Unearthing Weak Signals for safer and more efficient socio-technical systems

The Structured Exploration of Complex Adaptations (SECA) method

SUPPORTING EUROPEAN AVIATION

Contents

ACRONYMS

AI	Artificial Intelligence
ANSP	Air Navigation Service Provider
ATCO	Air Traffic Controller
ATM	Air Traffic Management
DIKW	Data, Information, Knowledge, Wisdom
ETTO	Efficiency-Thoroughness Trade-Off
NLP	Natural Language Processing
SECA	Structured Exploration of Complex Adaptations
SECI	Socialization, Externalization, Combination, Internalization
TETO	Thoroughness-Efficiency Trade-Off

Where is the wisdom we have lost in knowledge?

Where is the knowledge we have lost in information?

T.S. Eliot, 1934 – The Rock

INTRODUCTION

Traditionally, a system is considered safe if characterized by a limited number of failures. Nonetheless, uncertainty about future performance, continuous changes, and finiteness of resources are conditions that many systems commonly experiment when confronting with hazardous operations.

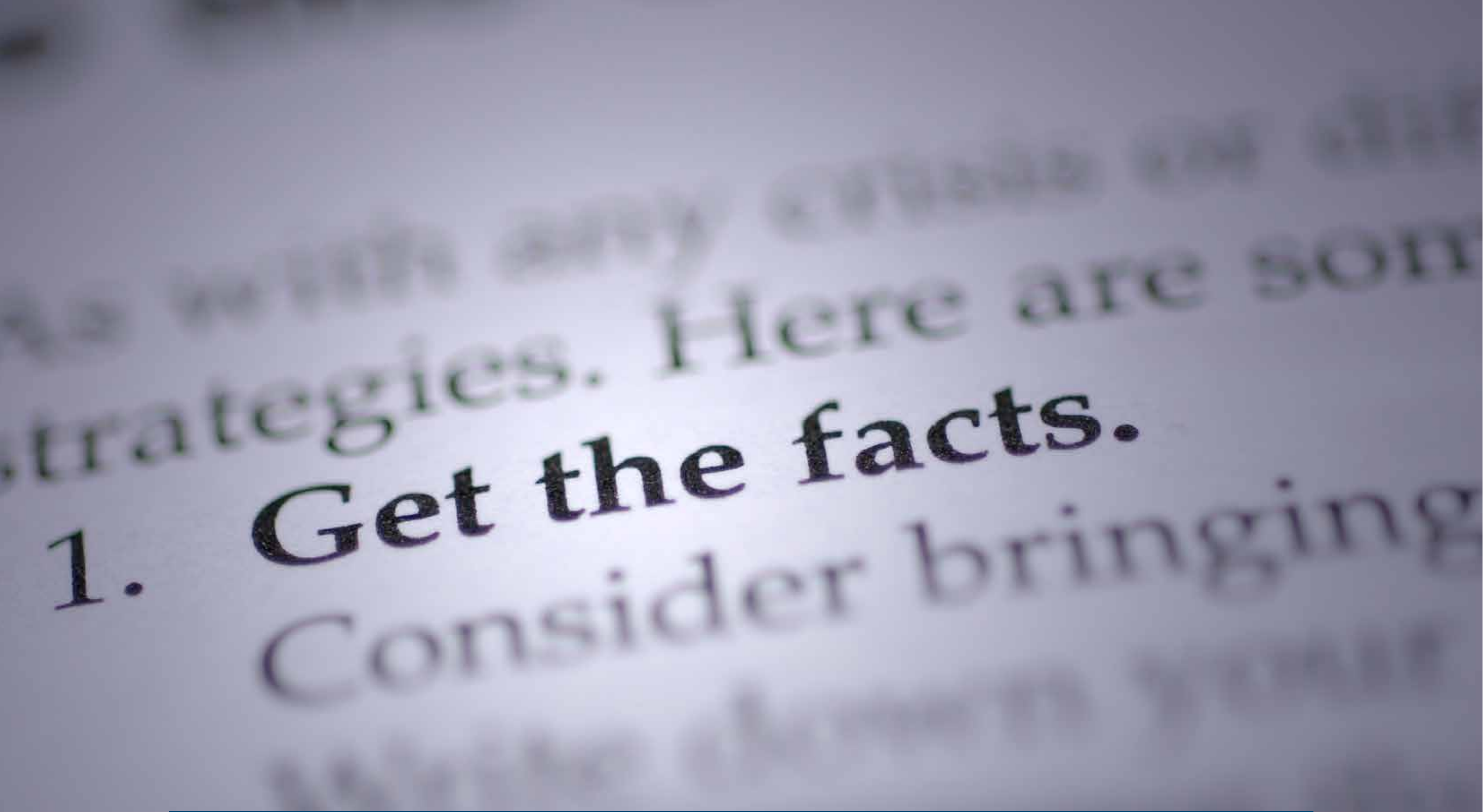
Understanding system's resilience becomes then relevant, being this latter concerned with systems' ability to sustain operations under both expected and unexpected conditions. Even before its first white paper on Resilience Engineering in Air Traffic Management (ATM) dated back to 2007, EUROCONTROL promotes the need for in-depth investigations of performance variability (Leonhardt et al., 2009). The goal of such investigations consists of capturing weak signals and offering proactivity against future uncertainty. On this path, towards the end of 2011, EUROCONTROL started a namesake project called "Weak Signals in ANSP's safety performance" to investigate what kind of data operators usually rely on and use to increase system's resilience (Hollnagel et al., 2021).

