# D5.2 Applicability Of The Resilience Model

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# FARO

FARO

This Report is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 892542 under European Union's Horizon 2020 research and innovation programme.

## Abstract

FARO WP5 contributes to the FARO project by introducing the perspective of resilience engineering and resilient performance to explore and develop an understanding of the characteristics of complex socio-technical systems. With this understanding, WP5 develops a baseline model of resilient performance that can be used to assess changes in the way that the work system design evolves. With this knowledge, assessment of an envisaged design can be explored in terms of resilient performance. Using this knowledge and understanding, an assessment of resilient performance can be undertaken. The results of this assessment can be used to derive metrics and indicators of resilient performance.

D5.2 reports further on the research undertaken and reported in D5.1 which developed a baseline model for the assessment of resilient performance of socio-technical systems using the ATM system as an exemplar. Resilience engineering is inherently qualitative in nature and character. WP5 also aims to transform qualitative results and findings into a form that can be used for data science applications.

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# 1 Introduction

Work Package 5 of the FARO project introduces a particular perspective of the ATM system drawing on resilience engineering. This perspective, here referred to as resilient performance, differs from other approaches and conceptions of safety. The focus is on how complex socio-technical systems sustain their performance in the presence of performance variability. Performance here in this context is not limited to safety but effective operational performance, e.g., achieving goals set for the system.

D5.2 forms a deliverable of FARO Work Package 5 (WP5). The deliverable reports research that continues the investigation of the impact of automation, digitisation, and increased integration of human and technology in the work system and its influence or effect on ATM resilient performance.

Deliverable "D5.2: Applicability of the Resilience Model" is a report covering two activities – T5.2 (Identifying Nature of Changes into the Work System) and T5.3 (Resilience Model Influence Factors and Acceptability Thresholds). D5.2 builds on the deliverable 5.1 (Resilience Model Description).

This report extends the work undertaken in previous WP5 tasks by situating the changes implemented in two work systems, that form two FARO specific use cases, and explore through a lens of resilience engineering, the influence these changes may have on resilient performance.

This is a requirement to understand the characteristics and nature of the socio-technical system from which metrics and indicators of resilient performance can be derived from and proposed for the FARO project.

Assessment of resilient performance is inherently qualitative in nature. D5.2 therefore explores the evolution and transformation of qualitative assessments of resilient performance into salient indicators of resilient performance that is usable for data science applications.

## 1.1 Purpose of the document

Tasks 5.2 and 5.3 of FARO are reported in FARO deliverable D5.2.

D5.2 has a twofold purpose:

- One is to document and report the process and methodology, of the application of the assessment that was undertaken for the two FARO use cases, grounded in the D5.1 baseline model of resilient performance. This includes deriving operational practices at micro, meso and macro levels of abstraction for the two use cases.

- Two ENAIRE ATC sector groups within Madrid ACC's area of operations were selected by FARO as use cases: LECMSAN (Santiago and Asturias) sectors (Use Case 1) and LECMBCC and LECMBCU (Barcelona central) sector (Use case 2).

  This document describes the differences in characteristics and operational dimensions of the two sectors groups before and after the implementation of changes in the operational environment. These changes are indicative of the changes in the way that the purposeful activity, and goals, of the sector groups are undertaken and the provision of ATS service.

From, these results, exploration of the influence on resilient performance was considered, drawing as far as possible on a naturalistic approach to eliciting the strategies and operational considerations that various actors in the work system use, have and deploy. This, as far as practicable, provided a view of one trajectory of the ATM system at various hierarchical levels.

Having identified the operational characteristics of sector operations and elicited specific sources and states of performance variabilities, these were synthesised with the principles of resilience engineering and characteristics of resilient performance e.g., that which sustains operations, as adaptive capacity, of the margins and buffers as well as the trade-off space that is navigated in response to performance variability.

The results of this research activity led to the derivation of a number of conditions and states form which a smaller number were selected for transformation into qualitative expressions suitable for data analysis. The outcome of this process was used to generate specific indicators of resilient performance.

Document Structure

This document is structured as follows:

- Section 1 is the introduction.
- Section 2 introduces digitisation and emerging technologies in the context of the ATM Master Plan and how these impacts on resilient performance
- Section 3 engages with the concept of resilience performance from a Resilience Engineering lens and how a change (e.g., new design solutions) alters resilience performance of the work system
- Section 4 describes the work system and changes identified in the work system based on the Use Cases
- Section 5 characterises the nature of these changes and identifies the influence on Resilient Performance
- Section 6 presents the methodology to transforming changes identified in the work system into deriving the indicators and metrics of resilience performance
- Sections 7 documents the derived indicators of resilient performance
- Section 8 engages in-depth discussion on the indicators of resilient performance and what this means for the work system from an RE perspective
- Section 9 reflects on gaps and difficulty in transforming qualitative data into quantitative data components as operational expressions of resilient performance and discusses future work to be carried out in this regard.
- Section 10 concludes the report.

## 1.2 Acronyms and Terminology

| Term | Definition |
|---|---|
| ANSP | Air Navigation Service Provider |
| ATC | Air Traffic Control |
| ATCo | Air Traffic Controller |

| Term | Definition |
|---|---|
| ATM | Air Traffic Management |
| ACC | Area Control Centre |
| ATS | Air Traffic Services |
| CWP | Controller Working Position |
| FLAS | Flight Level Allocation System |
| GE | Graceful Extensibility |
| IAS | Indicated Air Speed |
| LoS | Losses of Separation |
| NLP | Natural Language Processing |
| RE | Resilience Engineering |
| RP | Resilient Performance |
| RTF | Radio-telephony |
| SMI | Separation Minima Infringement |
| SysRes | Systemic Resilience Model |
| UAB | Unit of adaptive behaviour |
| UC | Use Case |
| WP | Work Package |

# 2 Digitalisation, automation, resilient performance, and changes in the work system

## 2.1 Digitalisation, automation, and resilient performance

The ATM Roadmap and EU Digital sky both seek to exploit the potential of new technology in ATM. Transformation of the ATM industry is widely anticipated. Whilst new challenges will be introduced, so too are benefits that are perceived to lead to more effective and efficient operations across the network which in turn lead to changes that benefit the wider aviation industry domain.

Orthodox approaches to safety and human performance emphasise specific views focused on the proximal aspects of the system. This is changing with recognition and acceptance of the distal influence on manifestations of safe performance. For FARO, the manifestation of safety that is of interest is Safety Minima Infringements – the classic loss of separation (LoS). This is one view of safety performance.

The aviation and ATM system has achieved what is considered to be high performance. And sustains this high performance across a range of variability challenges and surprises. One of the attributes that the ATM system has, it is now acknowledged, is the ATM and the aviation's system ability and capacity to adapt and adjust its operation to changes in the operating environment. This is labelled adaptive capacity and provides the capacity to manage the different system states that are invoked by the variability inherent through different situations and conditions that the ATM system is confronted with. Resilience engineering, and its principles, bring a view of how a complex socio-technical system is able to adapt and sustain its performance with performance variability and varying conditions.

Changes in operating capabilities, capacities of a system will influence its ability to respond to variations in operating conditions and states. As well as its capacity and capability to do so. Some of these changes can be seen as opportunities for benefits hitherto unforeseen or unanticipated. Others can induce changes in the capacity of the ATM system to adapt and respond to variations and lead to decisions being made that 'trade off', for example, managing the consequences of demand upon service provision at the cost of delay or non-optimal flight profiles.

The principles and philosophy of resilience engineering provide a means to be able to explore complex socio-technical systems and their performance. Not solely in terms of safety but in other ways too. The basis for this claim lays in cognitive systems engineering methodology and specifically the framing of the ATM system as a macro-cognitive work system.

This approach brings with it a very specific and intrinsic perspective of systems that are complex, adaptive, and designed to support near continuous interdependencies amongst humans and technical nee intelligent artefacts in undertaking purposeful activity I.e., work that the system and its actors undertake. Such systems constantly evolve over their lifecycle. As a consequence, there is never a complete understanding or perfect knowledge of the 'system' or its characteristics. The way the purposeful activity of the system is undertaken for example, and how it adapts or changes.

Digitalisation and automation, as it leads to greater integration of human and technology, will lead to different patterns of activity, dependencies and interactions between system actors and agents. The question that arises is how do these changes influence or change the nature of adaptative capacity and other resilience engineering principles that shape resilient performance and the ATM systems ability for sustained adaptability?

These include the strategies that different system actors deploy to respond to variability, complexity effects, considerations of buffers and margins that scope optimality and the trade-offs that are navigated. Exploring these can provide a view of how technological change influences resilient performance.

# 3 Resilient performance and the work system

## 3.1 System properties and behaviours

Today's systems and organisations function in ways that are responses to rapidly changing conditions with different degrees of uncertainty as well as complexity. In response, changes introduced into the system including opportunities that present themselves as potential pathways to improve system performance such as the introduction of new technologies, tools, and design solutions, it can be anticipated that the manner that the system sustains operations and the way it performs will change.

Change(s) introduced into the system influences the concept of operation in the short and medium term and form basis of new methods of working and the pattern of activities that is carried out in highly integrated, digitised, and interdependent human-technology work system [1]. The system's focus is thence to respond to the changed environment by adapting its performance to sustain production safely and effectively. Foster et al [2] explain that in response to the variabilities in the system, the human operator "act in some way to dampen, to use the language of functional resonance, the variability inherent in complex systems" [2]. This is resilient performance.

Resilient performance is characterised as the capability of the system to adjust its pattern of activities or actions in a dynamic, purposeful manner under expected and unexpected conditions underscored by the goals which the system strives to achieve or uphold [13]. Lundberg [3] notes that this could be core safety critical goals which the system aims to protect or flexible goals which exists in continuum and are constantly changing as the system navigates the unpredicatability of the operating environment.

## 3.2 Emergence of new system state(s)

The complex nature of complex social technical systems and unpredictability of the new operating environment, interactions between system actors and artefacts produce sets of conditions that influence the safe performance of the system.

In response to variabilities effected in the system following introduction of new technologies, the humans in the system adapt their performance by deploying a range of contingency plans & strategies enacted tactically to mitigate disruptive events or as conditions changes. The choice of strategies and capability to deploy them is however, based on the availability and accessibility of the system to readily bring them to bear in a timely manner to sustain operations.

Condition variabilities, performance variabilities and the interactions between system elements induce the emergence of novel system behaviours which could lead to unintended outcomes or create new system state(s) such as brittleness – changes to system performance at or beyond its boundaries and specifically, how the system collapses or fails [5]; graceful extensibility – capability to adapt performance to meet challenges that extend beyond everyday performance when the system is distant from boundary conditions [5].

For example, strategies to minimise the use of ATFM regulations may mean redistribution of traffic demand elsewhere in the network or sector groups which yields to higher workload for extended periods leading to fatigue for the receiving sector. It may also create conditions for sustained adaptability as the receiving sector adapt performance to accommodate the new demand.

These changes – both the different nature and characteristics of work and new interdependencies and coupling that emerge - will influence resilient performance of a system and its capacity and capability to respond to a disruption or a challenge event which can impact sustained adaptability. More so, these changes can defy our understanding of how the system behaves and performs as what emerges is often not predictable. This is especially the case where the system gains in complexity.

As such, how does an organisation effectively determine the state of the system? What are the indicators of system behaviours that support or create adaptive capacity that facilitates/enables resilient performance adaptation as the system adapt to sustain operations and production?

In the new system state, are extant surprises and challenge events able to be managed as they were in the old organisation and can sustained adaptability be continued or has brittleness been introduced?

# 4 The work system and use cases scenarios

## 4.1 The Work System and its dimensions

In Resilience Engineering, resilience, and resilient performance are considered through three hierarchical dimensions of the system – Macro, Meso and Micro - characterised as a network of interdependencies in understanding how the system performs under varying conditions [18].

Adaptive capacity and capabilities exist at different levels of an organisation and may be characterised at the Micro level (e.g., en-route sector made up of tactical and planner executive team); Meso (en-route sector groups within an ACC operations room); and Macro (e.g., an ANSP including their processes, networks etc). Adaptive units (or Units of adaptive behaviour) (see D5.1 and also Woods, 2018) are the units that 'work' at and cross scale of a network i.e., roles, agents, teams, networks, organisations. Such units and their associated networks, adapt their behaviours, resources, strategies and changing priorities in the pursuit of goals when confronting performance variability and uncertainty. For example, a decision made at the meso level by a shift supervisor to have 14 controllers on a morning shift rather than 16 is managed at the meso level (i.e., bandboxing of sectors, reduce demand, reroute traffic away from the sector) and impacts the micro level (i.e., increased workload and deployment of strategies to manage tasks).

These three levels can contribute to our understanding of how the system responds to both expected and unexpected variability and what trade-offs are made. Organisational decisions at the macro level, including processes, rules and structure influences the meso level such as decision making around sector operations and how these migrate to tactical strategies including controlling strategies at the micro level. Combined, these three hierarchies in the work system offer a robust landscape of insight into resilient performance.

In examining the work system – pre-change and post-change – the objective is to identify how the new design solutions have influenced the patterns and organisation of work, and how system actors have adapted their performance in response to, or in anticipation of variabilities introduced in the operational environment. This also includes new patterns of work that have emerged as a result of implementing the new design solution, and tighter coupling of processes through new dependencies. Of importance is the identification of new properties or system state(s) that have emerged as a consequence.

## 4.2 Use cases and scenarios

To identify the changes in the work system and how these impact the resilient performance of the ATM system (FARO Objective 3), three use cases were identified under the FARO project as having the potential to explore different aspects of change in operation following deployment of new design solutions in an ATC operational environment (see D2.2 for an in-depth description of the three Use Cases).

I. Use Case 1 (UC1) - The implementation of a Free Route Airspace (FRA);
II. Use Case 2 (UC2) - The change in operation procedures in a sector of the airspace; and
III. Use Case 3 (UC3) - The introduction of new label to the Controller Working Position (CWP).

### 4.2.1 Use Case 1 – Free Route Airspace (Madrid ACC)

Free Route Airspace (FRA) offers 'freedom' to airspace users to plan their route between defined entry and exit points of a specified volume of airspace without reference to air traffic service (ATS) route network [6]. Although free to choose their preferred routes (dependent on airspace availability), flights remain subject to air traffic control and are to observe all limitations/restrictions i.e., fixed entry and exit points, avoid danger areas (i.e., military), temporary segregated area, temporary reserved area, etc.

