summarized below:

- the task performance can be increased when it is done by automation although it was done formerly by human-operator;
- since the operator is required to monitor the automation and intervene in case of rare events (automation errors), it is needed to develop solutions and new design-automation interaction concept that will mitigate the negative effects resulted from operator's monitoring role such as lack of attention, loss of situation awareness and skill degradation in long term;
- to provide the controller with suitable and usable tools to supervise the system;
- to design algorithms and solutions that will automate and optimise both the decision making and implementation tasks for the controller;
- to identify potential parameters of assessment techniques that can help in prediction of the condition or failure of hardware to provide better insight into abnormal events which can adjust training, maintenance and procedure to prevent re-occurrence;
- to define new machine-learning tools and help in recognitions of controller's actions (behaviour and speech recognitions) by automation that will replace much of manual adaptation effort and that will increase the overall ATM performance;
- to provide guidance for the future design of fail-safe complex human-machine environments in the presence of high levels of automation;
- to monitor real-time controller's mental status driving monitoring tasks in different automation levels as well as to investigate optimal psychological states of human-automation interaction to ensure safe operations; and
- to explore highly automated Artificial Intelligence (AI) - based scenarios through analysis and experimental activities in order to derive general principles of transparency which pave the way for the application of AI technologies in ATM environments, enabling higher levels of automation

**ATM Performance** related projects include 10 projects from which eight are closed and two are still in progress. These projects are : APACHE (Assessment of Performance in current ATM operations and of new concepts of operations for its holistic enhancement), INTUIT (Interactive toolset for understanding trade-offs in ATM Performance), GAUSS (Galileo-EGNOS as an asset for UTM safety and security), AURORA (Advanced User-centric efficiency metrics for air traffic performance analytics), VISTA (Market forces trade-offs impacting European ATM performance), SAPIENT (Satcom and terrestrial architectures improving performance, security and safety in ATM), RETINA (Resilient synthetic vision for advanced control tower air navigation service provision), COCTA (Coordinated capacity ordering and trajectory pricing for better-performing ATM), OptiFrame (An Optimization Framework for Trajectory Based Operations), and ITACA (Incentivising technology adoption for accelerating change in ATM). Main objectives and results of these projects are the following:

- proposed new metrics and indicators providing new viewpoints of evaluating ATM performance;
- development of a set of visual analytics and machine learning algorithms for the extraction of relevant and understandable patterns from ATM performance data;

- investigation of new data-driven modelling techniques and evaluate their potential to provide new insights in connection between performance drivers and performance indicators;

proposing a new framework for ATM decision-making based on real-time performance monitoring of user-centric efficiency indicators, where the airspace users could take an active role.

**Other projects** group, relevant to the FARO scope of work, includes one finished project SESAR 16.06.01b (D04: Resilience Engineering Guidance Final Deliverable) and two on-going projects. These projects are CREATE (Innovative operations and climate and weather models to improve ATM resilience and reduce impacts) and START (A Stable and resilient ATM by integrating Robust airline operations into the network). The main objectives of these projects in connection to FARO are:

- to apply Resilience Engineering Guidance to relevant operational environments as well as organizational contexts, and to propose improved Resilience Engineering Guidance integrated into the SESAR methodology for safety assessment as well as into Safety Management Systems;
- to design, apply and verify optimised algorithms that will enable a robust ATM system to be resilient in disrupted circumstances using artificial intelligence, data science and applied mathematics;
- to study the vulnerability of ATM system in respect to the weather conditions to improve ATM performance and to propose ATM operational changes able to reduce such impact.

# 4 T2.3 Knowledge Transfer from Other Transportation Domains: Summary

This section represents a summary of the work done in Task T2.3 "Knowledge Transference from Other Transportation Domains" covering the application of Natural Language Processing (NLP) and/or Machine Learning (ML) to the analysis of safety reports in the Railway and Maritime transport domains.

The synthesis covers also the few examples of the application of NLP and/or ML to safety reports from the aviation domain.

More detailed information on the adopted methodologies can be found in Appendix B.

## 4.1 The Railway Domain

Modern railway systems rely on many sources of data, providing a vast amount of information on different aspects of the operations: train position, speed, passenger numbers and so on. Despite the wide application of data analysis in this field, there is not a large body of literature describing automated analyses of safety incident reports.

In fact, while many sources of information in this scope are collected as structured data, which are relatively easy to analyse, safety reports are usually semi-structured or unstructured data sources (e.g. handwritten files, free-text PDF, etc.), which typically require different techniques to deal with. In most cases reports contain both fixed-field entries and narratives that describe the characteristics of the incident/accident, possibly containing abbreviations, misspelled words and so on.