Weak signals are embedded in the socio-technical knowledge orchestration played by the parts the system is made up of. Knowledge is a crucial irreplaceable asset an organization owns: it is a key to organizational efficiency and success. Accordingly, understanding system performance implies delving into organizational knowledge, and the way it is generated, converted, shared, and used in case of both abnormal events and normal operations. Knowledge management thus plays an instrumental role to progress and improve system's performance, especially when the system at hand is a complex socio-technical one.

This White Paper seeks to provide an answer to the following questions:

- What is the relationship between knowledge management and weak signals in socio-technical systems?
- How should a pragmatical solution be designed to collect knowledge on these weak signals?

With specific reference to the latter question, this White Paper introduces SECA (Structured Exploration of Complex Adaptations), a novel method inspired by Resilience Engineering and knowledge management principles for capturing and analysing weak signals.



BEYOND *POST-MORTEM* INVESTIGATIONS

Air Navigation Service Providers (ANSPs) put considerable resources into the investigation of unwanted events. The need to go beyond major accidents and start collecting information on lower-consequence incidents and near-misses has been early acknowledged. The regulatory environment proposed by ICAO, EASA and other international and national authorities allowed to progressively improve safety levels. Despite the continuously challenging environmental conditions, this safety strategy allowed reaching an ultra-safe status. In terms of accidents count, a person would need to fly daily for 461 years before experimenting an accident with at least one fatality, i.e. 1.38 accidents per million flights as reported by IATA (2021). At national and international level, permanent systems have been established for mandatory and voluntary reporting of aviation occurrences, investigation, and information sharing. Even when looking at minor incidents, one of the largest ANSPs in Europe shows 0.0000525 events per flights. The subsequent *post-mortem* investigations are meant to better equip the system against failures and prevent these latter from happening again (Allspaw et al., 2016). In a longer run, they foster a virtuous sharing and learning cycle for aviation personnel, without fear of undue retribution.

Nonetheless, situations that are rapidly changing are not recurring. It becomes puzzling to compare one case with another without context. The knowledge gained after the investigation of a serious event is very limited: in other words, the organisation is managed based on numbers close to zero.

Modern ATM systems' complexity involves a tight orchestration of humans and technical artefacts, which act jointly to ensure operations' success. Assuming bi-modality of system components (either functioning or malfunctioning) and looking only at failures is not representative of the tensions that locally emerge during real operations (Hollnagel et al., 2013).

Vectoring an aircraft, prioritising taxiway movements, coordinating upper space traffic: it is more than just rule-following.

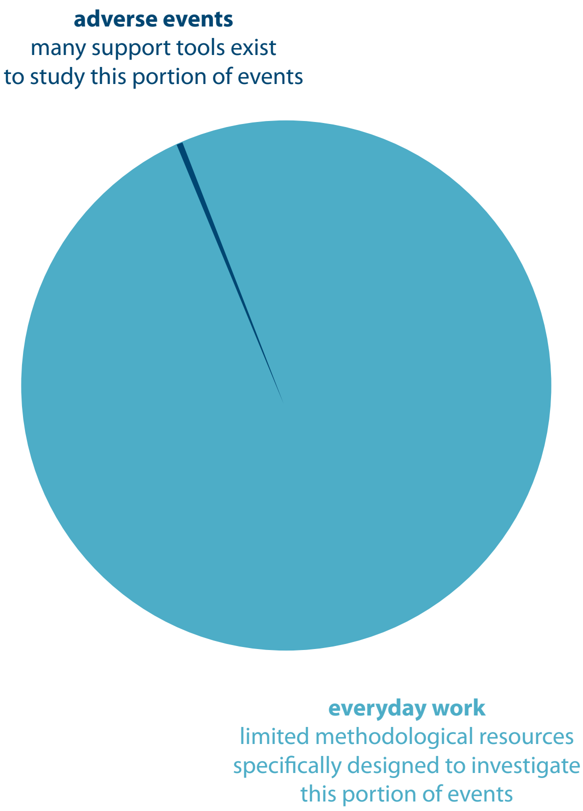
In such dynamic contexts, procedures are not necessarily sensitive enough to the many underlying subtle variations any operation carries on. There could exist also cases in which multiple events are happening at once generating contradictions among available procedures. There is thus a need for human adaptation in the face of unanticipated complexity. Operators do what makes sense to them at the time, considering their local knowledge and experience in the task, following their local rationality (Dekker, 2011). As such, investigations labelling human error or non-compliance as causes are constructivist and limited in scope. This reductionism is tempting and comfortable to guarantee keeping at the pace with the pressure to fix issues. It becomes however counterproductive for organizational learning. Focusing only on errors rather than on actions, prevents from gaining knowledge on what the actual trade-offs and conflicts were at the time. It inhibits a full understanding of complex realities people faced and will continue to face in different dynamic circumstances.