Introduced by EUROCONTROL in 2008, FRA as a concept is generally promoted as providing airspace users (airlines) with environmental (reducing emissions) and economic (reduced fuel consumption) benefits and improvement of flight efficiency [6].

The implementation of FRA in the Lisbon FIR and North-West Madrid FIR sectors of Santiago and Asturias (FRASAI) - Use Case 1 - guaranteed airspace continuity between Portugal and Spain. The airspace covers Lisbon and Madrid ACC with ATS services given by the Madrid ACC. FRA is implemented between FL245 and FL460 with procedures available 24 hours in the Santiago and Asturias ATC (D2.2).

FRASAI resulted in the elimination of existing ATS routes, creation of new points, and restructuring of the airspace (and associated SID/STAR procedures) to enable homogenous structure of traffic flows and balancing of workload amongst the different sectors.

Two EUROCONTROL reports [6][7] found that some of the challenges FRA introduces into the system includes difficulty for ATCos to detect conflicts due to the greater spread and increase in the possible confliction points; conflicts occurring immediately after entering an ATC area of responsibility requiring greater monitoring by ATCo during transfer/acceptance of control; and FRA introduction of changes to separation provision i.e., the use of direct routes as a tactical strategy since most aircraft are already flying directs. In addition, implementation of FRA may create a need for sectorisation to be optimised to better accommodate the new traffic flows. The lack of fixed route structure increases the risk of 'blind spots' within areas where controlling tasks take place at and near the borders and enables irregular use of odd/even levels as determined in the respective AIPs [7][6].

### 4.2.2 Use Case 2 – Sectorisation, implementation of new ATS routes, Flight Level Allocation System and change in operational procedures (Barcelona ACC)

Congestion in Europe's airspace and en-route capacity constraints caused by increase in air traffic demand have led to the need to organise and manage airspace in a more dynamic way to increase capacity and reduce delays [8]. To enhance airspace capacity and reduce ATFCM delays, ANSPs organise, plan, and manage their airspace configurations with enough flexibility to respond to changes in traffic demand, unexpected event, or update in airspace reservation [8].

Use Case 2 refers to the split of the LECBCCC into two new sectors – CCU and CCL – in the Barcelona UIR to increase capacity and reduce traffic delays occurring in the region due to the interaction of East-West overflights and the North-South arrivals from French airspace to the Islands (LEIB and LEPA). Splitting of LECBCCC into CCL and CCU was thus aimed at segregating these two interacting flows to avoid their encounters. In addition to the change in airspace design resulting from the split, a new direct route between ROCAN (located in French airspace) and LORES was also implemented to segregate and exclusively serve flights southbound to LEPA and LEIB.

The change in the airspace structure and introduction of new routes, by necessity, resulted in new operational procedures such as transfer procedures between CCU and CCL, and new frequencies. Other changes introduced in the work system included difficulty in carrying out Tactical control tasks especially during bad weather conditions due to the irregular shape of the two new sectors – CCU and CCL, and reduced room for manoeuvrability in vertical profile of CCL because of the limited number of flight levels it contains.

Use Case 2 exemplifies how change(s) made across the lifecycle of the system, can introduce new system states (i.e., differences in control tasks). To manage the operational environment and sustain operations, it can be anticipated that the system will adapt and change its performance as users find ways beneficial to system performance to make the system work despite its shortcomings. These may include the evolution of new techniques for controlling that exploit the technical design in ways that the design solution never embraced or considered. Wilson [9] describes this notion stating that systems in real use, with real users and under the constraints of time, space, and motivation in practice will display characteristics, and operate in ways which may not have been expected or planned for by the designer [9].

### 4.2.3 Use Case 3 – Display Aircraft Indicated Airspeed or Mach number in the Controller Working Position

The ATM Masterplan [1] states that the introduction of increased levels of automation support in air traffic control will improve productivity of air navigation services due to better connectivity and information sharing between ground systems, and introduction of new capabilities to enhance the interface between air and ground, enables data exchange, as well as separation management [1]. One such interface and data sharing between air and ground can be realised from the Indicated Airspeed (IAS) parameter downlinked from the aircraft as part of Mode S Downlinked Aircraft Parameters (DAPs).

The IAS measures the dynamic pressure of the outside air and reflects the true speed of the aircraft relative to the surface. As the aircraft climbs, the air density decreases, and the IAS will be less than the True Air Speed (TAS). In controlling an aircraft using speed control, it is used by air traffic controllers to manage traffic flow and solve conflicts which make the IAS of greater importance than the TAS as the future position of an aircraft (and, consequently, separation) is determined by the ground speed [10].

Use Case 3 is the implementation of the IAS displayed on the radar display of the controller working position (CWP) used by approach controllers, in Barcelona airport (LEBL) when sequencing arrival flows. The display of the IAS on the CWP enables the controller to apply speed control between pairs of aircrafts to maintain standard separation including wake vortex and final approach spacing. It is expected that knowledge of the IAS of the flight will reduce the number of go-arounds and non-stabilized approaches or LoS.

Use Case 3 reveals how controllers adapt to the new environment, and new controlling techniques that have emerged that enhance system performance.

# 5 Summary of Findings: Characterising the nature of the changes and identifying the influence on Resilient Performance

## 5.1 Identifying changes in the Work System following implementation of new design solutions

Resilience Engineering holds the view that in complex adaptive sociotechnical systems, such as the ATM system, interactions between system elements yield emergent properties in ways that the system behaves in a way and manner that was unanticipated or intended by the designer or users. This notion of emergence is based on the idea that the system operates under varying sets of conditions and contexts and to achieve system goals and manage the multiplicity of competing demands placed upon the system; adaptations and trade-offs are made by the human actors. As such, Wilson [9] asserts that all systems in real use, with real users and under the constraints of time, space, motivation etc. found in practice, will display characteristics, and operate in ways not expected or planned for by their designer.

Based on qualitative data obtained through interviews with practitioners and desktop research - e.g., simulation reports, T5.2 sought to identify changes introduced in the work system post-implementation of automation based on the use cases. The objective of T5.2 is to examine the new operational environment at the micro, meso and macro level of aggregation and to explore how the introduction of automation/new design solutions have led to changes in the operational work environment and how work is undertaken.

Assessing the changes introduced in the work system reveals how resilient performance in sector operations have changed after implementation of the solution, and new strategies that have emerged that improve resilient performance in some way.

To identify the changes in the work system and how these changes influence resilient performance for the two use cases (UC1 and UC2), we adopt EUROCONTROL's Systems Thinking perspective (see EUROCONTROL's Systems Thinking for Safety: Ten Principles, A White Paper Moving towards Safety-II) [11]. The basis for adopting EUROCONTROL's Systems Thinking paper [11] in identifying and discussing the changes in the work system in addition to being aviation-industry specific, is that the principles align to the Resilience Engineering view of safety management that is focused on how people cope with complexity and adapt performance to achieve success [13].

The principles strongly contrast with what is typical today in the orthodox safety paradigm and suggests a new way of thinking of organisations as socio-technical systems (human, technical, tools, artefacts, organisational) with different parts interacting in a dynamic, shifting context with changing priorities, goals, and demands to achieve or preserve an expected outcome/goal. The premise is that to balance conflicting demands and cope with varying conditions that arise in the socio-technical environment such as the ATM system, performance variability and adaptation is both necessary and required to sustain operations.

## 5.2 The nature of the changes for each Use Case

The way an organisation copes with performance variation can be characterised at the macro, meso and micro levels of aggregation. Due to limited data sources, the nature of the changes identified in the use cases reported here are mainly at the micro level.

### 5.2.1 Use Case 1: Santiago sector Free Route Airspace

**Micro Level - Multiplicity of potential conflicting points due to no fixed route network**

In the new work environment (Organisation 2), ATCos perceive that an additional form of complexity has been introduced in the work environment. Complexity is construed by the controllers as arising from new conflict points and/or conflict geometries that is introduced into the work system under FRA. The wider distribution of flights together with the number of flights increases the complexity of sector operations. This has led to an increase in search activities for aircraft interactions in conflict detection tasks that is different from the defined route system (Organisation 1) due to the multiplicity of conflict points that leads to uncertainty in identifying conflict points. Hence, the FRA system involves a larger area to search and detect potential conflicts, as well as uncertainty, as there are no fixed route networks:

> *"Introduction of FRA had resulted in a greater distribution of the conflict areas… conflict search is more problematic with larger conflict areas".*
>
> In interviews, ATCos also noted, that entry into the sector, i.e. the entry point also varied:
>
> *"The traffic enters the sector at no specific point, so each day there are new areas of conflict"*

This is a specific consequence and manifestation of downstream sectors using direct routes beyond the sector boundary of the transferring ACC. In effect establishing a new entry point that is different from the flight plan entry point.

One of the four capabilities of a resilient system or organisation proposed by Hollnagel [12] is the ability of the system to anticipate events and identify upcoming events potentially long in the future, and how interconnecting system elements may interact and affect each other. Based on the interviews with ATCos and analysis of the research on FRA that led to implementation, it is deduced that in the new system (Organisation 2), controllers' ability to anticipate potential conflicts points is reduced. This was described as an implementation issue in simulations of FRA operations in Norway [7] and these assertions are supported in controller interviews for a range of FRA implementations I.e. Copenhagen, Malmö & Madrid.

To adapt and respond to challenges encountered in the new operational environment, controllers deploy strategies involving an increase in search activities looking for potential conflicts within a larger area than required under the fixed route system.

> *"I discovered that I often checked conflicts that I'd already checked twice"*
>
> *"A lot of crossings that have to be monitored for a long time. More aircraft and more crossings needed to be monitored "*

*"Quite busy with a lot of crossings in conflict with inbound, outbound and other transit traffic. Several same level aircraft pass each other with about 10 NM or less, which requires a lot of monitoring"*

The increase in the number of conflict areas, and the fact that conflicts occurred at dynamic (non-fixed) points, increases controller's workload in organisation 2 and wider distribution of flights, together with the number of flights, increases complexity which influences resilient performance. To cope with this complexity and uncertainty in the system, controllers would strive to manage their workload to create a margin (or buffer) for the increased uncertainty. Tactical strategies that they may employ in this regard include delayed response to pilot's requests, increased use of tactical radar headings to provide certainty in tactical situations, or increased use of vertical separation to resolve conflicts.

Hollnagel refers to this as the efficiency-thoroughness trade-off (ETTO) principle. Principle 7: Trade-offs. Performance trade-offs such as speed of work, workload, commercial demands, incentives and targets, time, schedules, and communication. Trade-offs are mechanisms that enable the work system sustain performance and achieve its core goals and prioritisation between multiple competing goals [3].

EUROCONTROL's Systems' Thinking paper notes that trade-offs "underlies all forms of work" that is performed in an operational environment with competing demands, production pressure and conflicting goals. The human operator optimises performance by performing multiple activities within a given time frame, switching from one to another [11].

While the ability to anticipate events – conflicts, is reduced in the Organisation 1, the Organisation 2 creates opportunity that enhances or sustains another fundamental dependency of adaptive capacity: The ability to monitor [12], that is monitoring in a flexible way that is focussed on how the system is performing and external/other conditions essential to the systems operation.

*"A lot of overflights keep me occupied and alerted at all times, looking for potential conflicts and solving the actual conflicts"*

The objective is to possibly identify what could be critical soon as well as provide feedback on the suitability of a decision and/or strategy that is enacted. In the new organisation, the system is constantly reassessing and evaluating for threats and opportunities, judging how system entities may interact, and consequently reducing the degree of flexibility and adjustments required during an event. In this way, the Organisation 2 has enabled deployment of strategies that improve resilient performance or presents potential paths for improvements to performance and consequently, a safe and efficient ATM system.

**Micro level - Change to planning tasks due to uncertainty in flight path prediction**

Under the FRA system, there are a number of defined sector entry (boundary) points from where an aircraft must enter or leave a sector, however, once it is inside the FRASAI area, it will fly its preferred route. With no fixed route network, controllers describe the uncertainty created in the system due to the uncertainty of flight path prediction. The change is in the planner controller tactical taskload, as opposed to the sector team.

*"It is more difficult for the controller now to get a clear picture of what's actually going on. It's much easier when everything is just flying in the same point. If you're going to Stockholm flying to the same point, if you're going to London, to Paris to Amsterdam and so on. And that's how*

*the controller remains at a high level, at high capacity. That is, to be able to draw that picture inside your mind in advance. So free route airspace kind of messed with that"*

*"When an aircraft comes from Germany, from London, going to Stockholm, the Planner Controller needs to guess what point that aircraft is inbound. We don't know"*

*"The problem with free route airspace is that aircraft can fly inbound to a point that I'm not totally sure that thy are allowed to fly inbound. So, most of the time, the next sector will just accept that, and we change the aircraft to the next controller, and everything is good. But sometimes, they call us and say hey, it's not allowed to fly inbound that point. So, we messed up in a way. So, we have to say, okay, I didn't know that I'm sorry, and we should file a report on that"*

*I wasn't always able to predict the traffic entering my sector, and sometimes discovered them just before they entered my sector or when the aircraft called."*

To manage this new form of uncertainty introduced in the operational environment, a strategy deployed by controllers is to predict a fix that the aircraft may route to, which provides an initial routing into the sector and is then updated once the aircraft comes on frequency.

This invariably impacts on conflict detection tasks as changes to routings or headings may be required once the aircraft has established two-way communication with the receiving sector.

*"So, the Planner Controller adds into our system the best guess, which means actually when the aircraft calls and they can fly to another point than the one put into the system, so the planner controller is listening carefully then, of course, the pilots tell us what point the flight path, and we add that into our system. And that's actually some extra work you have to do instead of just knowing exactly where they're flying inbound"*

Wilson [9] describes the above as a second emergent property of the system whereby due to the ingenuity of people, new ways emerge as users find ways beneficial to system performance to make the system work despite its shortcomings. It is about the way the system adapts and adjusts its performance to cope with variability of system conditions and behaviours (Principle 8 – Performance Variability).

The scope of resilient performance is how the system performs, and adapts, under varying conditions and performance variability. In this way, it reveals adaptations that extend or enhance optimality, sustains adaptability in achieving the systems goals. Rankin et al [14] submits that as a result of and response to performance variability, complexity, and uncertainty inherent in socio-technical systems, people need to continuously adjust and adapt their performance to meet uncertainties that are present in everyday work.

It is argued in the EUROCNTROL's Systems Thinking paper that performance variability is "both normal and necessary, and it is mostly deliberate. Without performance variability, success would not be possible" [11].