The general aim in analysing safety reports is then to identify the main concepts in the free-text documents, possibly in an automated and not much supervised way, with two possible outcomes:

- extraction of qualitative information, which can suggest unknown connections between concepts via visualization;
- extraction of structured features to be used in predictive models (e.g., to predict the incident costs).

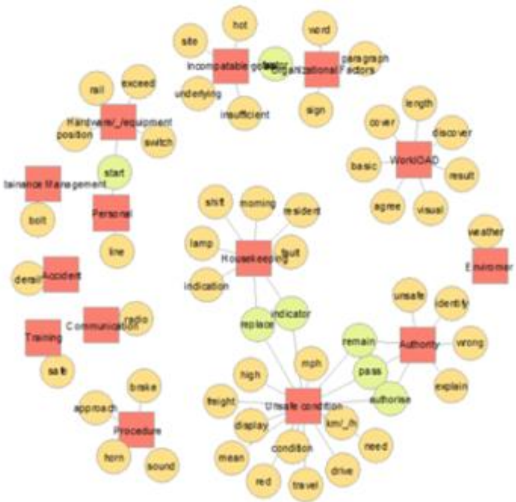

**Figure 13: An example of Network Visualisation**

In [70] and in [71] the representation of qualitative information is obtained via Network Visualization (see Figure 13: An example of Network Visualisation), converting the text into a spatial representation of linked words and entities, suggesting how different entities influence safety on railways**;** the distribution of these entities can provide useful indicators for investigations, and assist incident experts in establishing root causes. These visual representations can be automatically generated by using some Natural Language Processing tools, able to identify the most important words and expressions, other than their mutual interactions.

In particular, in [70] the entities identified and visualized by these tools are then used to support the ontology learning process, i.e. the creation of a formal representation of the domain knowledge by a set of concepts and their relationships, supported by human intervention.

In [71] instead, a network textual analysis is performed in parallel with Topic Modelling. Topic Modelling is a NLP unsupervised-learning text analysis technique which enables the discovery of the main themes that pervade a collection of textual data.

Thanks to this technique, the text collection can be organized according to the discovered themes and its information can be therefore made quantitative. This approach can be found in [72], where the probability of finding a topic is associated to every safety report, becoming a numerical feature describing the document. These features are included in a machine-learning model able to estimate the incident cost for each report. The main result is that these topic-modelling features were found statistically significant for the model accuracy.

Another example of a quantitative outcome from safety report analysis can be found in [73], where an Ontology learning process is again performed, but this time in order to build a classifier. In fact, the aim of the work was to find an automated way of **classifying reports** in 5 different categories (incidents about alighting vehicles, falling downstairs, boarding vehicles, closing doors or falling bags). This method demonstrated to provide very good in terms of specificity (98,5%), but with less control over false negatives.

These reported applications are really promising and show that NLP and ML can be very useful tools in identifying known issues from free-text railway safety reports, and possibly in discovering previously unreported connections.

## 4.2 The Maritime Domain

A number of studies conducted by various maritime organizations reported that the majority of accidents of ships worldwide are due to human errors. Hence, any attempt to reduce accidents at sea should concentrate on eliminating errors on board ships and on identifying where the biggest improvements should be made.

One way to do this is the analysis of accident reports to detect causal factors. However, this approach is not easy since the analyses contained in the reports are usually very complex and very subjective.

Two main approaches are found in literature: a text-mining application to classify free-text reports and a machine learning model fit on a structured description of some incidents.

The approach in [74] describes the attempt to determine automatically the extent to which a causal factor (in particular, the lack of three types of Situation Awareness) is a relevant issue. A sample of textual reports is manually associated to these classes and, after that, use is made of the Leximancer, a machine-learning tool for text mining. It is then possible to examine the accuracy and usefulness of such a data analysis tool by comparing the results of this computer analysis with that of the manual analysis (performed by two raters). The tool is shown to be valuable for analysing large data sets, but its accuracy degrades substantially without a preliminary manual cleansing of the text (which can eliminate noise and irrelevant parts), so it is not reliable as a fully automated approach.

Structured information about a small number of accidents, described by 94 categorical features, is exploited in [75]. Starting from this structured database reporting accidents and their contributing factors, first a data-driven predictive model is built able to predict the type of accident based on the contributing factors; then, the different contributing factors are ranked based on their ability to influence the prediction (Figure 14).

| | RF | |
|---|---|---|
| Pos. | Feat. | Description |
| 1 | F38 | Inadequate work preparation |
| 2 | F45 | Lack of knowledge |
| 3 | F89 | Training ignored |
| 4 | F15 | Emergency training program |
| 5 | F05 | Contingency plans not updated |
| 6 | F37 | Inadequate work methods |
| 7 | F24 | Improper performance of maintenance/repair |
| 8 | F01 | Anthropometric factors |
| 9 | F79 | Safety awareness, cutting corners |
| 10 | F52 | Lack of skill |

**Figure 14: Ranking of contributing factors [75]**

This second approach seems more promising, but its statistical relevance is limited due to the small amount of structured data available.