Vectoring an aircraft, prioritising taxiway movements, coordinating upper space traffic: it is more than just rule-following.

Moreover, complexity and dynamics do not only exist when a safety occurrence verifies, rather they accompany everyday work and normal operations. Attention should thus be diverted towards unearthing how operations are carried out in normal settings, success is achieved, and conflicting goals are managed effectively. Operations should be explored in terms of their socio-technical traits, and the operating context in which they happen, through a large inquiry of human, technological, organizational, regulatory, and environmental variables. This focus should complement – rather than substitute – the well-established *ex-post* investigations of facts.

While incident analyses stand on a consolidated repertoire of models, methods and tools that have been developed over years, the in-depth exploration of everyday work and the elicitation of weak signals is supported only to a limited extent by dedicated instruments.

Figure 1. Sample of proportion for successful vs. unsuccessful events.



A full understanding of system behaviours requires scratching the surface of activities as usually conducted, going beyond individual incident reconstruction. This understanding calls for abandoning distant views of workplaces. It demands to complement comfortable descriptions that rely on how work is expected or imagined being conducted. It leads to searching for underlying patterns of systemic factors: how people, teams, and organizations coordinate with cyber-physical elements to handle dynamic situations and cope with the complexities of a work domain. It acknowledges the sharp-end as the place where pressures, difficulties, trade-offs, and dilemmas emerge and are resolved daily.

It recognises as critical the resource investment in understanding how people cope with complexity and act resiliently to deal with daily demands, despite hazards and opportunities to fail.

Progress on system performance management requires bringing to light system's strengths and weaknesses, along its potentials to act resiliently. It is all about finding out what lies behind the complexity of cognitive systems, the features of knowledge owned and shared within the organization, the messiness of operational life.

KNOWLEDGE MANAGEMENT IN EVERYDAY WORK

An organization that has achieved good safety records, at least if measured through counts of adverse events, necessarily has found ways to deal with known hazards in an effective way. But history unluckily shows us that even such a safe organization may suffer the consequences of unexpected events at some stage. These rare accidents are usually not preceded by the sorts of occurrences that get formally captured by institutionalized reporting systems. They are rather preceded by silent improvisations and adaptations to get the work done, shortcuts to deal with missing tools, user-unfriendly interfaces, missing feedback, inapplicable procedures (Dekker, 2018). Strong signals *ex post*, just inert weak signals otherwise.

In other words, rare events are frequently preceded by normal, daily, successful work.

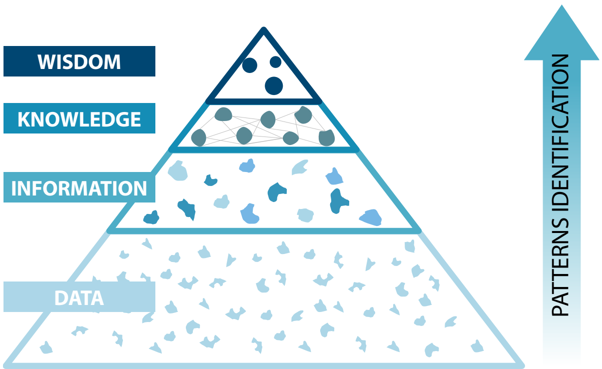
From data to wisdom

Identifying the root of an incident causal chain represents a laudable and valuable perspective yet limited in scope. The *eureka* (from ancient Greek εὑρίσκω, i.e., to discover, to fetch) must be extended towards studying more closely how operations are normally conducted, making sense of data as embedded in work routines. This extension seeks to transform inert data into usable knowledge, calibrating it into strategies that remain relevant at organizational level.

In wider terms, this revised inquiry creates opportunities to match modern systems science and nest it into knowledge management. For an organization, this management consists of a collaborative collection, generation and conversion of knowledge (Alavi and Leidner, 2001). It is about extracting data and connecting pieces of information that would have been otherwise stored in each individual mental model.

In more formal terms, these actions refer to the notions of data, information, knowledge, and wisdom, as expressed by the DIKW (Data-Information-Knowledge-Wisdom) pyramid (see Figure 2), where each step up adds value to the former.