**Micro Level - Change in tactical controlling techniques and decision making**

Under the ATS route system, aircraft are frequently given more optimal flight path involving the use of direct routings. In the FRA structure, aircraft operator chooses their preferred route, consequently limiting the range of tactical controlling options (e.g., reduced number of directs routes issued) available to the controller to provide the aircraft with an expeditious service. In Organisation 2, the range of adaptive responses the controller can deploy is reduced – for example, the use of direct routes to resolve conflicts to separation provision given that most aircraft are already flying directs.

> *"A noticeable reduction in the number of 'direct' instructions given with the higher level of FRA traffic"*
>
> *"Free route kind of changed the way we work a little bit. We still try to straighten the flight out as much as we can, but sometimes actually, we're not able to help the aircraft, the way that I would like to do. So, I'll just look at the flight and okay, let him fly. Even though in my mind, I could do something better for that flight, and send them direct"*
>
> *"But sometimes, I will just let it fly. Because it's too difficult to sort out why he filed that route. So, he will spend a couple of minutes more flying than I think that I could have provided for him"*

Here, the controller trades off efficiency: optimal flight path/direct route clearances… *Even though in my mind, I could do something better for that flight, and send them direct; So, he will spend a couple of minutes more flying than I think that I could have provided for him)* for workload *(communication with aircraft … because it's too difficult to sort out why he filed that route*).

FRA is designed to provide the user (aircraft operator) with improvement of flight efficiency but may not always be the case as aircrafts may be flying routes that are less than efficient.

In the old organisation (Organisation 1), aircraft would have been routinely given direct routes as a matter of course and the controller is the decision maker deciding the most optimal flight management. In the new Organisation (Organisation 2), this aspect of decision making is removed from the controller and handed over to the operator.

In response, controllers engage in trade-offs that involves choosing an option that achieves a goal in a range of possible, but uncertain, scenarios using experience, knowledge of procedures and rules, and skills. One of such option/strategy the controller may deploy is choosing not to intervene. Trade-offs and decisions are however not made in isolation but take into account demands and pressures that exist in the environment at the given time. A controller's decision whether to send a flight on a direct route or not is influenced by demands (i.e., traffic - demand and mix), available resources, pressures, and constraints. Forster et al [2] expresses that controller make conscious or unconscious decisions that involve goal trade-offs. The adaptive decision of trading-off attempt to address multiple competing options by searching through possible responses and selecting the best option across multiple goals that achieves a basic threshold of acceptability [2].

### 5.2.2 Use Case 2: Barcelona Sectors Re-sectorisation and airspace design changes and accompanying procedural changes

**Micro Level – Reduced Manoeuvrability and room for adaptation**

Resectorisation and the introduction of a Flight Level Allocation System (FLAS) in the Barcelona sectors changed the nature of how work is done in the new operating environment. The vertical profile of the CCL reduces controllers' degrees of freedom for manoeuvrability due to the limited number of flight levels available in the new sectors – CCU and CCL. The implication particularly during weather conditions where aircraft need to deviate from the standard route structure is that controllers lose their degree of freedom due to limited room for manoeuvre or to enact some adaptation.

> *"The GO sectors are located next to the Central sectors. These sectors are designed to manage outbound traffic departing from the Balearic Islands but due to how narrow the sectors are, if traffic find a build-up on their route, sometimes they deviate to their right, which means entering the Central sectors. The resulting situation is that climbing traffics are flying in opposite direction to traffic that need to descend which is a quite common situation with big areas over the sea affected by thunderstorms"*

> *"It's a very complex situation, you have a lot of traffic going south and needing to fly lower, then you have one, just one traffic disturbing the complete flow of traffic. So, I would say you need more room because you have no room there. If you have seen the sector, the sector is very narrow, and you have most of the traffic flying on the left-hand side of the sector on that airway. And that's very close to the GO sector. So that means that you have no room to, you know, to fly parallel"*

> *"If I had more room, if I didn't have so many airways so close together, if my limits, if my airways were not so close to my sector limit, then maybe I could have more space, so that I could do a bit more".*

In the field of Cognitive Engineering, the nature of work and how work is done changes with introduction of new design solutions or automation, or an aspect or function of the design given that functional design and capability of tools and design solutions influence the concept of operations and form the basis of the methods of operation.

In Use Case 2, the new airspace design introduced new ways of working as the previous way of working is no longer possible in the new structure, that is, controllers' loss of the degrees of freedom in effect for tactical action due to the new structure of the airspace.

This creates a trade-off as the system gains from the new opportunity in the system as it shapes the nature of work-as-done as evolving use of the tools and aids can offer benefits to users.

## 5.3 Comparison of changes against the baseline model: Influence on resilient performance

D5.1 developed a baseline model that categorises the core elements that informs controllers' decision-making process in the pursuit of system goal(s). In FARO, the goal is defined as conflict detection and resolution in avoidance of LoS. The baseline model derived from the micro level perspective of the work system, lends to our understanding of how the ATC system leverages the adaptive capacity of its system to respond to variations that exists in the operational environment.

In this section, the baseline model is revisited. The model was developed in D5.1 (Figure 1 below) and assesses how controller's decision-making processes in the achievement of the system goal is influenced in Organisation 2 of the work system.

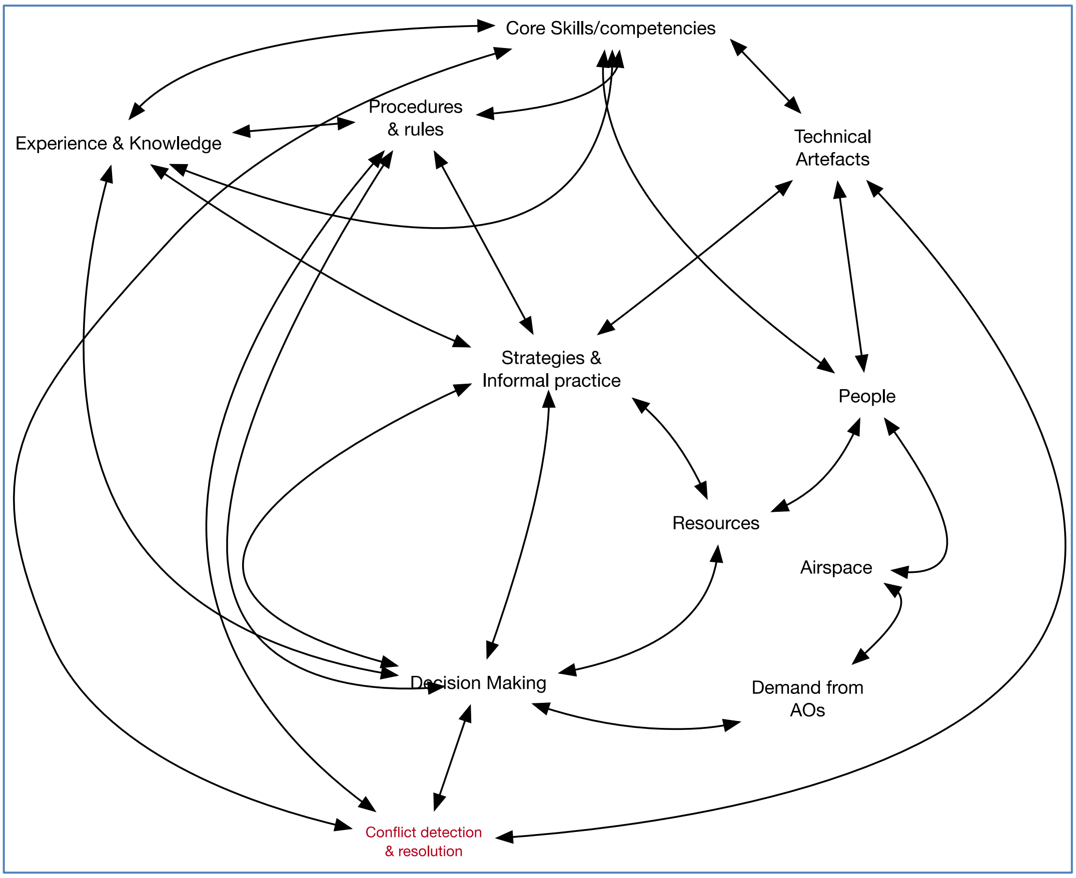


**Figure 1: Baseline model developed in D5.1**

**Experience and Knowledge:** Over the course of their work activities, controllers have developed experience and knowledge of the operational environment which informs their capability to anticipate events and recognise patterns. As a consequence, they are able to routinely adapt and prioritise their work tasks in anticipation of future criticalities and scenarios. This capability is related to SysRes's notion and Hollnagel's expression of resilient performance as ability to *"anticipate event"*.

In the new organisation (UC 1), the removal of the ATS route structure and introduction of FRA operations reveals that ATCos capacity to rely on past experience and knowledge to build in advance a picture of future scenarios, events of what the system is doing or going to do is reduced or altered as a multiplicity of new conflict points and regions within the sector are introduced. Some of the direct routes used will have been used before the introduction of FRA; some new ones will nevertheless be introduced.

This is evidenced by the statement of an ATCo-interviewee:

> *"The traffic enters the sector at no specific point, so each day there are new areas of conflict".*

As was earlier noted, the new organisation also increases controllers' risks of blind spots due to the removal of the fixed route structure Controllers can become blindsided by unanticipated aircraft within the area of control or around sector boundaries, subsequently creating scenarios for increase in irregular use of odd/even levels [6,27]

Nonetheless, it can be expected that over an extended period, controllers begin to build their knowledge and experience of the new operational environment – such as informal aircraft route structure and based on this knowledge are able to anticipate in advance potential areas of conflict and enact strategies in response. Thus, controllers in everyday work situations continue to test, develop, and share knowledge of what works or does not. Fster [2] describes this as learning through system feedback (learning from experience is one of the expressions of resilient performance).

**Procedures and rules:** Resilience Engineering has as one of its concepts, the notion of work-as-done versus work-as-specified (including other archetypes of work). The notion of work-as-done acknowledges that procedures, rules, checklists, and related instruments that shape work are underspecified and the human actor in almost all situations will be required to adapt their activities and actions in the pursuit of system goals and objectives. Rankin et al. [14] emphasises this notion by stating that the ability of a system to deal with challenge events cannot be fully defined. Instead, it is related to the surrounding social, technical and environmental constraints present at any given time.

Opportunities to adapt procedures and rules are visible in the new organisation (UC 2). We find that controllers have degrees of freedom to adapt procedures and rules in the delivery of expeditious service to an aircraft:

*"In some cases, <u>you think not to penalise, not to be too restrictive</u> with the traffic. Because they are many miles from this point. Until the traffic arrived for Palma de Majorca. So, <u>you tend to allow the traffic fly higher up to this point</u> where they can start a very comfortable descent profile, so that <u>you avoid penalising the traffic</u>."*

Procedures and rules are necessary to support adaptation as they are often the first thing tried in the presence of a challenge event, however, should offer flexibility for the operator to go beyond the rules in the achievement of the system goal. Forster et al notes that 'rules that give no flexibility to operators create issues of compliance in situations of goal conflicts' [2].

As such, safety and adaptation are related and in socio-technical systems such as the ATM, adaptation is necessary for system performance.

One of the benefits of a resilience engineering view, which is influenced by systems thinking, is that it offers a broader perspective that most reflects the operational realities of socio-technical systems as opposed to the traditional view of safety/safety I which suggests that safety is only achieved by standardising and reducing uncertainty in work tasks by putting in place system procedures and rules to control behaviour and outcomes.

**Core skills/competencies:** In the new organisation (UC1 and UC 2), controllers' skills and competencies are improved through new trainings they had received following re-sectorisation (new frequencies and transfer procedures between CCU and CCL) and learning to work in the new FRASAI environment.

Controllers' skills and competencies are enhanced as they acquire additional experience working in the new organisation, and through shared knowledge with other actors in the system.

# 6 Methodology

## 6.1 Approach to deriving the Indicators of Resilient performance

The central tenet of resilient performance is to explore an organisation and system and understand through observation, analysis, design, and development the adaptive ability of organisations to function effectively and safely [15]. Resilient performance is a function of both proximal, near distal and distal elements of an organisation. This emphasis is upon the local and proximate facets of the work system. The unit of analysis in studying the socio-technical system is the work system, hence, multiple narratives and perspectives provide the basis for a synthesis of data that provides an understanding of resilient performance.

FARO D5.1 determined a baseline of resilient performance of the system based on synthesises of multiple sources of data and information to produce a narrative description of the system and its characteristics. The work system was explored through interviews with system actors and the outcome with the associated synthesis of domain specific data, provided salient inputs into the baseline model of resilient performance and to hypothesise candidate indicators.

Penoloza et al., [16] contends that leading and lagging safety performance metrics and indicators are characterised as principally reactive and though may not appear to map the requirements of resilience engineering directly, they are however a source that can bring some understanding to resilient performance indirectly.

It is not practicable to measure resilient performance directly because resilient performance is intractable, and just limiting the assessment of resilient performance to a single event or events, does not meet the needs of assessing resilient performance over time. Hence, a series of assessments are ideally required but as this can be infeasible, Hollnagel asserts that proxies are a viable alternative [12].

Indicators of resilient performance to be derived need to suit the specific characteristics of organisations and systems as they adapt to sustain operations and production and resilient performance. And reflect the reality of operational practice with respect to 'work-as-done'.

The approach taken in WP5 is to derive indicators through transformation of knowledge elicited from practitioners with a framework derived from resilience engineering and objectified into domain specific indicators.

## 6.2 Method used to develop the indicators

In this section, we describe the process that was followed to derive the indicators of resilient performance based on transformation of the qualitative data into quantitative data used in evaluating the impact of new solutions on the resilient performance of an ATC sector (see D5.1 for in-depth description of the methodological process in obtaining qualitative data for UC1 and UC2).

Visual representation of the steps adopted, and explanation of each step is presented below.