## 4.3 The Aviation Domain

Even if relatively few papers were published about NLP applied to the aviation domain, it seems that available data, results, approaches and limits are often similar to the ones in the railway domain. In the explored literature, the main aim is to extract from the safety reports information as quantitative as possible in order to produce descriptive statistics of the incidents. In particular, the most interesting studies resulted in identifying correlations between risk factors and discovering risk trends in time.

Topic Modelling is again used with different purposes and outcomes:

- In [76] it resulted able to recognise topics which the domain experts found meaningful;
- in [77], it allows the analysts to compute the correlations between topics, confirming reasonable relationships and suggesting unknown links between risk factors.

The work in [76] also explored an approach based on automatically computing similarity between reports, which was also graphically represented on the time axis, outlining interesting trends. Another powerful trend representation can be found in [78], which exploits a complex mixture of ML and Bayesian statistics to establish how much different types of incidents/accidents are predictive of fatal injuries; this technique allows the automatic association of a numeric severity score to each event, which can be visualized over time (see Figure 15).

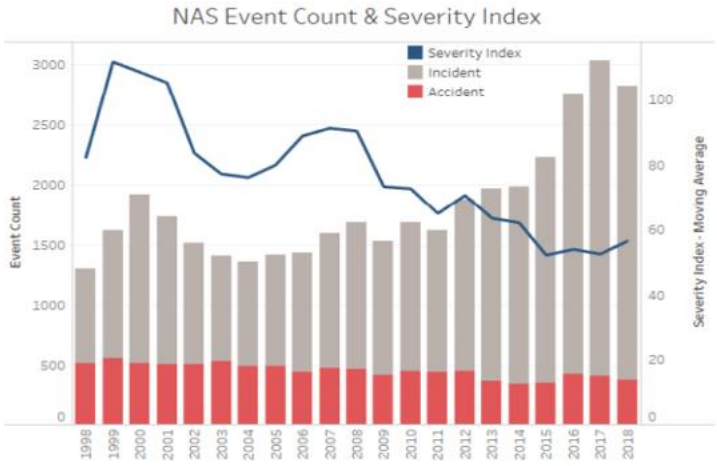


**Figure 15: The severity score proposed in [78]**

Even if most of these information extractions cannot really be evaluated from a quantitative point of view, the most interesting global conclusion is that ML and NPL tools can help in highlighting relationships which safety experts consider meaningful.

Furthermore, most of the reported studies suggest that different techniques can be exploited in parallel to mutually complement themselves, and the application of a mixture of approaches seems to really enrich the process of meaning extraction.

## 4.4 Conclusions

From what has been presented above, it is possible to summarise some interesting approaches to deal with the automated analysis of safety reports:

- Extraction of statistical information, like for example the occurrence of words (or combination of words) in the reports and the prevalence of keywords (e.g. some ATSs appear more than others);
- Topic modelling;
- Report similarity;
- Network visual representations of keywords in reports.

This work will be the starting point of the WP3 "*Data Management and Engineering*".

# 5 Conclusions

Deliverable "D2.1: Project Scope" is a report covering the project scope and general approach of FARO project, framed in WP2 "Safety and Resilience Conceptual Framework". **FARO** stands for *saFety And Resilience guidelines for aviatiOn*, and it addresses the evaluation of the impact of new automation solutions on safety and on resilient performance by applying mixed knowledge - and data-driven approaches.

The deliverable presents the main objectives of the project as well as a summary of the work to be conducted after alignment of the interests of all stakeholders involved, including the SJU. This is done through the presentation of the required entry and exit criteria for each of the work packages of the project, as a way to identify potential gaps, overlaps and misalignments:

**WP3 "Data Management and Engineering"** will use safety reports, existing taxonomies, common ATM look-up tables and other complementary information to generate an automated report field extraction for statistical analysis and topic modelling and training and testing datasets, to be used by the rest of work packages.

**WP4 "Safety Analysis: identification of Safety Performance Functions"** will use a complete dataset on airspace design and organisation, human dynamics and organisational interrelation to build the so-called Safety Performance Functions that will allow the analysis of the frequency of safety events and quantification of thresholds for independent variables.

**WP5 "Resilience Analysis"** will rely on the Use cases developed within WP2 and the dataset produced by WP3 in terms of safety and also in the use of a resilience theoretical framework and definition to generate a resilience performance framework with its assumptions and structure clearly defined.