Figure 2. Data-Information-Knowledge-Wisdom pyramid for knowledge management.

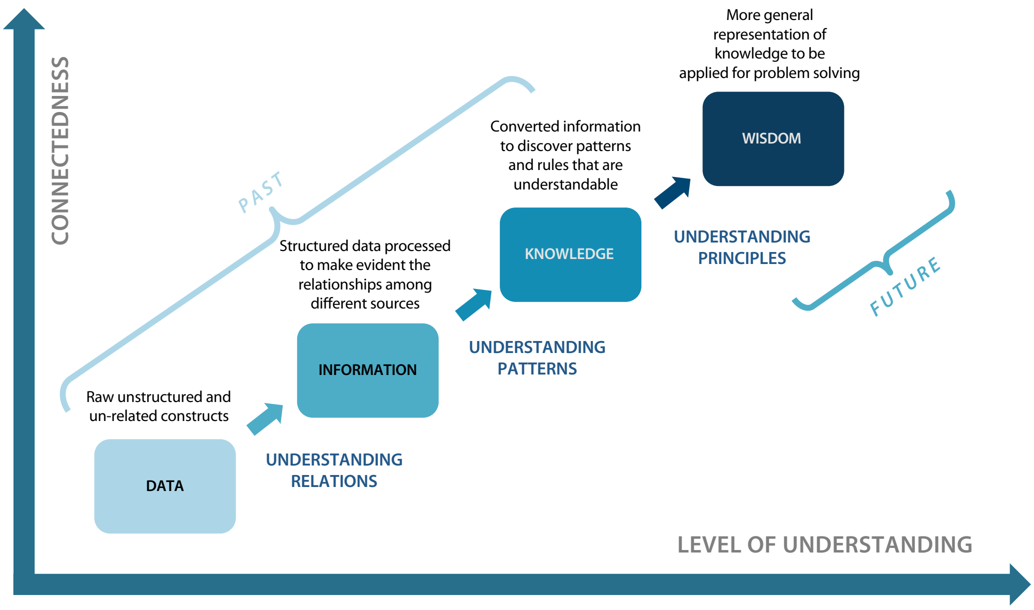


Several definitions exist for each DIKW element, with scholars agreeing on the lack of a unified consensus.

- Commonly, data are interpreted as the basic building block of the pyramid consisting of a raw unorganized collection of bits, such as numbers or characters. Data *per se* are not capable to inform a human mind, and offer low relevance for decision-making, at least as long as they do not appear into a context or mapped through some relevant dimensions.
- When this happens, data then are converted into information. At this stage, non-relevant pieces of data are excluded, and the meaningful ones are structured in a way that fosters the quality of knowing. Information allows a systematic understanding of what, when, where, which were otherwise intrinsic in data. This transformation is about deriving, structuring, contextualizing, and categorizing relevant pieces of data.
- The act of connecting information is then linked to the production of knowledge. This latter goes beyond single pieces of information, towards grasping the underlying relationships between them. It is about the application of information to achieve a certain goal, in a way that is not necessarily explicitly stated into individual fragments.
- The last step is converting knowledge into wisdom. This conversion uses the obtained knowledge to isolate the best flows of actions, and take proactive decisions, moving from the past towards the future.