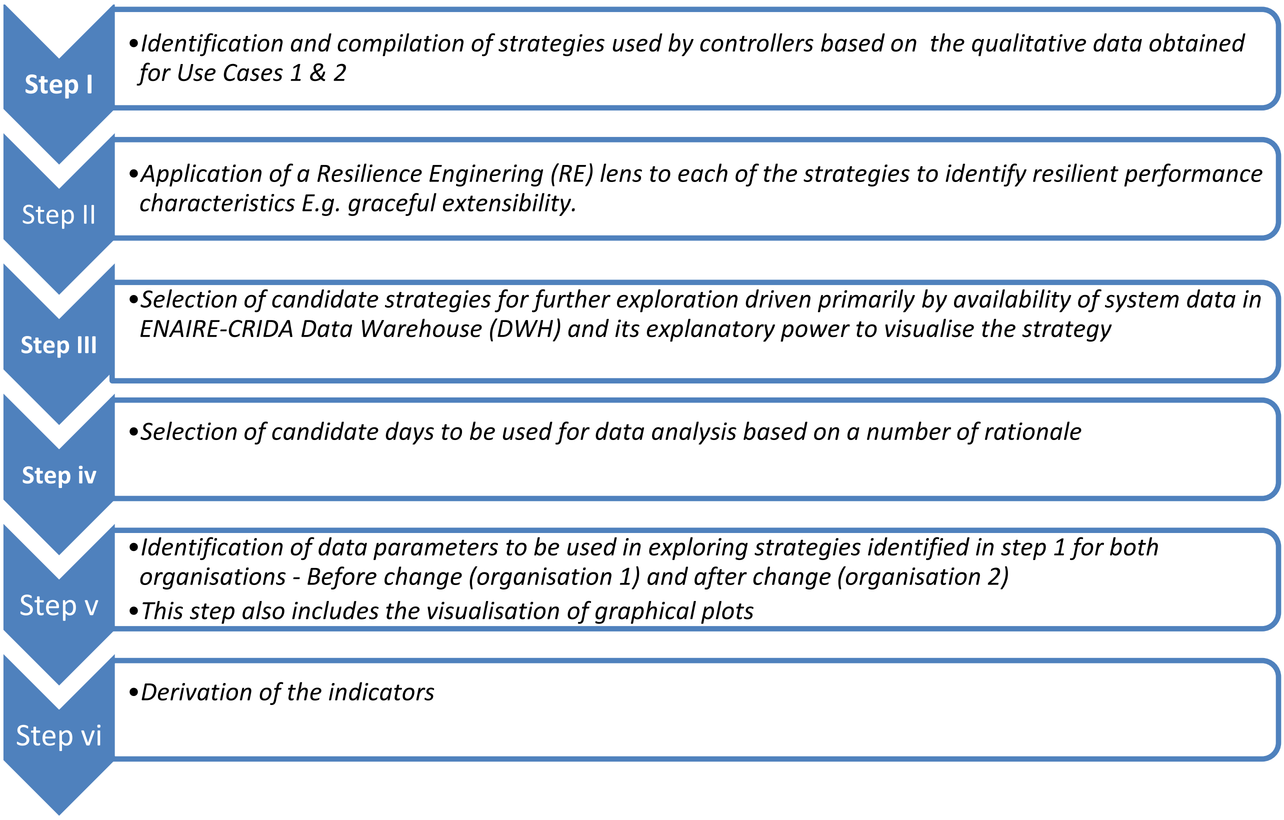


**Figure 2: Visualisation of the process followed to derive the indicators to assess resilience performance**

### Step 1: Identification and compilation of strategies

Based on strategies elicited from primary interviews with Air Traffic Controllers from four area control centres (see D5.1, section 4) and desktop research of published outputs from similar projects (e.g., *Air Traffic Controller assessment of the free route airspace implementation within ZAGREB Area Control Centre, Croatia),* full list of all identified strategies was compiled into a table.

The strategies identified were either expressly stated or implied to reveal indications of the dynamics of a complex socio-technical system and provided insight to understanding dependencies and variabilities in the work system and how the work system in turn, adapts resources and strategies to facilitate its adaptive capacity (resilience).

For use Case 1, a total of nine (9) strategies were identified including strategies obtained from both the interview with ATCos and via desktop research. Strategies identified in Use Case 1 were purely operational strategies deployed at the micro level.

For Use case 2, sixteen (16) strategies were identified based on the interviews with controllers. The identified strategies were deployed across the meso and micro levels of aggregation (Table 1).

**Table 1: Example of strategies obtained directly from interview texts**

| Transcribed interview texts | Identified strategy from interview texts |
|---|---|
| *"Some of my colleagues use speed restrictions, so that they can gather, they can get some horizontal separation, not just vertical separation, which is the standard way of separating traffic going to the same place. But this is saving you a lot of time because you are sure that they will not overtake one another".* | Micro Level - Use of speed restrictions to achieve lateral separation |
| *"There is also an additional source of variability linked to procedure which is what I told you about descending the traffic to flight levels 310… which is normally the rule during the wintertime, and it tends to be that way during the summertime as well, but there is also this tendency to allow the traffic to flow higher, and then they start to descend a bit a bit later.*<br><br>*You can call it the operational pressure in terms of favouring the traffic which is the deviation from the standard delivery procedures to follow".* | Micro Level - Late descent of traffic by not applying level restrictions |
| *"I think that there's some resilience inside the ATM system and we can decide when to split, or when to bandbox sectors".*<br><br>*"In Copenhagen, I believe we have 13 sectors all together. But normally, we only work around two or three of them, because we combine them into two or three larger sectors. If it gets busy, we can split the sector, the big sector down to smaller ones. Or if there's nothing to do, for example, at night-time, and we can combine it down to only two sectors in Copenhagen. You can use that if it's gets busy. You can split the sectors to cope with more workload".* | Meso Level - Bandbox/split of sector |
| *"There is also a strategy, the use of directs to avoid Bravo, Charlie November (Barcelona- BCN). I tend to avoid as much as possible traffic overflying Bravo, Charlie November and tend to coordinate that airspace to avoid, you know, the concentration of potential traffic on a specific area".* | Micro Level - Use of directs to reduce conflicts and interactions |

### Step 2: Application of a Resilience Engineering (RE) prism to strategies to identify resilient performance characteristics

In Resilience Engineering, resilient performance is characterised as how production is sustained effectively and safely. The discipline is concerned with understanding how the system adapts to challenges, disturbances, and surprises as it pursues its purposeful goals, delineated by Woods as: resilience as graceful extensibility (ability to stretch, reconfigure beyond everyday typical performance when the system is distant from boundary conditions) and resilience as sustained adaptability; and by Hollnagel as the resilience potentials [14, [12].

Resilient performance characteristics are discussed in detail in D5.1 (see sections 2 and 3), but a brief recap here is necessary to aid understanding of this section.

Hollnagel considers there are four (4) capabilities that can be seen in a resilient system or organisation. They include the capability to:

- Anticipate threats and opportunities: Identify upcoming events potentially long in the future;
- Monitor in a flexible way with the focus being to possibly identify what could be critical soon as well as provide feedback on the suitability of a decision and/or strategy that is enacted;
- Respond including readiness to respond, by adjusting responses in a flexible manner to unexpected demands; and
- Learning from experience both from events what goes well and what goes wrong.

Another expression of resilient performance includes the system's ability to recover. Lundberg & Johansson [3] introduced this fifth characteristic. During the recovery phase, the system strives to restore its abilities to uphold its core goals, but this should extend beyond 'bouncing back to how things were, but forward to a state that is well-adjusted to actual circumstances and foreseen threats, as seen during recovery' [3].

Today's systems and organisations function in ways that are responses to rapidly changing conditions with different degrees of uncertainty as well as complexity. The system's focus is to cope with increasing demands and compensate for the increased demand by adapting its performance. Hence, adaptations are a vital part of system functioning to cope with multiple goals, organisational pressures, and complexity.

Understanding the adaptive capacity of the system and the need to adapt is a critical element of understanding resilient performance. This view influences the nature of the parameters of resilient performance that contribute to the metrics and data dimensions that can be used to explore safety performance measurement.

Step II involved exploring how implementation of new design solutions may have resulted in change in resilient performance in sector operations, and by adjusting its patterns of activities that enables it to handle changes in the system, the new system states that have emerged that improve or limit resilient performance.

RE principles are then applied to each of the strategies complied in step 1 for both Use Case 1 and Use Case 2 to produce a narrative of visible dimensions of resilient performance for each of the strategies (Table 2).

**Table 2: An example of identification of resilient performance characteristics for each of the strategy**

| Strategy | **Description of Strategy** | Resilience characteristics and dimensions seen from the strategy |
|---|---|---|
| Late descent of traffic by not applying level restrictions | ATCo delay descending traffic by not applying restrictions, leaving aircraft to continuous climb, or left at cruising level.<br><br>ATCOs strategy is to achieve traffic optimality. Controllers' workload enables or limits the pursuit of optimality. | Graceful extensibility - How resilience is sustained at the boundary when the system is distant from boundary conditions<br><br>Adaptive behaviour - Controller's ability to adapt to the operating environment by managing their taskload/sustain multiple activities<br><br>Ability to anticipate future scenario and create buffers (time) to respond and readiness to respond to an unfolding event<br><br>Trade-offs and prioritisations – aircraft left at continuous climb versus planning or controlling buffer |
| Use of direct routes to reduce conflicts and interactions | The strategy is to reduce the number of interactions at a particular geographical area by limiting the flow of traffic in that area (e.g., a conflict point)<br><br>The aim is to spread out the interactions between aircraft pairs thus avoiding convergence at BCN. | Controller's ability to anticipate events<br><br>Readiness to respond to anticipated events<br><br>Graceful Extensibility<br><br>Margin or capacity for manoeuvre/buffer (time) – Capacity to enact strategy is influenced by surrounding environment, time. |
| Bandboxing/Split | Opening and closing of sectors to manage traffic demand and resources (e.g., peak in traffic, staff availability).<br><br>Tactical reconfiguration of sectors to better match available capacity to demand characteristics of traffic flows | Ability to anticipate, monitor, and respond<br><br>Strategy that can be used to sustain adaptability<br><br>Capacity for manoeuvre<br><br>Graceful extensibility<br><br>Managing the risk of saturation<br><br>Base adaptive capacity |

**Step 3: Selection of candidate strategies to explore using system data**

To support evaluation of the impact of new solutions on the resilient performance on an ATC sector, twelve (12) areas of analysis (refer to Section 4 of D2.2) were identified by the project partners as candidate areas to be used in investigating conditions that could lead to a Loss of Separation between en-route aircraft.

However, data made available from ENAIRE-CRIDA data warehouse (DWH), does not cover all of these 12 areas (e.g., data related to Human Resources, Organisation and Management of Human Resources), thereby reducing the number of strategies that could be investigated numerically.

Besides, not all the strategies identified from the interview texts can be derived from the system data as they reveal adaptations and informal strategies deployed in the work system based on the human operator's knowledge and experience of the work that is being done.

For example, one of the interviewees noted that:

> *"This also brings to my mindthe strategy that I try to apply all the time, I tend to figure out the situation on the sector I am going to coordinate with, so that I tend to <u>avoid increasing their workload to take up my call</u>, so I do something which I could do to resolve the situation by doing something different. So, I'm trying to buy them time in terms of reducing and helping them manage their workload".*

The above interview reflects the view by Rankin et al [14] which surmises that 'unfortunately, knowledge about performance variability is not commonly recognised as an asset, and informal solutions to systemic problems often go unnoticed by organisations'.

Based on the quantitative data components/areas that is available in the DWH, candidate strategies (for Use Case 1 and Use Case 2) were thus selected to be used for analysis. The selected strategies were transformed into quantitative data components (see D5.1, section 7.3 for an example of how qualitative data is transformed to quantitative data components) to be used in evaluating the impact of new solutions on the resilient performance of an ATC sector.

Four (4) candidate strategies were finally selected for UC 1 and five (5) candidate strategies selected for UC 2.

**Step 4: Selection of candidate Days to be used in exploring the strategies (Data analysis)**

To enable the evaluation/analysis of the numerical data obtained from the system, two scenarios were designed for use in the investigation of resilient properties of the new system that support sustained adaptability (Table 3).

**Table 3: Scenarios to enable the evaluation of the data obtained from the system**

| | Scenario Description | Organisation 1 | Organisation 2 |
|---|---|---|---|
| **1** | The selected scenario will involve a southerly Eastbound Oceanic track structure which onloads the Santiago sector earlier than envisaged as a result of high tailwind components. | Sectorisation and route structure of the Santiago Sector pre free route operations | Sectorisation/airspace organisation post implementation of free route operations |

| | Scenario Description | Organisation 1 | Organisation 2 |
|---|---|---|---|
| **2** | Disruption to the traffic flow inbound the Balearic Islands (e.g., runway closure or airport evacuation, radar outage, French strike) | Barcelona sector and airspace design pre-implementation of the airspace changes and resectorisation | Barcelona sector and airspace design post- implementation of the airspace changes and resectorisation |

For the two use cases, 32 candidate days were selected (16 per use case) across the winter and summer period (Table 4) to accommodate and reflect variations that exists in these periods (e.g., traffic demand is lower during the winter period than in summertime).

**Table 4: Selection of candidate days**

| Period | Organisation 1 – Pre-Change | Organisation 2 – Post Change |
|---|---|---|
| **Winter Period** | Less busy weekday | Less busy weekday |
| | Less busy weekend | Less busy weekend |
| | Most busy weekday | Most busy weekday |
| | Most busy weekend | Most busy weekend |
| **Summer Period** | Less busy weekday | Less busy weekday |
| | Less busy weekend | Less busy weekend |
| | Most busy weekday | Most busy weekday |
| | Most busy weekend | Most busy weekend |

For the data analysis, the month of December was selected as the winter period and the month of July selected for the summer period. Based on the data retrieved from the DWH, individual days were selected by applying either one or all of the following assumptions:

- Presence of variable conditions such as weather incidents, CBs, increase in non-scheduled/regular flights as this is likely to impact the flow of traffic into the sector;
- Similar representation in traffic parameters (e.g., traffic mix considering that ATCos task load is informed by the amount of traffic in descent/climb vs cruise level);
- Days with varying peak periods and shoulders around these periods – This provides opportunity to explore in-depth possible causes of the variations in peak periods and identify adaptations and strategies that are thus deployed in response to the variabilities in the system;
- Relative similarity between traffic level in Organisation 1 and Organisation 2. The rationale is to aid comparison in data with shared similarities and what this means in terms of staff resourcing, number of sectors open/ bandboxing, etc.;
- Day of the month or known events that are known to generally impact the amount of traffic - i.e., Christmas day, these days are discounted/not selected; and

- Preference to select similar day of the week in both organisations where possible (e.g., Sunday) applied as additional criteria for days with similar data elements (i.e., traffic volume, weather event etc)

By applying one of, or all the above listed criteria in the selection of the candidate for the analysis (see Table 5 below), a range of different scenarios (i.e., weather activities, unusual pattern of activity) can be explored to identify characteristics of resilient performance of the ATC sectors and extended adaptability. That is, how the system adapted in response to these variable conditions (e.g., collapse of sectors/bandboxing, resourcing, etc.).