Finally, **W6 "Safety and Resilience Guidelines"** will use both WP4 and WP5 outputs as inputs and will produce a Validation Plan and Validation Report where the combination of safety and resilience models will be showcased.

The review of the State of the Art in Safety and Resilience domains in aviation and in other transportation modes (such as train, maritime and road) has highlighted the extensive literature that exists in the field. It presents an overview of some works on the safety and resilience domain, as well as a comprehensive list of other SESAR projects that are related to FARO. Additionally, the document also identifies the relationship with the maritime and railway domains and presents the main synergies from which FARO can take advantage.

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# Appendix A List of other related SESAR Projects

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Future Sky Safety | https://cordis.europa.eu/project/id/640597 | Safety | H2020-MG-2014_SingleStage_A | n/a | H2020-EU.3.4. - SOCIETAL CHALLENGES - Smart, Green And Integrated Transport | 1 January 2015 | 30 June 2019 | 16.270.348,00 | Closed |
| 2 | Safe Cloud-Data-driven research addressing aviation safety intelligence | https://cordis.europa.eu/project/id/724100 | Safety | H2020-MG-2016-SingleStage-INEA | n/a | H2020-EU.3.4. - SOCIETAL CHALLENGES - Smart, Green And Integrated Transport | 1 October 2016 | 30 Septmeber 2019 | 5.576.288,75 | Closed |
| 3 | EUNADICS-AV-European Natural Airborne Disaster Information and Coordination System for Aviation | https://cordis.europa.eu/project/id/723986 | Safety | H2020-MG-2016-SingleStage-INEA | SESAR Enabling project | H2020-EU.3.4. - SOCIETAL CHALLENGES - Smart, Green And Integrated Transport | 1 October 2017 | 1 October 2019 | 7.509.318,75 | Closed |
| 4 | EWIS SAT-Safety Analysis Tools for Electrical Wired Interconnected Systems | https://cordis.europa.eu/project/id/325965 | Safety | SP1-JTI-CS-2012-02 (FP7) | JTI-CS - Joint Technology Initiatives - Clean Sky | FP7-JTI - Specific Programme "Cooperation": Joint Technology Initiatives | 1 January 2014 | 30 June 2015 | 554.160,00 | Closed |

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | SAFEMODE-Strengthening synergies between Aviation and maritime in the area of human Factors towards achieving more Efficient and resilient MODE of transportation | https://cordis.europa.eu/project/id/814961, http://www.safemodeproject.eu/ | Safety | H2020-MG-2018-TwoStages | n/a | H2020-EU.3.4. - SOCIETAL CHALLENGES - Smart, Green And Integrated Transport | 1 June 2019 | 31 May 2022 | 10.683.032,06 | On-going |
| 6 | VISION - Validation of Integrated Safety-enhanced Intelligent flight cONtrol | https://cordis.europa.eu/article/id/300590-enhancing-flight-safety-during-near-ground-operations | Safety | H2020-MG-2015_SingleStage-A | IR / Flight Demo | H2020-EU.3.4. - SOCIETAL CHALLENGES - Smart, Green And Integrated Transport | 1 March 2016 | 31 August 2019 | 1.796.877,50 | Closed |
| 7 | OPTICS2 - Observation Platform for Technological and Institutional Consolidation of research in Safety and Security | https://cordis.europa.eu/project/id/770138 | Safety | H2020-MG-2017-SingleStage-RTD-MOVE | CSA - Coordination and support action | H2020-EU.3.4. - SOCIETAL CHALLENGES - Smart, Green And Integrated Transport | 1 October 2017 | 30 September 2021 | 1.493.597,50 | On-going |
| 8 | PJ19 Content Integration | https://cordis.europa.eu/project/id/731765 | Safety | H2020-SESAR-2015-2 | IR/VLD | H2020-EU.3.4.7. - SESAR JU | 1 November 2016 | 31 December 2019 | 25.145.687,35 | Closed |
| 9 | MINIMA- MItigating Negative Impacts of Monitoring high levels of Automation | https://cordis.europa.eu/project/id/699282/reporting | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 May 2016 | 30 April 2018 | 582.780,00 | Closed |
| 10 | AUTOPACE- AUTOMATION PACE | https://cordis.europa.eu/project/id/699238/reporting | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 28 February 2018 | 599.867,50 | Closed |