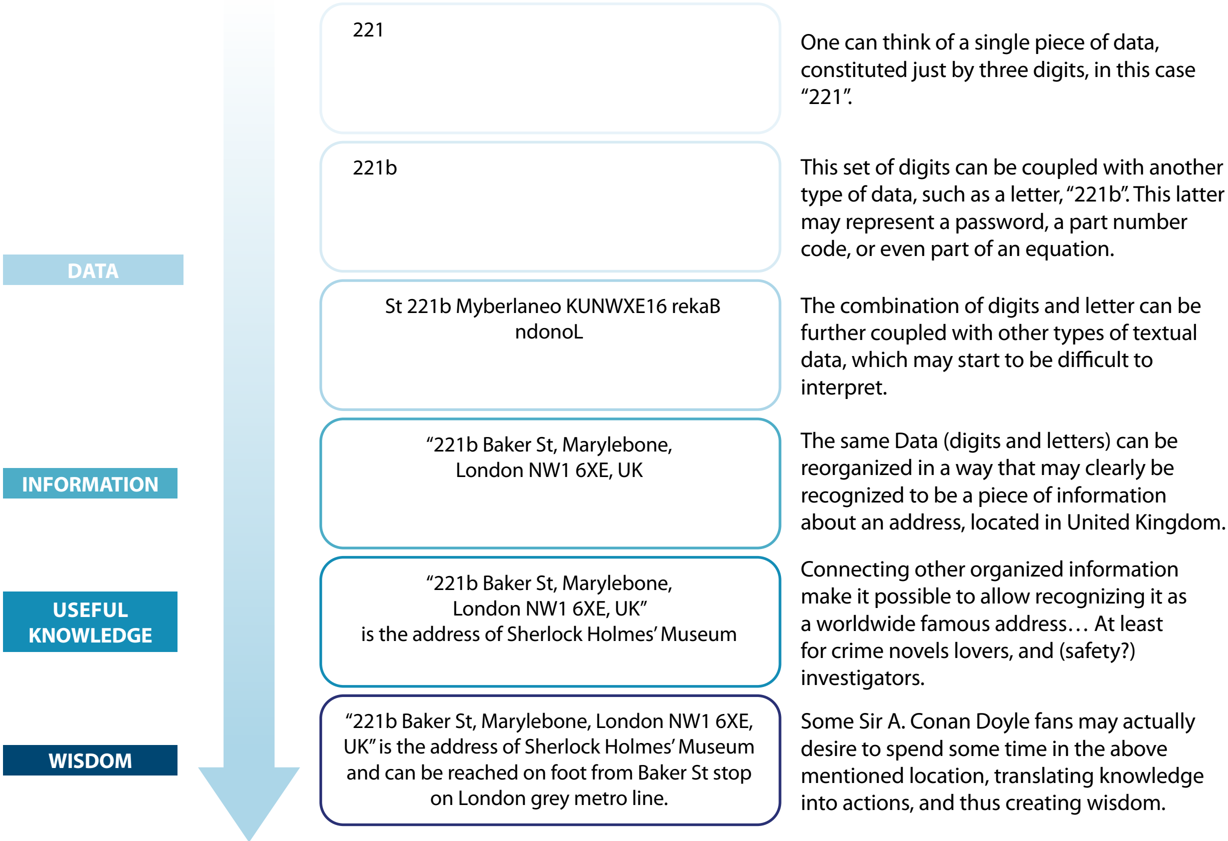
A visual summary of the relationships among these entities is provided in Figure 3.

Figure 3. Mapping DIKW elements in terms of level of connection and level of understanding.



For example, "Category1", "MSAW", "95%" are examples of unstructured data, which may become information. Such transformation may happen in case data start to be structured and contextualized: "for MSAW (Minimum Safe Altitude Warning), Category 1 is the first situation of encounters". The same are converted into knowledge when "For MSAW, Category 1 refers to a situation where alert is necessary since it involves a serious deviation below safe altitude or avoided terrain by a late manoeuver". It extends further in terms of wisdom when we refer to "for MSAW design requirements, performance should ensure a minimum percentage of 95% of Category 1 encounters alerted" (EUROCONTROL, 2017).

Similar non-aviation examples can be retrieved in the following box.



Tacit and explicit knowledge

A major part of knowledge comes from rationalized data and information embedded into hierarchy, command structures, roles, formal rules, and procedures. These dimensions do not capture the value of discretion and tacit knowledge, the deliberate research for balancing competing demands, the professional pride and responsibility of any actor involved, their often conflicting, functional purposes. Controllers, supervisors, pilots, ground operators act jointly to ensure system's functioning under both expected and unexpected working conditions. Considering the increasing digitalization and automation of work processes, socio-technical systems are progressively including interconnected cyber technical artefacts, thus becoming cyber-socio-technical systems (Patriarca et al., 2021).

To this scope, defining a unique, unambiguous, and omni-comprehensive structure for organizational knowledge is possible only if embracing a tayloristic perspective, which subsumes the organization behaves as a working machine with humans as its cogwheels (Weber, 1946).

The shortages of this logic are rather evident when considering the social multi-faceted complexities of modern organizations (Mayo, 1933).

A full rationalistic illusion should be abandoned in favour of a socialized representation. One that encompasses both formal and informal structures. One that aims to extract information from intertwined socio-technical actors and about how they apply, try, and adapt rules in context through the experience they progressively accumulate. One that captures the way the social environment affects organizational behaviour and success.

Since knowledge is relational, it depends on the perspective of its beholder, and it cannot be considered entirely true or ultimately complete. A theoretical milestone in this sense is offered by Nonaka et al. (2000) through the concept of knowledge flows. These latter are representative of the dynamic processes actioned by system's actors who capture, codify, transmit and use knowledge in their everyday work. From a systems-theoretic perspective, this logic remains valid in joint cognitive systems such as the ATM, where ATCOs and technical artefacts tightly cooperate and take part on these knowledge transformation processes. Knowledge should be then interpreted as a justified true belief, where the abandonment of the "truthfulness" leaves room for its justified nature. The corresponding DIKW cycle demands for a relative, dynamic, and humanistic dimension, which distinguishes explicit and tacit dimensions of knowledge.

- Tacit knowledge is the one embedded in the human mind. It involves personal context-specific competences and experiences, insights, intuitions. It refers to what is learned over time and through experience. It is usually difficult to extract and codify.