**Table 5: An example of application of the criteria process adopted in the selection of candidate days for analysis (Central sector, summer period, most busy weekday)**

| | Day | Weekday | Traffic Level | LEBL Weather | Peak Entry | Peak entry (10 min) | Peak occupancy (hour) | Peak occupancy (10min jump) | % of ac in cruise | % of ac in descent | % of ac in climb |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **ORG 1** | **20130729** | Monday | 520 | 0 | 11 | 6:30 - 6:40; 7:00 - 7:10 | 51 | 6:30 - 7:30 | 47 | 48 | 8 |
| | **20140704** | Friday | 596 | CB activity | 12 | 8:10 – 8:20 | 53 | 6:50 - 7:50 | 41 | 54 | 9 |
| | | | | | | | | | | | |
| **ORG 2** | **20170731** | Monday | 661 | 0 | 15 | 11:50 - 12:00 | 63 | 11:20 - 12:00 | 50 | 42 | 8 |
| | **20180720** | Friday | 699 | CB activity | 13 | 8:10 - 8:20 | 66 | 7:20 - 8:20 | 45 | 42 | 13 |
| | **20190729** | Monday | 734 | 0 | 15 | 7:50-8:00 | 64 | 7:20 - 8:20 | 55 | 33 | 12 |

In Table 5 above, the primary criteria applied are CB event, peak occupancy of aircraft in the sector and the distribution of aircraft in descent and climb mode versus cruise mode (reflects ATCo taskload).

**Step V: Identification of data parameters applied to each of the use Cases**

Step 5 culminates in the transformation of the selected candidate strategies identified in step 3 into quantitative data elements to be explored in the analysis of the system's resilient performance after deployment of new design solutions.

Under the FARO project, the following areas of analysis were identified to cover the entire spectrum of possibilities with which to explore resilient performance (See D2.2 Report for detailed description):

- Airspace (flow and airspace structure, sector configurations, etc),

- Operational procedures (strategies used by ATCos for solving and managing traffic flows e.g., Use of speed control, managing descent flows, sequencing, etc),
- Traffic Demand (traffic counts, vertical profile, traffic density),
- Potential conflict (e.g., umber of aircraft that require level changes e.g. inbound/outbound to airfields where the Top of descent or climb to cruise, will be within the sector, opposite direction levels may be used)

The data parameters developed in step 5 (see Table 6 below and **Appendix I**) are aspects considered of interest in facilitating visualisation of the operational expression of strategies identified in steps 1-3.

**Table 6: Example of data identification and parameterisation**

| Strategy | Parameter | Description | To be observed | Discretisation criteria | Discretisation example |
|---|---|---|---|---|---|
| This strategy involves managing ATCo's workload around conflict detection tasks due to the change to FRA.<br><br>ATCos would manage their workload so as to create a margin for the increased uncertainty.<br><br>Tactical strategies employed: Delay in response to pilot's requests, increased use of tactical radar headings to provide certainty in tactical situations, increased use of vertical separation to resolve conflicts | Entry (Traffic flow) | Entry Sector data at the 15-minute interval | Pattern of traffic entering the sector as a function of distribution over time | It is divided into 4 intervals that represent the percentage of entries in the sector respect to the sector entry declared value at the AC entry hour. The values of the intervals depend on the sector data. | Value <55%<br><br>55% <value <65%<br><br>65% <value <80%<br><br>80% <value |
| | Exit (Traffic flow) | Exit from sector at the 15 min interval | Pattern of traffic leaving the sector as a function of distribution over time | Track miles flown in the sector segment within time interval point (Nominal vs actual) | 5 nautical miles either side of the nominal track,<br><br>Greater than 5 nautical miles either side of the nominal track |

# 7 Developed Indicators and metrics

The data parameters extracted in Step 5 directly inform the derivation of indicators (Step 6). These are, by necessity, operational expressions of resilient performance.

The derived indicators (e.g., frequency of use of opposite direction levels (ODL) as intermediate cleared level or as a cruising level; variations of top of descent points to achieve defined coordination conditions (standard transfer levels) for specific flows of traffic; number of direct routes given tactically; trade-offs and prioritisation: number of level offs in: the vertical plane for aircraft climbing and descending etc.) are thus, used to explore and understand work-as-done in both organisations (pre change and post change).

One intention of the indicators is to reveal patterns of adaptation, how ATCos adapt to respond to foreseen and unforeseen (surprise) events and how these may have changed in the new organisation i.e., the controlling techniques, the interaction, dependency, and coordination with other sectors/units.

The basic frame of reference to understand and explore resilient performance, is that of an 'adaptive unit' – a unit of adaptive behaviour (UAB). That is, 'units' that adapt activities, resources, strategies as they confront variability and uncertainty to sustain operations, as well as the goals that the system and UABs seeks to maintain through prioritisations of goals for example. UABs can also be referred to as adaptive units. In essence this is the work system: the socio-technical system and productive function of the organisation that embeds the way that performance variation is managed or coped with, at the macro, meso and micro level.

In WP5, the macro level is construed to be an ANSP organisation, including its processes, procedures, networks, organisational goals, and objectives; at the meso level, an en-route sector groups within an ACC operations room; and the micro level as an en-route sector, involving the tactical and planner executive team.

Based on the candidate strategies identified in Step 3 for exploration using system data, indicators and metrices to investigate resilient performance were identified for each of the use cases (Tables 7 and 8).

## 7.1 Use Case 1

**Table 7: Developed indicators and metrics of resilient performance**

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| This strategy involves managing workload around conflict detection tasks due to the change to FRA. Therefore, ATCos would manage their workload to create a margin for the increased uncertainty. | Conflict prevalence and distribution.<br><br>Traffic Demand<br><br>Sector Entry and Exit (traffic Flow) - actual | 1. Traffic Demand<br><br>2. Sector entry and exit time<br><br>3. No of clearances (restrictions or | Has brittleness been introduced in the new organisation around the conflict detection task as workload because there is greater uncertainty around the future position of A/C interactions? |

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| Tactical strategies employed: Delay in response to pilot's requests, increased use of tactical radar headings to provide certainty in tactical situations, increased use of vertical separation to resolve conflicts. | Time to requested flight level or oceanic entry level<br><br>Tactical management of the lateral route of aircraft | instructions e.g. (headings and levels),<br><br>4. Use of vertical separation instead of horizontal separation to solve conflicts because of uncertainty<br><br>5. Use of radar headings early and large heading changes to account for uncertainty: duration of heading clearance<br><br>6. Longer time to respond to A/C requests, time to respond and issue a clearance | What are the new defensive strategies that ATCos have developed?<br><br>Within the scope of Base Adaptive Capacity, aircraft would have been routinely given direct routes as a matter of course. Therefore, there exists at least two, if not more, route structures that ATCos work with, and have knowledge of: Extra Adaptive capacity may involve exploiting this.<br><br>Sustained Adaptability<br><br>Increased complexity<br><br>Changes to coordination |
| Managing a multiplicity of different points at which tracks cross the boundaries of adjacent sectors of ACCs.<br><br>Potential reasons for this include airspace utilisation in adjacent centres e.g., military reserved airspace, CB activity downstream, ad hoc, cross boundary direct routes outside LOA entry and exit points.<br><br>The effect is increase in instantaneous workload because of the increased uncertainty around the coordination of the ac with the next ACC.<br><br>Tactical strategies: Increased communication with pilot to clarify the route the ac have been cleared to and use of tactical radar headings to manage the uncertainty of | Sector Entry (planned and actual)<br><br>Sector exit (planned and actual)<br><br>Radar heading as instructed by ATC<br><br>Tactical management of the lateral route of aircraft: tactical and direct routing<br><br>Reports related to variations of LOA and agreed coordination procedures | 1. Planned and actual sector entry and exit points (coordination points)<br><br>2. No of clearances (restrictions or instructions e.g., headings and levels),<br><br>3. Heading changes<br><br>4. Changes to the Pattern of activity for direct routes that lead to interactions in ORG 1 and ORG 2 | In their pursuit of optimality/safety, how has controller's workload changed between the two ORGs?<br><br>Has the workload increased leading to brittleness as the boundaries have changed?<br><br>Sustained adaptability<br><br>Trade-offs made<br><br>Changes in Optimality and the tactical objectives that the Sector strives to achieve |

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| both route and coordination status of the ac, last minute coordination close to the boundary, and changes of the next sector in the coordination sequence. | | | |
| Strategies for dealing with traffic levels at or above declared sector capacity.<br><br>Traffic management measures that are used for managing demand versus capacity.<br><br>Tactical strategies are: The ATCo will intervene more, sector split/reconfiguring the airspace, ATFCM regulations, or tactical measures such as managing vertical profiles, re-routes and changing of entry and exit conditions into and out the sector. | Traffic Demand (expected and actual)<br><br>Sector capacity (Planned and actual)<br><br>Occupancy<br><br>Sector configurations (planned and actual)<br><br>ATFCM/NM restrictions<br><br>Managing Vertical Profiles -The management of specific inbound traffic flows | 1. Time and duration that restrictions are applied for<br><br>2. Tactical routings<br><br>3. Level changes from sector to exit<br><br>4. Exit level changes tactically coordinated but different from the Letters of Agreement | How have ATFCM measures and traffic management changed the sector operations and the management of the sector? Less? More? Different?<br><br>Are new trade-offs introduced as well as new or different coordination costs - delay to aircraft?<br><br>• Ability to anticipate, plan, respond<br>• Sustained adaptability<br>• Buffers/Contingencies<br>• UABs<br>• Boundary conditions/margins<br>• Saturation<br>• Optimality<br>• Trade-offs |
| The uncertainty around the ac entering the sector and its associated entry point at the boundary with adjacent ACCs on transfer to the sector.<br><br>Strategy to address the limitation of the Ground-based system (i.e., flight data processing, radar data processing) to support | Tactical actions to aircraft before sector entry<br><br>A/C planned and actual trajectory<br><br>Sector Entry (planned and actual)<br><br>Managing route and lateral profiles | 1. Deviation in sector entry points for planned and actual entry. Number of clearances issued per A/C both for nominal and actual trajectory<br><br>3. Tactical actions given to A/C before sector entry | What is the nature of changes to the Planning controller's task?<br><br>The additional workload that is placed on the sector team due to uncertainty in Free Route Airspace.<br><br>• Adaptive Behaviour<br>• Adaptive Capacity |

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| flexible route across ACC sector boundaries.<br><br>Controllers predict a fix that the ac may route to, which provides an initial routing into the sector which is then updated once the ac comes on frequency.<br><br>Strategies used by sector team to build a picture of the route of the ac about to enter the sector.<br><br>Change to routings or headings once the ac has established 2-way communication with the receiving sector, change of heading<br><br>Changes to the fix that the ac is cleared to and this impacts on the conflict detection tasks. | (Lateral route efficiency) | 4. Routing of A/C within sector<br><br>5. Deviation in exit points where A/C are sent direct to a point in the receiving sector (as a tactical strategy to deconflict traffic) after coordination with the receiving sector | • Sustained adaptability<br>• Optimality<br>• Brittleness<br>• Opportunities<br>• Trade-offs |

## 7.2 Use Case 2

**Table 8: Indicators and Metrics of Resilient Performance**

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| ATCOs delay descending traffic by not following level restrictions, leaving AC to continuous descent, or left at cruising level for longer. | Traffic Mix<br><br>Opposite Direction levels<br><br>Occupancy<br><br>Sector Configurations (Actual)<br><br>Vertical Profile | 1. Frequency of use of opposite direction levels (ODL) as intermediate cleared level or as a cruising level - The use of FL320 as an assigned East bound level<br><br>2. Variations of top of descent points to achieve defined coordination conditions (standard transfer levels) for specific flows of traffic.<br><br>3. Trade-offs and prioritisation | In the new organisation, are extant surprises and challenge events able to be managed as they were in the old organisation and can sustained adaptability be continued or has brittleness been introduced?<br><br>Does the new organisation support or create adaptive capacity that facilitates/enable resilient performance?<br><br>• Ability to manoeuvre |

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| | | 4. Number of level offs in the vertical plane for A/C Climbing and Descending<br><br>5. Descents: Flight level changes, flight level clearances<br><br>6. Continuous climbs: Number of climb clearances given per ac to being cleared at RFL or Pilot requested RFL cruising level | • Adaptation/Adaptive Behaviour<br>• Work-as-done vs Work-as-imagined<br>• Trade-offs<br>• Informal practices/short cuts (New system states)<br>• Prioritisations |
| Strategy to reduce the number of interactions at a particular area/fix/crossing point by reducing the potential for interactions between the flow of traffic in the specific area i.e., BCN - The aim is to spread out the interactions avoiding convergence at BCN.<br><br>The strategy is in the service of managing workload and creating buffer. This is integral to the changes in the Barcelona sector group through resectorisation and instituting a flight level allocation system that deconflicts N-S and E.W traffic flows<br><br>Tactical strategies include increase in the number of reroutes given to ac | Occupancy - BCN<br><br>Traffic Mix<br><br>Managing route and lateral profiles (reroutes)<br><br>Managing East/West and North/South interacting traffic flows<br><br>A/C planned and actual trajectory | 1. Occupancy of the sector<br><br>2.Compare Density of ac and instances of ac within 20NM of BCN<br><br>3. Occupancy within 20NM of the BCN<br><br>4. Traffic flow around the BCN VOR - East west flow vs north south<br><br>5. Direct routes: direct routes given tactically. | Are strategies for tactically managing the convergence of traffic overhead BCN in the new organisation enacted in the same way or are new coordination loads introduced?<br><br>Does the new organisation deconflict traffic overhead BCN or is there an increase or change that introduces brittleness in the new organisation?<br><br>If the strategy is effective at building a buffer into the tactical situation: is this buffer still used, needed or is it not possible because of brittleness, forcing the operation to work at the boundary of sustained adaptability?<br><br>• Adaptive Behaviour<br>• ability to anticipate, respond<br>• Room /Buffer (time)<br>• Margin or capacity for Manoeuvre<br>• Graceful extensibility |
| Declared/nominal sector capacity used as means to build buffers and | Sector capacity (Planned and actual) | 1.Occupancy - increments in 15 mins for all traffic volumes and sectors within the configurations | How and when are these buffers used or deployed? |