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | STRESS- Human Performance neurometricS Toolbox foR highly automatEd Systems design | https://cordis.europa.eu/project/id/699381/reporting | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 15 June 2016 | 14 June 2018 | 644.821,00 | Closed |
| 12 | TACO- Take Control | https://cordis.europa.eu/project/id/699382 | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 20 June 2016 | 19 June 2018 | 599.992,50 | Closed |
| 13 | SVETLANA-Safety (and maintenance) improVEment Through automated fLight data ANAlysis | https://cordis.europa.eu/project/id/265940 | ATC Automation | FP7-AAT-2010-RTD-RUSSIA | n/a | FP7-TRANSPORT - Specific Programme "Cooperation": Transport (including Aeronautics) | 1 August 2010 | 31 December 2012 | 3.920.503,00 | Closed |
| 14 | COTTON- Capacity Optimisation in TrajecTory-based OperatioNs | https://cordis.europa.eu/project/id/783222 | ATC Automation | H2020-SESAR-2016-2 | ER (3) | H2020-EU.3.4.7. - SESAR JU | 1 January 2018 | 31 December 2019 | 1.008.342,50 | Closed |
| 15 | MALORCA: Machine Learning of Speech Recognition Models for Controller Assistance | https://cordis.europa.eu/project/id/698824 | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 April 2016 | 31 March 2018 | 805.587,50 | Closed |
| 16 | SALSA- SATELLITE-BASED ADS-B FOR LOWER SEPARATION-MINIMA APPLICATION | https://cordis.europa.eu/project/id/699337/reporting | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 April 2016 | 31 March 2018 | 995.063,75 | Closed |
| 17 | AGENT- Adaptive self-Governed aerial Ecosystem by Negotiated Traffic | https://cordis.europa.eu/project/id/699313 | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 February 2016 | 31 January 2018 | 598.750,00 | Closed |

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 18 | COPTRA- COmbining Probable TRAjectories | https://cordis.europa.eu/project/id/699274 | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 28 February 2018 | 1.280.818,75 | Closed |
| 19 | EVOAtm- Evolutionary ATM. A modelling framework to assess the impact of ATM evolutions | https://cordis.europa.eu/project/id/783189 | ATC Automation | H2020-SESAR-2016-2 | ER (3) | H2020-EU.3.4.7. - SESAR JU | 1 January 2018 | 31 December 2019 | 968.880,00 | Closed |
| 20 | ADAPT-Advanced prediction models for flexible trajectory-based operations | https://cordis.europa.eu/project/id/783264 | ATC Automation | H2020-SESAR-2016-2 | ER (3) | H2020-EU.3.4.7. - SESAR JU | 1 January 2018 | 31 December 2019 | 997.250,00 | Closed |
| 21 | PARTAKE- cooPerative depArtuRes for a compeTitive ATM networK sErvice | https://cordis.europa.eu/project/id/699307 | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 28 February 2018 | 986.250,00 | Closed |
| 22 | MOTO- the embodied reMOte Tower | https://cordis.europa.eu/project/id/699379 | ATC Automation | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 31 May 2018 | 999.000,00 | Closed |
| 23 | AISA-AI Situational Awareness Foundation for Advancing Automation | https://cordis.europa.eu/project/id/892618 | ATC Automation | H2020-SESAR-2019-2 | ER (4) | H2020-EU.3.4.7. - SESAR JU | 1 June 2020 | 30 November 2022 | 990.125,00 | On-going |
| 24 | MAHALO - Modern ATM via Human/Automation Learning Optimisation | https://cordis.europa.eu/project/id/892970 | ATC Automation | H2020-SESAR-2019-2 | ER (4) | H2020-EU.3.4.7. - SESAR JU | 1 June 2020 | 30 November 2022 | 997.215,50 | On-going |
| 25 | TAPAS -Towards an Automated and exPlainable ATM System | https://cordis.europa.eu/project/id/892358 | ATC Automation | H2020-SESAR-2019-2 | ER (4) | H2020-EU.3.4.7. - SESAR JU | 1 June 2020 | 30 November 2022 | 997.410,00 | On-going |

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 26 | APACHE- Assessment of Performance in current ATM operations and of new Concepts of operations for its Holistic Enhancement | https://cordis.europa.eu/project/id/699338 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 9 May 2016 | 8 May 2018 | 783.837,50 | Closed |
| 27 | INTUIT-Interactive Toolset for Understanding Trade-offs in ATM Performance | https://cordis.europa.eu/project/id/699303 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 30 April 2018 | 998.125,00 | Closed |
| 28 | GAUSS- Galileo-EGNOS as an Asset for UTM Safety and Security | https://cordis.europa.eu/project/id/776293 | ATM Performances | H2020-GALILEO-GSA-2017-1 | IR / Flight Demo | H2020-EU.3.4.2.2., H2020-EU.3.4.1.2., H2020-EU.2.1.6.3., H2020-EU.2.1.6.1.2. | 1 March 2018 | 28 February 2021 | 3.695.758,31 | On-going |
| 29 | AURORA-Advanced User-centric efficiency metRics for air traffic perfORmance Analytics | https://cordis.europa.eu/project/id/699340 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 April 2016 | 31 March 2018 | 829.312,50 | Closed |
| 30 | VISTA- Market forces trade-offs impacting European ATM performance | https://cordis.europa.eu/project/id/699390 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 13 June 2016 | 12 June 2018 | 742.956,25 | Closed |
| 31 | SAPIENT- Satcom and terrestrial architectures improving performance, security and safety in ATM | https://cordis.europa.eu/project/id/699328 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 April 2016 | 30 September 2017 | 999.500,00 | Closed |