- Explicit knowledge is the one codified and digitized in data sheets, procedures, reports, and other documentary tools in general. It is frequently easy to be identified, articulated, shared, and analysed.

An example of explicit knowledge could be the procedure to open the flight plan for a particular plane, (e.g.) a hydroplane. Tacit knowledge could be what leads a controller's decision to anticipate the opening since hydroplanes usually take-off from a harbour area that suffer poor radio coverage, thus generating frequent problems to communicate.

Socialize, Externalize, Combine, Internalize

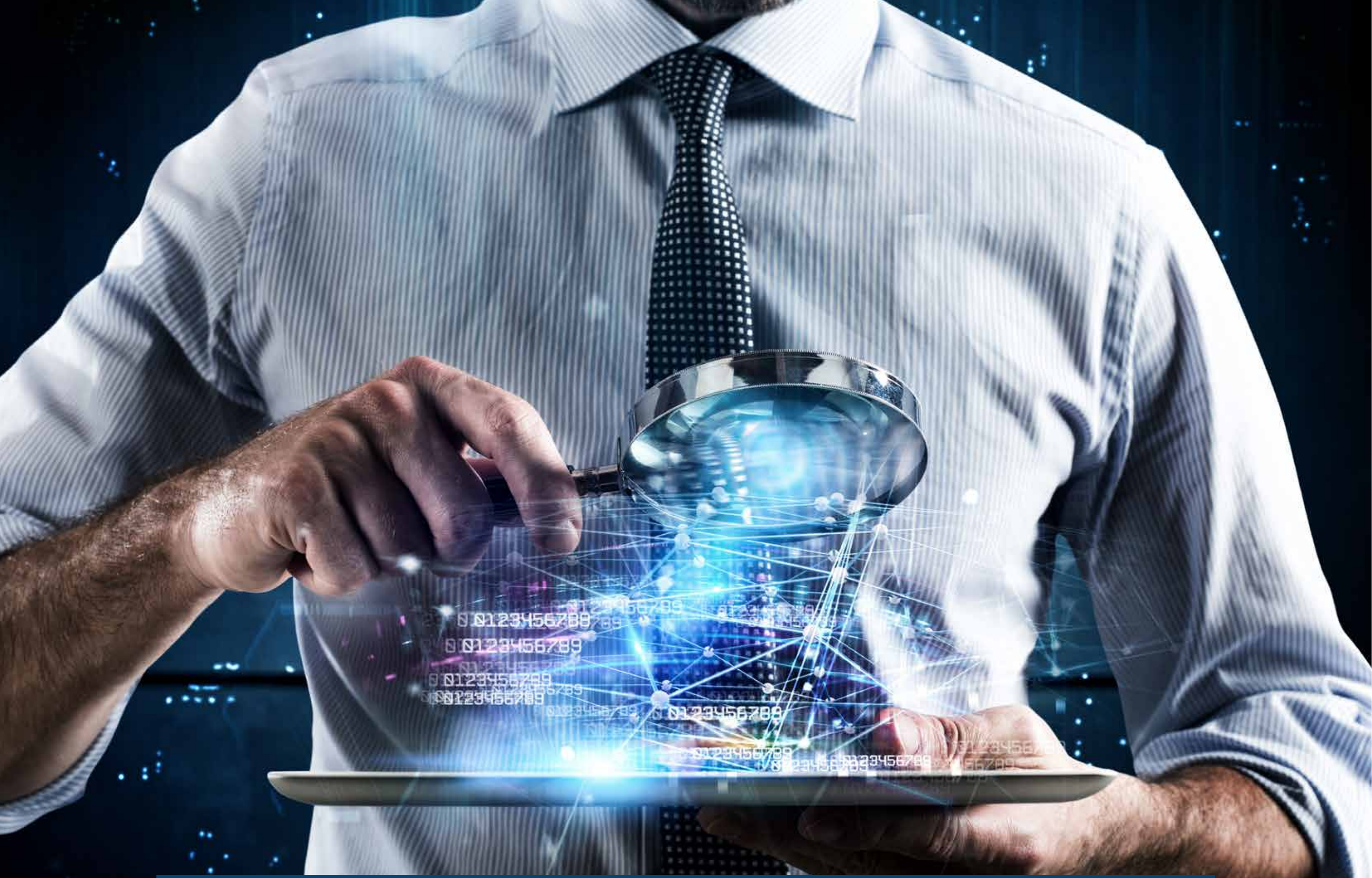
Knowledge conversions happen when tacit and explicit knowledge interact with each other and increase their quality and/or quantity. Four different conversions exist which give name to the SECI model (Nonaka et al., 2000): Socialization, Externalization, Combination, Internalization.