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| contingencies into the system.<br><br>The strategy is to optimise sector capacity and sustain operations by creating contingencies (buffers) within the system | Traffic Demand (expected and actual)<br><br>Sector configurations (planned and actual)<br><br>Occupancy<br><br>ATFCM/NM restrictions<br><br>Managing route and lateral profiles (reroutes) | 2. Sector configurations - planned and actual<br><br>3. Percentage of traffic above the declared capacity<br><br>4. No of clearances issued for each flight for each configuration, and clearances time to get to RFL<br><br>5. Delay statistics - ATFCM regulations<br><br>6. Reroutes away from the sector | Base adaptive capacity in the declared capacity leading to extended adaptive capacity in actual sector capacity (in the BCN sector during weather event). What is the capacity for each of the sector configurations - no of sectors and values used?<br><br>• Base adaptive capacity<br>• Extended Adaptive capacity<br>• Buffers and contingencies<br>• Ability to anticipate<br>• Ability to Respond/readiness to Respond |
| Controllers' strategy is to optimise safety of the system rather than efficiency in response to a challenge event. E.g., CB or instantaneous peak in workload, traffic bunching - e.g., into LEPA.<br><br>Tactical strategies employed: Delay in response to pilots' requests, increased use of tactical radar headings to provide certainty in tactical situations, increased use of vertical separation to resolve conflicts. | Managing route and lateral profiles<br><br>Managing route and lateral profiles<br><br>A/C planned and actual trajectory<br><br>Sector configurations (actual)<br><br>Sector Transit (nominal and actual) | 1. Sector configurations (and no of open sectors)<br><br>2. No of clearances (restrictions or instructions e.g. (headings and levels), longer time to respond to AC<br><br>3. A/C will stay on headings longer before being released on their own navigation and back to its route<br><br>4. Clustering of A/C around certain FLs<br><br>5. Defensive controlling indicator/ different pattern of activity characterised by more instructions given. | • Ability to monitor, respond to event<br>• Trade-offs - Safety vs optimality<br>• Capacity for manoeuvre<br>• Adaptive strategy/adaptive behaviour- preserves or adjusts buffers<br>• Managing complexity<br>• Prioritisation |

| Strategy | Parameter | Indicators/Metrics | Link to Resilience |
|---|---|---|---|
| Bandboxing/Split: Opening and closing of sectors to manage traffic demand and resources (e.g., peak in traffic, staff availability). | Occupancy<br><br>Traffic Demand (expected and actual)<br><br>Sector capacity (Planned and actual)<br><br>Sector configurations (planned and actual)<br><br>Managing Vertical Profiles -The management of specific inbound traffic flows | 1.Top of descents profile will be different<br><br>2. No of clearances given and time to clearances<br><br>3. Flight path<br><br>4. Traffic bunching<br><br>5. Sector configurations and reconfigurations (duration, transition) | Different configurations indicate Unit Adaptive Behaviour (UAB).<br><br>Extra capacity available: How close was ORG 1 to brittleness and how has ORG2 changed this?<br><br>Managing the risk of saturation - How has capacity to manoeuvre changed? How has ORG 2 changed this?<br><br>• Ability to anticipate, monitor, respond<br>• Strategy that can be used to sustain adaptability<br>• Capacity for manoeuvre<br>• Graceful extensibility<br>• Managing the risk of saturation<br>• Saturation of the UAB<br>• Base adaptive capacity |

## 7.3 Understanding and interpreting the indicators and metrics

The purpose of the system of indicators and metrics is to support and facilitate developing an understanding of resilient performance of elements of complex social technical system. The characteristics of some a system's resilient performance have been, in the following example, derived as described above. These indicators therefore, individually and together, may provide explanatory power in understanding how the strategies and adaptations in response to the performance variability, now operationalised, lead to identifiable different patterns of activities.

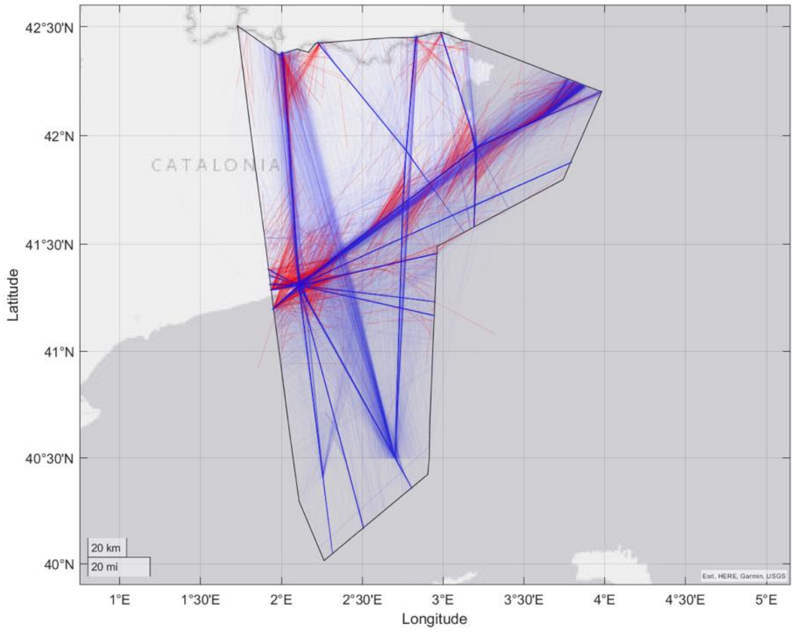


Figure 3: Visualisation of an indicator of the Occupancy of traffic around the Barcelona Reporting point *before* the changes made in the Barcelona Central Sector

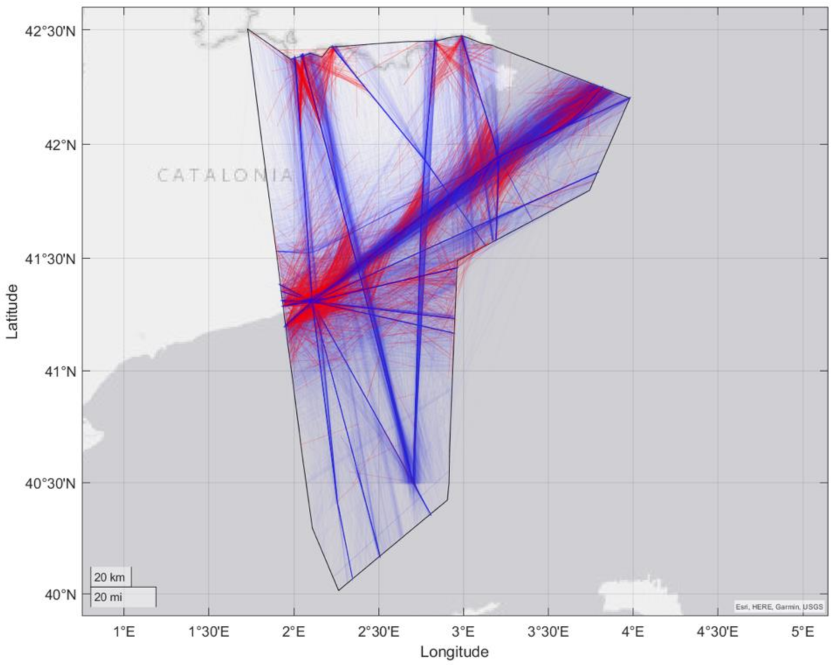


Figure 4: Visualisation of an indicator of the Occupancy of traffic around the Barcelona Reporting point *after* the changes made in the Barcelona Central Sector.

These two figures show a different flow of traffic and dispersion around BCN. It is a marginal change, nevertheless discernibly different. The density of the traffic flows is assumed to be different as a result of the growth in traffic.

This pattern of activity Is further examined in the next two images. In this case depicting the interactions around the BCN between aircraft pairs, co-level and >20 nms.

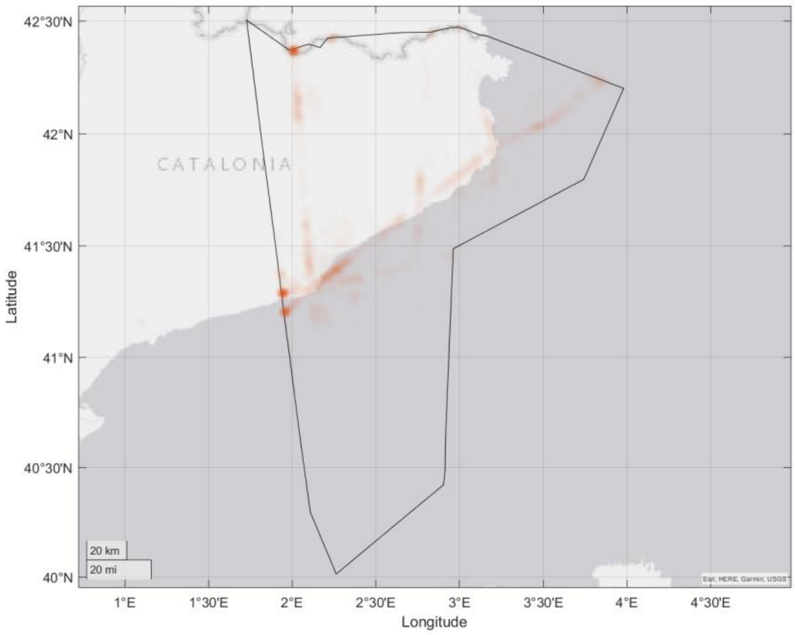


Figure 5: Visualisation of interactions between aircraft < 20 nms of Barcelona reporting point, *before* the changes to the Barcelona Central sectors.

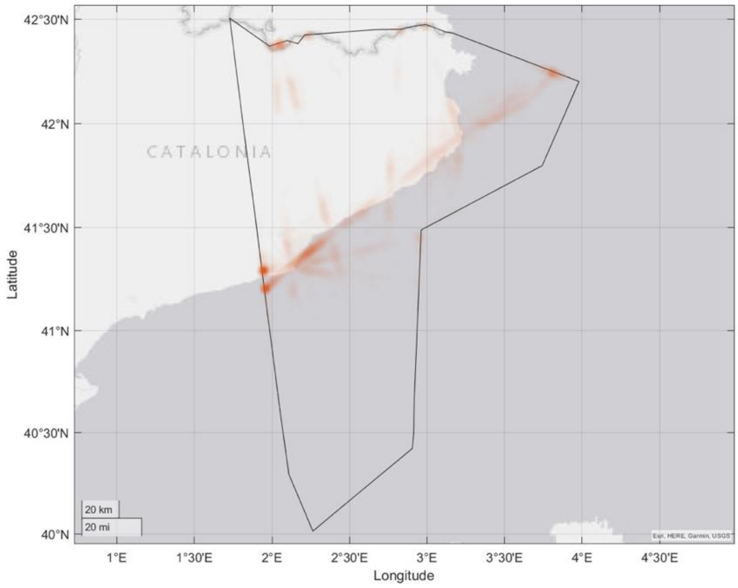


Figure 6: Visualisation of interactions between aircraft < 20 nms of Barcelona reporting point, *post* the changes to the Barcelona Central sector

In the case of this indicator, it is evident that there is a redistribution of traffic to the North and North-East of BCN and also to the East as well as the sector boundary and entry and exit points to the West. Again, in part, there is an effect related to traffic growth. But the difference is also a factor of some other phenomena as there are geographical differences

These two indicators lead to a series of questions around the operating performance of the sectors pre and post the changes. There are a range of metrics that support the synthesis of a view of the performance of the sector. For example, instantaneous traffic counts and sector occupancy, the horizontal and vertical efficiency of these traffic flows

These depictions of the indicators provide the basis for exploring the strategies that are used to adapt. This takes the form of a synthesis of the metrics in combination to create a narrative description and argument for the changes in resilient performance that are elicited during fieldwork.

Further synthesis and assessment of resilient performance of Use Cases 1 and 2 will be undertaken in the validation activities of WP6 and reported at this juncture.

## 7.4 Limitations

A limitation of FARO in derivation of indicators and metrics of resilient performance is that not all specific aspects required to aid the investigation of resilient performance and sustained adaptability of sector teams were available from CRIDA DWH. As such, parameters, indicators, and metrics developed are constrained to the available data from the system.

Further, the derived indicators are interpretations of the data obtained through interviews with practitioners and is based on project partners' domain knowledge of the operational work environment.

In addition, due to the current pandemic situation, access to practitioners, and opportunities to undertake fieldwork were limited. Consequently, micro perspective was mostly accessible through interviews and workshops, but the data lacks macro and meso perspectives on adaptation to changes in operating conditions.

# 8 The derived indicators of resilient performance and their salience to changes in the work system

## 8.1 Making sense of the indicators in the context of changing characteristics of complex social technical systems

Any system of indicators for resilience or safety performance measurement or assessment needs to be grounded in the theoretical framework related to the particular underlying concept. Resilience engineering, particularly resilient performance, is defined not solely in terms of safety alone, but by other considerations such as the characteristics and capacities of social technical systems to adapt as well as the characteristics of resilient performance itself. Synthesising these two views, can yield a view of the nature of resilient performance and how these systems adapt. Thereby providing a foundational basis for developing an indicator system.

In addition, any such view should be able to provide a complement to orthodox approaches of safety performance measurement. Mindful that pursuing resilient performance has a broader view than safety *per se*. Nevertheless, there are points of synergy between the two.

Hollnagel [13] defines resilience in a foundational sense in that resilience is an "expression of how people alone or together, cope with everyday situations – large and small – by adjusting their performance to the conditions. An organisation's performance is resilient if it can function as required under expected and unexpected conditions alike (changes/disturbances/opportunities)". Can this provide a view of the nature of indicators of resilient performance and what they are required to fulfil?

Indicators and measurement of resilient performance need therefore to reflect the characteristics of this performance. Mindful that single, unitary, or binary indices of 'resilience' or more precisely 'resilient performance', are not compatible with the underpinning philosophy and assumptions of resilience engineering.

Other desideratum of any system of indicators is that they be situated in the 'naturalistic' nature of the work that the system is pursuing to achieve its aims of sustaining resilient performance and adaptability (at the systems boundaries or margins) and that they encompass the joint nature of the work system.

### 8.1.1 Naturalistic perspectives

Naturalistic in that they are grounded in the work that is undertaken by practitioners at different system scales in day-to-day operations. This will involve patterns of adaptation as a matter of course for situations that are both regular or frequent sources of variation as well as other adaptations that are required for irregular or infrequent situations.