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| 32 | RETINA- Resilient Synthetic Vision for Advanced Control Tower Air Navigation Service Provision | https://cordis.europa.eu/project/id/699370 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 28 February 2018 | 1.072.910,00 | Closed |
| 33 | COCTA- Coordinated capacity ordering and trajectory pricing for better-performing ATM | https://cordis.europa.eu/project/id/699326 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 15 April 2016 | 30 September 2018 | 534.157,50 | Closed |
| 34 | OptiFrame- An Optimization Framework for Trajectory Based Operations | https://cordis.europa.eu/project/id/699275 | ATM Performances | H2020-SESAR-2015-1 | ER (1) | H2020-EU.3.4.7.1 - Exploratory Research | 1 March 2016 | 28 February 2018 | 857.241,25 | Closed |
| 35 | ITACA - Incentivising Technology Adoption for Accelerating Change in ATM | https://cordis.europa.eu/project/id/893443 | ATM Performances | H2020-SESAR-2019-2 | ER (4) | H2020-EU.3.4.7. - SESAR JU | 1 May 2020 | 31 October 2022 | 999.937,50 | On-going |
| 36 | CREATE - Innovative operations and climate and weather models to improve ATM resilience and reduce impacts | https://cordis.europa.eu/project/id/890898 | Environment and Metorology | H2020-SESAR-2019-2 | ER (4) | H2020-EU.3.4.7. - SESAR JU | 1 June 2020 | 30 November 2022 | 998.165,00 | On-going |
| 37 | START - a Stable and resilient ATM by integrating Robust airline operations into the network | https://cordis.europa.eu/project/id/893204 | Optimized ATM Network Services | H2020-SESAR-2019-2 | ER (4) | H2020-EU.3.4.7. - SESAR JU | 1 May 2020 | 31 October 2022 | 1.999.411,25 | On-going |
| 39 | Application of Resilience and Robustness Guidance to Remote Tower and ASAS | https://www.sesarju.eu/sites/default/files/16_06_01b_D01_Management_Report_and_F | Resilience | SESAR1 WP16: R&D Transversal Areas | IR/VLD | SESAR 1 Programme | 2011 | 2016 | n/a | Closed |

| No | Name | Website | Area | Call | Activity | Programme | Start Date | End Date | Overall budet (euro) | Status |
|---|---|---|---|---|---|---|---|---|---|---|
| | | inal_Project_Report.pdf | | | | | | | | |

# Appendix B Knowledge Transference from Other Transportation Domains

This section gives a more detailed overview of the most relevant text-mining methodologies mentioned in Section 4.

## B.1 Ontology learning

In computer science, ontology can be defined as a formal representation of the knowledge by a set of entities and relationships in a domain. It is possible to develop an ontology entirely manually, although the process is laborious; a number of semi-automated processes exist (which also involve NLP), but there is a need for human intervention to support any of these techniques.

The main idea is to carry on an interactive learning approach between a human and a computer software. First, key terms are identified in an automated way (typically via NLP); then, thanks to human intervention, these terms are connected with ad hoc relationships. This approach aims to recreate human ability to understand words and their connections, but in principle does not provide more information than what a human would already know by reading the reports: it automatizes as much as possible the process of making unstructured information computable and operational for further statistical analyses.

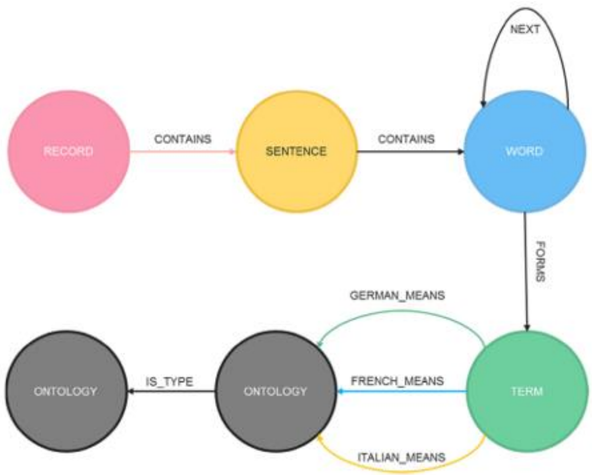


**Figure 16: An example of the graph database [73]**

This method is used and described in detail in [73]. For example, to identify records relating to “passengers falling downstairs”, a query is submitted to the database that:

- identifies the ONTOLOGY nodes describing the action “falling”, and the place “stairs”;
- identifies all TERM nodes linked to these ONTOLOGY nodes, all WORD nodes linked to these TERM nodes and so on until reaching the links with respective RECORD nodes.