Table 1. Knowledge conversion flows

Knowledge conversion	Flow	Description
Socialization	From *Tacit* to *Tacit*	It is about fostering a positive attitude to learn from adaptive practices, and tacit underlying management strategies realized by system operators. It is what happens through observation, imitation, and practice. For example, it concerns sharing beliefs or mental models about the way a flight operation in bad weather might be conducted.
Externalization	From *Tacit* to *Explicit*	It is the attempt to create a codified explanation of a tacit knowledge that can be then used by others. For example, it refers to the dialoguing act of an external actor to understand and code the way an ATCO may operate in practice (work-as-done) in a specific operating scenario. It is the first step for recognizing adaptive practices and in turn potential weak signals.
Combination	From *Explicit* to *Explicit*	Since a single externalized excerpt of knowledge does not necessarily provide enough content at organizational level, it could be helpful to combine multiple sources. Combination is about generating a new and more complex set of explicit knowledge to facilitate dissemination. For example, multiple externalized ATCOs ways of operating in a certain scenario may be categorized and modelled to spot patterns of adaptive practices.
Internalization	From *Explicit* to *Tacit*	Internalization process aims to embody explicit knowledge into tacit knowledge, empowering system actors with knowledge emerging from the identified patterns. For example, this conversion refers to the actions played by ATCOs to revise their mental models for some operations, following a new procedure development.

Even though tacit and explicit knowledge are complementary in nature, the conversion from one to another is entropic, carrying on an incomplete transformation towards either higher or lower dimensional particulars to be studied jointly.

The challenge for safety analysts and designers in general refers then to render explicit, aggregate and analyze individuals' tacit knowledge. This should become a continuous race to elicit, interpret and combine these fragments into a multi-faceted harmonious construct to capture the nuances of a work setting, and to ultimately instruct system improvements and redesigns.



STRUCTURED EXPLORATION OF COMPLEX ADAPTATIONS, SECA

The conductor of an orchestra doesn't make a sound.
He depends, for his power, on his ability to make other people powerful.

Benjamin Zander

The inescapable complexities in everyday work are acknowledged to be a vital resource for understanding and analysing system's performance to the fullest. Strong signals represent the information that is acknowledged as necessary and distinctive of large disruptive events, often leading to an adverse outcome (e.g., an incident or an accident). Besides strong signals, system resilience is dependent on adaptive capacities, i.e., system's ability to sustain operations despite disturbances. This adaptive capacity is often appointed to the social element of the system: human's ability to foresight and perform approximate adjustments. Even in case of largely automated systems, automation cannot fully substitute human actions without larger impacts, see the *substitution myth* previously discussed by Nash (2015). These cases require setting adaptative capacities as a necessary unit of analysis, possibly studied through the lens of co-agency, and joint cognitive systems (Hollnagel, 2007; Woods and Hollnagel, 2006).

Accordingly, the full grasp of adaptations demands to go beyond *post-mortem* investigation. Studying adaptations implies studying resilience, a vital resource to ensure proactivity and success in both expected and unexpected scenarios. Resilience assessment should rely on capturing weak signals, i.e. the "normal work, anticipation, adaption and trade-offs" that lie below the threshold of reporting or criticality but represent routines, habits, trade-offs (Hollnagel et al., 2021; Schoemaker and Day, 2009). These latter may favour thoroughness over efficiency in situations where safety or quality are the dominant concerns, and efficiency over thoroughness if productivity gets prioritized. More formally, operators constantly balance ETTO (Efficiency-Thoroughness Trade-Off) and TETO (Thoroughness-Efficiency Trade-Off) to ensure system success (Hollnagel, 2009).

For example, an ATCO who automatically accepts a flight on a direct track close to its destination does not follow the standard procedure, especially if the acceptance may not guarantee the receiving sector to have enough timing for stating the entry conditions. However, at the same time, during a nightshift with reduced traffic, ATCOs are expected to accept all directs. These underlying factors may generate a trade-off for the ATCO who has to struggle with procedures and external pressures from pilots and management.

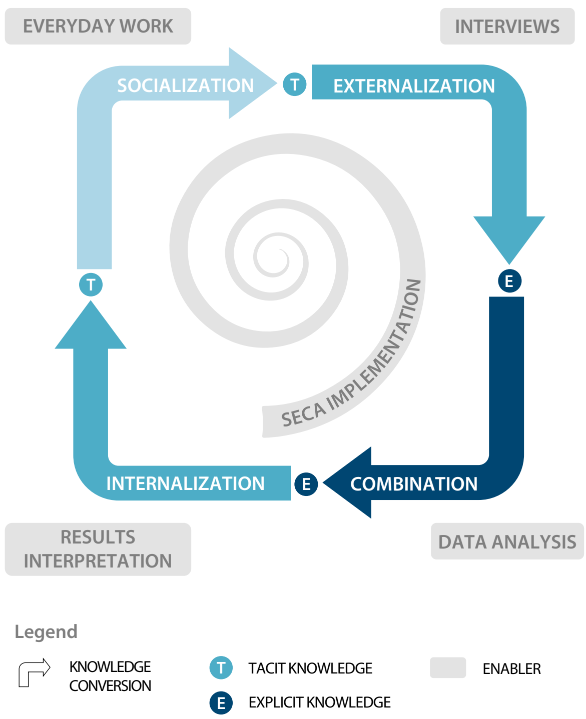
SECA structure

The notion of weak signals promoted by Resilience Engineering (Patriarca et al., 2018) and reinforced by the theoretical underpinnings offered by knowledge management principles (Nonaka et al., 2014) fosters the necessary study of adaptations and trade-offs. This consciousness served as a basis for the development of the so-called SECA (Structured Exploration of Complex Adaptions, SECA).