These can be explored through eliciting and investigating the strategies that are deployed and used as the basis for exploring through data synthesis. The strategies that are chosen or enacted in adapting to performance variability, surprise and challenge events are the means through which FARO WP5 has chosen to develop indicators. Identification of the strategies alone is insufficient. These can be explored through eliciting and investigating the strategies that are deployed and used as the basis for synthesis of the data. Further transformation is needed through the operationalisation of the strategies with respect to resilience engineering. This is to better understand the characteristics of resilient performance cross scale, and through this gathering a view on coordination costs, dependencies trade-offs and goals. Through these meaning is made of the data in terms of resilient performance. And a synthesis of data can be achieved.

In a number of cases, there was some scope to consider the strategy through different functional roles across the system and the sub-systems that comprise the wider macro system which they are situated within and which they interact with. The use of Units of adaptive behaviour, for example is one way of expressing this. Representative of this, at Micro-scale, may be the ATC sector team, or two or more ATC sectors: how these are organised within a strategy that sustains the micro level performance, situated within the wider meso and macro work system.

Specific strategies were selected to develop from which potential candidate indicators could be derived and because of their potential to provide explanatory power in their contribution to the research questions as well as considering resilient performance in the before and after organisations of use cases 1 and 2.

There will be meso scale influences that will be drawn upon, such as a sector group supervisor and or network manager as well as supervisors of other ATC sector groups or air traffic service units – terminal control area functions or airfield units that interface with, in use case 1 and 2, en-route ATC sectors. These adjacent ATCs are elements of the environment that can coalesce as the system is reconfigured to adapt to changing demands of performance variability.

These configurations, which are better termed units of adaptive behaviour, form vectors or trajectories at scale as well as different scales within the work system. These therefore are of particular interest in the context of the changing characteristics of the work system. As they introduce different patterns of coordination which can bring attendant costs as well as opportunities for new patterns of adaptation.

### 8.1.2 Joint Complex Adaptive Socio-technical systems

The significance of the joint nature of the system is once again built around a fundamental assumption about the nature and characteristics of the work system as seen in resilience engineering - characterised as a joint activity, in complex worlds where adaptation occurs to sustain adaptability.

The nature of the joint activity transcends mere human-machine interface. The use of *joint* in resilience and cognitive engineering is a counterpoint to human machine interaction, emphasising the interdependent nature of joint activity in complex work systems in undertaking its purposeful activity i.e., work. This implies a broader context of work especially the different scales that the work in the system is undertaken, as a feature of adaptation, interdependence, and the collaborative nature of work both with other system actors as well as with technical artefacts.

When considering potential changes in resilient performance in work systems, the nature of the purposeful activity of the system can be explored as adaptations by a joint 'system' activity to cope with complexity.

How, then do technical artefacts contribute to the nature of the work undertaken, the joint pattern of activity? It is a common view that design solutions are implemented that are in some respects incomplete. The design may be developed in ways that are appreciative of the reality of operational praxis but can simply not consider all possible operational situations. Practitioners therefore adapt, using the technical systems, such that the nature of their work changes. These changes can bring new and or different opportunities for sustained adaptability and resilient performances. In other cases, the differences emanating from changes may lead to fewer degrees of freedom to adapt. The point is, that the capacity of the joint system is different, and how this difference influences resilient performance is of signal interest.

## 8.2 Joint human - technology activity: a macro-cognitive perspective of the work system as seen through indicators

The influence and introduction of greater human-technology integration and digitisation within the work system can be expected to lead to changes in the way that the ATM system. The processes that are undertaken within the work system have not only a social component but a social-technical component too. Therefore, assessment of resilient performance through any system of indicators, needs to be able to account for these constituent components.

The work system, as envisaged in the FARO resilience engineering activities, is characterised by Klein [30] as a macro cognitive work system, implicit in which is that the contexts are naturalistic or field settings and flowing from this comes specific features of the work setting. These are seen as having salience in forming an assessment of resilient performance. For example:

- Decisions are typically complex, often involving data overload;
- Decisions are made under time pressure and involve high stakes and high risk;
- Goals are sometimes ill-defined and multiple goals often conflict;
- Decisions must be made under conditions in which few things can be controlled or manipulated; indeed, many key variables ad their interactions are not even fully understood.

All examples that characterise 'messy' operational worlds. Intrinsic to this view, which is significant in the FARO approach, is that the functions and activities undertaken by practitioners, are collaborative processes accomplished as part of a team, predominantly together with technical artefacts. It is with this foundational perspective, that it is possible to find a methodological approach to consider changes in work systems that are influenced through automation, digitisation that result from changes in the collaboration activity.

What does this mean for indicator systems in the context of, not only resilient performance but also safety performance? Moreover, how can any effects that flow from differences in the joint system be assessed?

The perspective that this provides is one that better describes the characteristics of the work system, and which therefore influences the characteristics of resilient performance. And therefore, through this perspective explore changes in resilient performance, and salient indicators of resilient performance.

## 8.3 FARO WP5 indicators as expressions of resilient performance of a joint macro-cognitive work system

Indicators of resilient performance therefore need to reflect characteristics of the work system as well as characteristics of resilient performance. Reflecting the nature of the joint activity of the work that the system is pursuing to achieve.

Macrocognition is defined as the study of cognitive processes affecting practitioners who 'had to wrestle with difficult dilemmas such as planning, sensemaking and uncertainty' [27]. Elsewhere, it is proposed that 'macrocognition' provides perspectives of both social and sociotechnical as well as, for example adaptive behaviour for example the management of technical artefacts in terms of kludges and workarounds. This approach provides a means to explore and synthesise resilient performance, the joint character of the work system and with relevance to safety *per se*.

Operationalisation of the strategies with respect to resilience engineering and through this a macro-cognitive approach can provide insight as well as the means to normalise data across scales.

The table below is one expression of this. Here, using one strategy used by ATCos on the BCN sector, it has been characterised through different categorisations. Any indicator system needs to be able to be capable of contributing to exploring and providing explanatory power across these categorisations.

**Table 9: An example of operationalisation of strategy**

| Adaptive strategy | Characteristics of the Joint work system in adaptation | Characteristics of resilient performance in adaptation | Dimensions of macro-cognitive functions | Safety |
|---|---|---|---|---|
| Use of ODLs | Adaptive strategy<br><br>Optimisation<br><br>Taskload<br><br>Expedition<br><br>Monitoring<br><br>Common ground<br><br>Coordination<br><br>Work arounds | Trade off<br><br>Buffers/margins<br><br>Adaptation<br><br>Dependencies<br><br>Complexity<br><br>Brittleness<br><br>Boundary conditions<br><br>Surprise<br><br>Optimisation<br><br>Sustained adaptability | Planning<br><br>Leverage points as triggers<br><br>Uncertainty management<br><br>Attention management<br><br>Situation assessment<br><br>Problem detection | Risk<br><br>Non-standard/nominal operations<br><br>Adaptation<br><br>Tactical strategy<br><br>Separation standards<br><br>Procedures |
| Transversal characteristics | Dependencies | Goals | Trade offs | Tactical Strategies |

In the illustration above, one derived strategy is characterised in four ways that represents four perspectives germane to this research. Indicators of resilient performance need to be capable of having some explanatory power to be account for the various descriptive elements. They also need to be able to reflect the context or conditions that necessitates the use of a particular adaptive strategy including factors at the meso and macro level. Including the use of technical artefacts.

These factors provide one view of the facets of system behaviour and performance that can yield the basis or a system of indicators of resilient performance as well as other perspectives that hold explanatory power.

## 8.4 The implications

The research that WP5 undertook as part of the FARO project introduced resilience engineering, particularly a perspective of resilient performance. It should be recalled that resilient performance is the specific focus that is consistent with current thinking about resilience engineering [26].

This particular theoretical framework of resilient performance holds promise in providing the means by which qualitative narratives of resilient performance can be considered in, for example, safety performance measurement and assessment. Bringing new dimensions introduced by the inclusion of narratives informed through quantitative perspectives gained by transforming qualitative narratives, mediated with the inclusion of the characteristics by which complex adaptive systems sustain adaptability.

# 9 Reflections

## 9.1 Resilience engineering and Safety science: qualitative and quantitative

One of the challenges that FARO has confronted is transforming qualitative narratives of resilient performance that are amenable for use by data science as quantitative data.

Within the resilience engineering discourse, how resilience engineering can be used in safety performance measurement [20],[21],[22][16] is an ongoing debate. In general, it has been found that resilience engineering can bring new perspectives that, it is argued, would be largely unknown using orthodox safety performance measurement and assessment. The philosophy of resilience engineering and resilient performance has a different emphasis than orthodox safety.

Whilst it is increasingly recognised that organisational factors contribute to the conditions of possibility for manifestations of safety events. For example, separation minima infringements having contributing factors at distance from proximity to the event. There are other dimensions that can contribute to understanding safety performance that adopting a resilience performance prism can bring. Not, however, at the expense of orthodox safety performance measurement. For which there will be reasons for organisations to have a need for. Occurrence reporting is one means to monitor operational safety as well as automated safety methods such as Air Traffic Control Separation Monitoring Tool (ASMT). In the case of the latter, it is widely accepted that the context surrounding any event is needed to make sense of the event.

Understanding typical operations through the notions of work-as-done and work-as imagined, which are expressions of approaches to understanding naturalistic work in joint systems, however, are different and will provide a different view. Therefore, will draw upon different sources of data that can lead to additional or different interpretations and narratives. As well as different perspectives to adopt and pursue with the orthodox sources of safety performance.

Transformation of the characteristics of resilient performance and the control task in the SAN and BCN sectors, as elicited from practitioners, has led to deriving metrics that are quantitative. These will provide an understanding in a limited sense of the distal factors of the work system that can lead to conditions or system states that can contribute to the conditions of possibility of an episode that may lead to an SMI. What will be more readily apparent however, will be the adaptations and strategies that are employed at the micro scale that minimises SMIs. These being adaptations as responses to situations that emerge from operations within the work system.

## 9.2 Limitations and enhancements

FARO WP5 took this approach in deriving the indicators for WP6. As far as possible using the data elicited from practitioners. These indicators, as a proto set to explore changes in resilient performance, have an inherent focus at the micro scale of the work system. That is a proximal view.

Whilst, from several sources, a view of distal i.e., meso and macro scale views were identified, the research was limited to the available data sources principally micro scale. Where it was possible, hypotheses of meso and macro dimensions were posited drawn from an interpretation of the structure and organisation of the work system. For example, one indicator of resilient performance was derived with reference to the declared capacity of sectors as defined through internal processes within the ANSP. In a limited sense, this is macro scale component that influences the micro and meso scale.

In exploring the contribution that can be brought from better understanding the perspectives that studying resilient performance of complex adaptive work systems can bring, further work needs to be undertaken. This specifically should explore how data can be used in different ways that supports representations not only the different scales of the system, cross scale units of adaptive behaviour. This would include, for example, organisational decisions made and the characteristics of new business models that cascade changes through the organisation, again cross scale, and that can influence the way that work is undertaken. For example, where new designs are implemented, or improvements are made over the lifecycle of an ATM system. Here there is an argument for the intrinsic nature of any assessment of resilient performance to contribute to monitoring ATM system performance through understanding the changing nature of adaptive strategies that are employed, the trade-offs that are made and the strategies that enable sustained adaptability at the margins and how buffers built into the work system are used or drawn upon.

The different scales in which a system (Such as the ATM syetm) can be considere, and scalability of social technical systems such as these are significant dimensions of resilient performance at the macro level that influences resilient performance at the meso and micro levels. WP5 was unable in FARO to develop indicators and metrics in any practical and applicable way in this project. However, there is scope for this in further research.

One example is the assessment of resilient performance at the macro – ANSP – level presented by Stanley [29] at the CANSO-Eurocontrol Resilience Summit in December 2021. This perspective is one labelled 'Organisational Resilience' where this is defined as the ability to adjust to meet evolving service performance or service delivery goals or needs in a sustainable or healthy manner, responding to changing external context, disruption or stresses' [29].

Potential metrics that consider organisational aspects of resilient performance in the way that were derived for FARO and can be found in D2.2. These are similar in character to two used as exemplars in the analysis of organisational resilience: a) the ratio of frontline service staff to ATCOs and b) % of total costs attributed to operational ATCOs employment. Like any system of indicators, indicators such as these need to be able to complement others to provide meaningful complementary power.

Extending this perspective, and following a meeting in December 2021 with representatives of SESSR PJ19-4, several recommendations for further research emerged. Two of these resonate with organisational resilience. Both using a prism or perspective of resilient performance, the following dimensions research questions are of interest:

1. Using resilient performance as a framework for exploring variations in the performance of specific defined operational tasks and functions e.g. Low Visibility Procedures or management of periods of demand and how variations occur over time.

2. Associated with this research question is developing an understanding of what ATM has done in the past, in managing non-nominal situations. In some respect this is the basis of the approach taken in FARO WP5. However, this approach can be extended by deeper examination and study of the phenomena that leads to variation

3. How Research and Development is contributing to changes in resilient performance in specfic ATM solutions e.g. Virtual Centres, Multiple and Remote tower operation

4. The consequences of the interdependencies between, for example, the SESAR Key performance areas as well as, at a lower level of aggregation: human performance, resources safety and capacity

The theoretical framework that Is used as its foundation, lends itself to these types of exploration of performance of complex socio-technical systems.

## 9.3 Guidance for WP6

It is part of WP6's deliverables that guidelines and guidance material that can facilitate the application of FARO guidelines are produced for ANSPs, and other users.

The following are proposed as suggestions for inclusion in these guidelines:

- Monitor and understand typical or normal work, where these terms refer to adaptations and how the work system adjusts to patterns of activity that lead to adaptation. Adaptation is typical work: Work-as-done and work-as- imagined are two starting points to explore adaptation.

- Some sources of performance variability are very familiar, others are not. Both need to be considered when considering the challenge and surprise events that a work system can be confronted with. Some are in fact elements of the typical work undertaken and in essence tacit knowledge that needs to be elicited.

- Understand and derive the conditions that support or enable adaptations in terms of coordination, procedure, and rule under-specification common ground, etc.

- Understanding resilient performance is an activity that needs to consider cross scale interactions and interdependencies.

- Activities investigating/assessing resilience and resilient performance of the system needs to be undertaken in an ongoing manner, multiple times across the lifecycle of the system as opposed to a one-off exercise. The goal each time being to identify new sources of resilient performance and adaptation (as well as how it may have changed or continues to evolve) as the human element of the system adapts resources, strategies, and activities in response to threats and opportunities.