This method has shown very good results in terms of specificity, but with less control over false negatives.

## B.2 Network visualization

Visualization is one of the most powerful tools to make large quantities of data understandable by humans. Visualization is not just useful to represent results, it can also be an integral part of the data analysis, or even being a result itself.

In the field of transportation safety, information related to incident factors may be scattered across the documentation. NLP can be used to identify the salient points and terms of the reports by using stemming, lemmatization, part-of-speech tagging and descriptive statistics like term frequencies distribution. Furthermore, it can also automatically generate visual representations (networks) showing the words with similar appearance patterns, i.e., with high degree of co-occurrence, connected by edges.

Network visualization is vastly used in literature and slightly different approaches can be found; in particular, if the focus of the analysis is to evaluate not only the connections between words but also the connections of words with some selected topics, classic network visualization can be extended to include also this kind of information.

In [71] these selected topics are called Entities of Interest (EOIs). They are abstract concepts that represent different types of faults and causal factors, which are derived from past literature on incident analysis. In deriving EOIs the goal is to cover a broad spectrum of incident relevant concepts. The broader the spectrum of EOIs, the lower the probability that NLP analyses based on these EOIs will miss any relevant incident factors. In this context EOIs are a point of reference for the NLP approaches to conduct their search.

The network graph derived from this mixture of free NLP search and supervised selection of entities shows, in addition to the previous connections, the entities-to-text mapping which represents the association between entities and words. This can provide an understanding of how the entities influence safety (e.g., the words linked to an entity can highlight factors of heightened risk for that type of incident).

## B.3 Topic Modelling

While selecting some entities or factors of interest can be a powerful method when we already know which the topics are to focus on, in some occasions a less supervised approach can lead to discover the existence of hidden patterns or concepts in the text.

Topic Modelling is an unsupervised-learning technique which enables the discovery of the main themes pervading a collection of textual documents. It is one of the most used methodology in the literature about safety reports analysis, since it is a flexible technique which can be applied to different data structures and can produce results both in terms of qualitative meaning discovery and in terms of quantitative features extraction.

The statistical assumptions behind topic modelling can be summarised as follows: a document can be seen essentially as a set of words; a document expresses a number of topics with different salience according to a certain distribution; a topic is expressed with words according to a specific distribution. Therefore, the idea is that these distributions can be empirically estimated by observing the frequencies of words in the documents. From a practical point of view, given a collection of documents, the analyst just has to fix a number $T$ of topics to extract and tune a few hyper-parameters. Each document can then be described as a vector of numbers indicating the importance of each of the $T$ topics in the document. Furthermore, each of the $T$ topics is represented as weights associated to each word, identifying the words most frequently associated to each topic (see Table 1). This information can be used to interpret the topics, for example by presenting these words to a domain expert.

UNIQUE WORDS IN THE 10 TOPICS IN THE ACCIDENT REPORTS

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| shove<br>yard<br>pull<br>cut | unit | curv | conductor<br>walk | broken<br>inspect |
| **6** | **7** | **8** | **9** | **10** |
| bridg<br>fire<br>equip<br>oper<br>contain | gallon<br>fuel<br>ton<br>spill<br>approxim<br>capac<br>gatx | truck<br>cross<br>struck<br>stop<br>signal<br>fail | main<br>line<br>travel<br>east<br>side<br>load | hazard<br>materi<br>leak |

**Table 1: An example of most frequent words in topics [72]**

| Report ID | Topic 1 | Topic2 | Topic 3 | Topic4 | Topic5 |
|---|---|---|---|---|---|
| 1 | **0.2039801** | 0.07462687 | 0.08955224 | 0.09950249 | **0.53233831** |
| 2 | **0.28823529** | 0.11176471 | 0.10588235 | 0.13529412 | **0.35882353** |
| 3 | **0.2056962** | **0.48417722** | 0.11708861 | 0.09493671 | 0.09810127 |
| 4 | 0.41441441 | 0.12612613 | 0.16216216 | 0.11711712 | 0.18018018 |
| 5 | 0.13846154 | 0.13846154 | **0.49230769** | 0.07179487 | 0.15897436 |
| 6 | 0.11911357 | 0.09695291 | 0.09418283 | **0.65096953** | 0.03878116 |

**Table 2: An example of topic probabilities [71]**

For Topic Modelling, Latent Dirichlet Allocation ( [72] [71] [76] [77] ) is one of the most effective techniques, based on the generation of probability distributions. Standard LDA model can be represented as a generative process for documents composed of topics that are themselves composed of words. As explained in [71], the way LDA works is that for each topic two actions are performed: first, if computes the proportion of words in document *d* that are currently assigned to topic *t*, and secondly, the proportion of assignments to topic *t* over all documents that contain this word *w*. It then reassigns *w* a new topic based on generative model (essentially the probability that topic *t* generated word *w*), and the process is repeated until it reaches a steady state where all assignments are good.

In [77] Structural Topic Modelling in used, which extends the LDA framework. STM allows for taking into account covariate data, including document metadata, and assuming they influence topic prevalence within documents. So, STM also uses document-specific covariate data to define distributions, overcoming the assumption of randomness in LDA.

In general, the information extracted via Topic Modelling can offer an insight not only into the main themes of the documents and their frequencies, but also into their correlations and connections.

## B.4 Similarity computation

The main objective of similarity computation is to determine if a particular incident is an isolated case or if similar conditions are recurrent and, in that case, to identify its frequency and possible trends. Similar conditions don't necessarily mean same kind of incident: similarity can be due to same weather conditions, same mitigating factors, same causes, same actions taken and so on.

Identifying these similar reports (see Figure 17) is important when, for example, safety managers want to take action to strengthen the defences against future accidents and want to understand underlying patterns and possible recurrences. When investigating into a particular issue or risky scenario, experts need a vast number of examples covering many aspects: one way to approach the problem is to identify from the reports database a particular occurrence and then use it as a query to search for similar reports.

Another possible application is when, in the moment a new report arrives, the receivers may want to verify if this incident is part of a larger trend and, if so, he would want to estimate the frequency of the events in question, judge the risk they represent and, if necessary, take corrective actions.

Similarity computation can be performed in different ways, taking into account that the most straightforward methods can be less precise but more interpretable, and vice versa. In general, given a pair of documents, the system produces a similarity score, between 0 and 1. The score is based on the lexical overlap of the narrative parts of the two documents. In the simplest systems ( [76] ), the more words they share in common the more similar the documents are. In particular, first the texts are tokenized and stemmed, so that each document is represented by a vector where each dimension corresponds to a term in the collection and each value is the relative weight of the term in the document. Then, couples of documents are compared by computing the dot product between the vectors that represent them.

More complex semantic analyses can be performed, which also take into account the order in which words appear, and not just their occurrences [79]).

**Selected event: SEA86LA050 (100.0% similar):** DURING LANDING ROLL ON THE 1800 FOOT LONG 30 FOOT WIDE WET RUNWAY, THE AIRCRAFT VEERED RIGHT OFF THE RUNWAY AND THEN NOSED OVER. THE PILOT APPLIED BRAKES TWICE WITH NO EFFECT AND THE THIRD TIME THEY GRABBED. NO MALFUNCTIONS WERE FOUND DURING INSPECTION OR EXAMINATION. HYDROPLANING PROBABLY OCCURRED.

**Most similar narrative: WPR10CA176 (85.9% similar):** The pilot reported that he felt a slight wind gust on touchdown. The landing was smooth and occurred in the first 1/3 of the runway. When the nosewheel made contact with the runway, the airplane veered left. The pilot applied right rudder and braking in an attempt to correct the airplane, but before it stopped the airplane veered off the runway, went down an embankment, and nosed over. No mechanical malfunctions or failures were found during the postaccident examination of the airplane.

**Second most similar narrative: SEA99LA154 (85.8% similar):** The pilot reported that during the landing roll on a wet runway surface, he applied braking action and the airplane skidded to the right and veered off the runway. The aircraft ground-looped and came to rest in the mud next to the runway. The pilot reported that there were no mechanical failures or malfunctions with the airplane at the time of the accident.

**Figure 17: An example of similarity computation [79]**

## B.5 Partial Least Squares

When the focus of the analysis is not on unveiling meaning in a qualitative way but to predict a quantitative variable (e.g., incident cost), it can be really useful to find a method to summarize narratives information in some numerical features.

Partial Least Squares is not specific for textual analysis, but it’s used in supervised learning problems when there is a large number of predictive variables; so, in text analysis, it can be a powerful tool whenever the number of words is large. The basic idea is similar to the one of Principal Components Analysis: it constructs latent variables that are linear combinations of predictors. But unlike Principal Components, which use only the predictor variables, PLS linear combinations are formed to maximize the covariance between the predictors and the response variable.

The resultant PLS predictors are then simply linear combinations of the words in the safety report narratives. In [72] the PLS predictors are proved to be consistently the most important variables used by their random forest models. The possible drawback of this approach is that the predictor is not interpretable, unlike for example the Topic Modelling approach.