# 10 Conclusion and recommendations

D5.2 explores the nature of changes that new system design solutions has on the resilient performance of the system, and the ability of the system to successfully adapt to changes in operating conditions.

WP5 builds on the approach developed in SESAR 16.06.01b Guidance for the application of Resilience and Robustness and SESAR Safety Reference Material (SRM) [22]. The FARO WP5 methodology, drawing on the SRM method, involved interviews with ATCos, supervisor and other actors to derive examples of situations in base adaptive capacity so that these serve as a comparison when considering changes in sector and sector group operations before and after the changes have been implemented. Thus, the work that is explored is specific aspects of the work system that controllers considered are exemplars of performance variability: CBs, weather events, technical equipment failure, limitation of the ground-based system such as meteorological radar, resourcing, etc.

D5.2 investigated resilient performance and changes to resilient performance following implementation of new system design solutions as well as enhancements and weaknesses in the new system and compared that to the old system (before implementation of new system design), to assess if in the new organisation, extant surprises and challenge events are being managed as they were in the old organisation or has brittleness been introduced. The data reveal patterns of how the ATC system adapts and respond to foreseen and unforeseen surprise events and how this have changed in the new organisation i.e., the controlling techniques, the interaction, dependency, and coordination with other sectors/units.

Qualitative data such as the strategies elicited from the interviews with air traffic controllers and from desktop research should be transformed into quantitative data components derived from system data using the indicators/metrics proposed in Section 7 in evaluating the impact of new solutions on the resilient performance of an ATC sector. The derived indicators represent the operationalisation of facets of controlling strategies that were elicited from controller informants.

Particular aspects of the strategies were sought, for example, trade-offs are particularly informative, because they are indicators of the boundary conditions that can lead or are indeed, an indicator of brittleness in the system or approaching brittleness. This can be analogous to the trade-off space that is pivotal in understanding and interpreting movements of gradients in Rasmussen's gradient model. Two trade-offs are of particular interest, Hollnagel [23] introduces the idea of ETTO – Efficiency Thoroughness Trade Off, where typical work of practitioners is seen as a trade-off between achieving efficiency and thoroughness. In this view of work, adaptations are made that match the prevailing conditions influence by performance variability, by an efficiency thoroughness trade off.

The second trade off, discussed by Woods [24] is known as Doyle's Catch: in this notion, the trade-off involves the way that designs are simulated and prototyped, can lead to an increase in complexity when the design is implemented, potentially leading to brittleness. This is a trade-off between optimising system design for specific demonstrations of system's responses to performance variability but these are not reflecting behaviour in the messy details of the real world [24].

In exploring adaptive capacity, and how this may change through digitisation and use of automation, consideration needs to be given to the buffers and margins that are present, that are situated such that the work system is constantly navigating them. Digitisation and automation can influence the coupling and dependence and interdependence of these. Changes flowing from the implementation of automation and digitisation can also have positive effects too, bringing new strategies better adapted to the new operational environment.

There is, however, a fundamental difference in the way that resilience engineering, drawing upon cognitive engineering and macro-cognition, views the nature of digitisation and automation. These are seen as joint systems in the sense that they are joint human-machine collaboration systems that undertake the purposeful activity of the work system. Which, being characterised as complex adaptive systems, it is the characteristics of resilient performance that are the research interest, as they adapt to changing situations.

Indicators of resilient performance need to focus on the characteristics of resilient performance. One consequence of this is that understanding resilient performance can bring a different perspective to orthodox safety performance assessment and measurement.

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# Appendices

## Appendix I - Data Parameters

**Table 10: Example of data definition and parameterisation**

| | Strategy | Parameter | Description | To be observed | Time interval | Details (visualisations in histogram except specified differently) | Discretisation criteria | Discretisation example |
|---|---|---|---|---|---|---|---|---|
| 1 | This strategy involves managing their workload around conflict detection tasks due to the change to FRA. Therefore, ATCos would manage their workload to create a margin for the increased uncertainty. | Occupancy | Occupancy of the sector data within 15mins interval | The actual sector capacity in use, defined as a % of maximum sector capacity along the day | 15 min | Y – Actual sector capacity (%)<br><br>X -Time in 15minute intervals | It is divided into 4 intervals that represent the percentage of occupation in the sector at the AC entry hour respect to the maximum value detected in the sector. The values of the intervals depend on the sector data. | Value <40%<br><br>40% <value <65%<br><br>65% <value <85%<br><br>85% <value |
| | Tactical strategies employed: Delay in response to pilot's requests, increased use of tactical radar headings to provide certainty in tactical situations, increased use of vertical separation to resolve conflicts. | 1. Occupancy - SAN | The vertical distribution of traffic overflying SAN | Traffic count at each FL and the distance from SAN | 15 min | Y - FL (Altitude)<br><br>X – Distance in nms<br><br>Scatter plots | The concentration of traffic overhead SAN | FL 335+<br><br>FL 335 - FL 305<br><br>FL 305 -<FL255<br><br>>FL 255 |
| | | 2. Entry (Traffic flow) | Entry Sector data at the 15-minute interval | Pattern of traffic entering the sector as a function of distribution over time | 15 min | x: time (15min)<br><br>y - % of entry into the sector per interval<br><br>y2- % of exits from the sector per interval<br><br>Plot: 2 histograms | It is divided into 4 intervals that represent the percentage of entries in the sector respect to the sector entry declared value at the AC entry hour. The values of the intervals depend on the sector data. | Value <55%<br><br>55% <value <65%<br><br>65% <value <80%<br><br>80% <value |
| | | 3. Exit (Traffic flow) | Exit from sector at the 15 min interval | Pattern of traffic leaving the sector as a function of distribution over time | 1. Duration of the segment<br><br>2. 15 min | x: time (15min)<br><br>y - % of entry into the sector per interval | Track miles flown in the sector segment within time interval point (Nominal vs actual | 5 miles either side of the nominal track,<br><br>Greater than 5miles either side |

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| | | | | | | y2- % of exits from the sector per interval<br><br>Plot: 2 histograms | | of the nominal track |
| | | 4. Sector Transit | The time of the duration for an individual aircraft within the SAN sector and the distance of the sector transit | Pattern of AC duration within the sector as a function of distribution over time and distance | None | Y – Traffic count of number of aircraft = specified time intervals<br><br>X – Time<br><br>1) as a function of duration within the sector<br><br>2) as a function of sector transit distance in nms | The duration of the time that that an aircraft is within the SAN sector from the sector entry point as defined and the defined sector exit point (a)<br><br>The distance in nms between the sector entry point and the sector exit point (b) | (a) Duration: minutes and seconds: 00:00<br><br>(b) Distance in nms |
| | | 5. Instantaneous demand | Ac entry into the sector in 15-minute periods | Pattern of AC entry into the sector as a function of distribution over time | 15min | Y – Traffic count of number of aircraft = specified time intervals<br><br>X – Time 15-minute intervals | Divided into 4 intervals that represent the percentage of the maximum instantaneous demand value for 15-minute intervals.<br><br>The values of the intervals depend on the sector data.<br><br>Peaks of demand: instantaneous demand in 15-minute intervals | Value <60%<br><br>60% <value <90%<br><br>90% <value <120%<br><br>120% <value<br><br><Value = Declared sector capacity<br><br>Sector |
| | | 6. Conflict prevalence and distribution | The pattern of conflicts and interactions between the fixed route and free route | Geographic spread of ac pairs within sector boundaries for ORG 1 and ORG 2 | 1. 15 min<br>2. 1 hour | x: Latitude<br><br>y - Longitude<br><br>Plot: Scatter plot - Map of the sector showing the geographic | An indicator comprised of Five vertical intervals and four horizontal intervals that represents the pattern of aircraft interactions<br><br>The distance between aircraft interaction co-level | Vertical:<br><br>FL 355+ -+ FL 335<br><br>- FL 335 - + FL 315<br><br>- FL 315 - + FL 285 |

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| | | | airspace structures | | | spread of AC pairs less than 20nm across the sector boundaries<br><br>Per 15min and 1 hour interval | | -FL 285 - + FL 255<br><br>-FL 255 - + FL 105<br><br>Horizontal:<br><br>< 20nms<br><br>>20 nms – < 15 nms<br><br>>15 nms - < 10 nms<br><br>>10 nms - < 5 nms |
| | 7. | AC distribution by FL: Entry | Vertical Distribution of entry FL at entry points | Pattern of FL distribution at sector entry points | | Y – FL (Altitude)<br><br>X – entry points<br><br>Scatter plots | Is divided into 6 intervals with uniform counts to model the vertical distribution entering the sector at specified entry points. Including vertical transfer and entry into the sector<br><br>The values of the intervals depend on the sector data. | FL <250<br><br>250 <FL < 330<br><br>330 <FL <360<br><br>360 <FL <370<br><br>370 <FL <380<br><br>380 <FL |
| | 8. | AC distribution overhead SAN | Vertical Distribution overhead SAN | Indication of traffic density overhead SAN fix as a function of the distribution within the SAN sector at specified time interval | 15min | Map of the SAN sector boundary showing AC distribution at a significant SAN fix versus distribution across SAN sector = specified time interval<br><br>1. Function of distance less than 20nms from the SAN fix<br>2. Greater than 20nms of the fix | Is divided into 6 intervals with uniform counts to model the vertical distribution over a significant navigation fix within the sector: SAN.<br><br>The values of the intervals depend on the sector data. (Provides Traffic density) | FL <250<br><br>250 <FL < 330<br><br>330 <FL <360<br><br>360 <FL <370<br><br>370 <FL <380<br><br>380 <FL |

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| | | 9. Managing Vertical profiles | Number of level changes in the vertical plane for A/C Climbing and Descending from entry to exit<br><br>Number of level offs + ac kept down below its requested flight level or sector exit level | | Null (number of intermediate levels) | Y – number of level changes = per ac<br><br>X – Time, 15-minute interval | For a/c entering via xxx and leaving sector SAN via exit point nnn, the number of level changes per flight to the:<br><br>1) RFL or<br><br>2) pilot requested RFL<br><br>3) sectors exit level | |
| | | 10. Managing Vertical Profiles | The management of specific inbound traffic flows | | Null | Y - number of level changes = specific traffic flow<br><br>X – Time, 15-minute interval<br><br>Function of:<br><br>1) Distance to exit point | For a/c Eastbound leaving OAC/NAT from OAC entry point to exit point of the Sector<br><br>2) the number of level changes to exit point xxx | 5-minute intervals |
| | | 11. Managing route and lateral profiles (1) | Tactical management of the lateral route of aircraft (1): radar headings | | 15min | x - time (15min)<br><br>y -number of tactical clearances per ac<br><br>plot: 1 histogram | For a/c exiting SAN sector OAC/NAT Westbound OAC point the number of headings allocated from sector entry<br><br>For a/c entering via OAC Eastbound and leaving via exit point nnn the number of tactical routing clearances allocated<br><br>1) flows aggregated as EAST/WEST and NORTH/SOUTH cross SAN<br><br>2) Other flows outside of 20nms | No of interventions per A/C<br><br>1) 15minute intervals<br><br>2) sector transit time |

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| | 12. Managing route and lateral profiles (2) | Tactical management of the lateral route of aircraft (2): tactical and direct routing | | 15min | Y – number of tactical clearances per ac<br><br>X – Time, 15-minute interval | For a/c exiting SAN OAC Westbound OAC point the number of route clearances issued per flight from sector entry<br><br>For a/c entering via OAC Eastbound and leaving via exit point nnn the number of tactical routing clearances allocated<br><br>EAST/WEST and NORTH/SOUTH cross at SAN | No of interventions per A/C<br><br>1) 5-minute intervals<br><br>2) sector transit time |
| | 13. Managing route and lateral profiles (3) | Tactical management of the lateral route of aircraft (3): Traffic that is routing via or overhead SAN | | 15min | Y – number of tactical clearances per ac<br><br>X – Time, 15-minute interval | Three intervals that describe the occupancy of traffic in the vicinity of SAN<br><br>(Supports the assessment of tactical routing of aircraft away from SAN as a conflict point and cardinal routing fix) | Occupancy of traffic within 5nms SAN<br><br>Occupancy of traffic within >5-10 nms SAN<br><br>Occupancy of traffic within 10 - 20 nms SAN |
| | 14. Managing route and lateral profiles (4) | Lateral route efficiency | Pattern of tactical clearances between nominal and actual track flown per ac | 15min (consider mean transit time further) | Y – number of tactical clearances per ac | For a/c entering via entry point aaa, bbb, ccc the route clearances (track miles) between the nominal flight | 5 minute intervals |

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| | | | | | | X – Time, 15-minute interval<br><br>Multiple line graph (1. Nominal; 2. Actual) across time interval | plan route and the actual track flown. | |
| | | 15. Opposite Direction Levels | Frequency of use of opposite direction levels (ODL) as intermediate cleared level or as a cruising level - The use of FL320 as an assigned East bound level | | 15min | Y – frequency – No of ac at ODL<br><br>Y2 - % of ac at an ODL to the total number of ac<br><br>X -Time (duration) at ODL in 15 minute and one hour | AC in sector N cruising at even FLs: e.g., 320, 340, 360, etc on a heading between 000 degrees and 179 degrees | 10-minute intervals |
| | | 16. Time to RFL or OAC entry level | The time and distance from the coordinated-out level/RFL of the SAN sector or the OAC entry level as per the Oceanic clearance | | None (entry to RFL) | x1 – time (entry to RFL)<br><br>y1– Distance (nms) from the coordinated boundary level to when the ac is cleared<br><br>y2 - time from the coordinated boundary level to when the ac is cleared<br><br>plot: 2 histograms | The time and distance from the sector boundary or coordination fix that an aircraft is cleared to the Oceanic entry level, the RFL or the exit coordination level | Distance in nms where CFL ≠ RFL until cleared and level at the RFL or OA Entry level<br><br>Time in minutes and seconds where CFL ≠ RFL until cleared and level at the RFL or OAC Entry level |
| | | 17. Traffic Demand (planned and actual) | The actual demand that was placed on the sector group after NM | Pattern in traffic demand distributed in 15-minute interval | 1 hour | x: time (15min)<br><br>y1: number of demand per interval<br><br>y2: number of conflict per interval | The managed sector capacity used and the actual traffic flow that was experienced per hour | 1 hour |

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| | | | interventions e.g. restrictions etc | | | Plot: 2 histograms | | |