SECA interprets knowledge as a social phenomenon that needs to be understood from the perspective of those living it. As such, SECA envisages the process of capturing and codifying knowledge as dynamic and continuous. It is meant to support the SECI cycle (Socialization, Externalization, Combination, Internalization) as per the continuous conversions between tacit and explicit dimensions of knowledge (Figure 7). SECA methodological dimension relies on systems-thinking and risk management principles (Rasmussen, 1997), as well as Resilience Engineering (Woods, 2015). It builds upon approaches previously documented in safety science such as the Resilience Analysis Grid (RAG) (Hollnagel, 2018, 2011) or the Systemic Contributors Analysis and Diagram (SCAD) (Walker et al., 2016).

SECA aims to support analysts to go beyond root cause analysis and linear decomposition of a work domain. It envisages the need to capture adaptations in practice, without the need for incidents or accidents to be the triggers of such analyses. It starts from the exploration of an event, which could be a situation operators feel to be interesting for various reasons. One could be because it forced deviating from a procedure, or because it did not link to any. Another case could be because it put some operator in an uncomfortable situation, or even in danger, yet without reaching the threshold for reporting. It could be also something the operators do but feel a dumb not necessary act; or any situation where the normal way of operating is acknowledged to be different from what happened or was expected to happen, or what colleagues normally do.

Figure 4. Knowledge conversion process within SECA.



In essence, SECA is a guideline for interviews on normal successful work, and an analysis process for elicited data. SECA builds around the four dimensions depicted in Figure 4, and further documented in Table 2.

- Context
- Responses
- Pressures
- Conflicts

Figure 5. SECA interview flow.

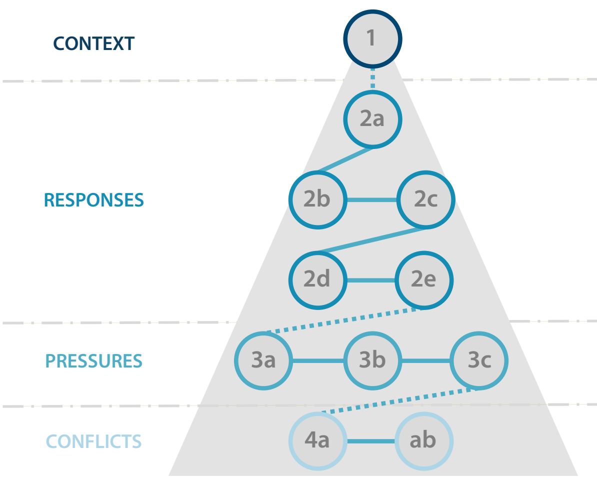


Table 2. SECA dimensions of investigation and detailed elements.

Code	Dimension	Element
1	*Context*	Description of the situation
2a	*Responses*	Personal response
2b	*Responses*	Procedures (written rules)
2c	*Responses*	Units' normal way of working
2d	*Responses*	Less experienced colleagues' response
2e	*Responses*	Experienced colleagues' response
3a	*Pressures*	Pressures from Management in the organization (blunt end)
3b	*Pressures*	Pressures from the outside the unit (work related environment)
3c	*Pressures*	Pressures from colleagues
4a	*Conflicts*	Goal conflicts
4b	*Conflicts*	Trade-offs

The first point, i.e., "Context", is the central element of the entire interview. It should be clarified from the very first moment the explorative nature of the process, distant from accident analyses of blame apportioning. From the outside, it would be more correct to consider such interview a war-story narration, or even a coffee-break chat. This simple semi-structured interview flow is indeed helpful to reduce the bias in the externalization process (from tacit to explicit knowledge) and elicit the most meaningful pieces of inert knowledge in the organization.

As an example, Context might be established through these exemplary statements: *"Tell me something about your experience that stood out to you or something from your everyday work that you, or someone from the outside, would find remarkable. What happened around you? How did you find out about this situation, yourself, a colleague, technology, or something else?".*

A longer list of exemplary questions for each SECA element is included in Appendix 1, with additional best practices for facilitating dialogue and knowledge elicitation in Appendix 2.

SECA analysis

Since SECA guides interviews and then generates narratives and linguistic descriptions as outputs, its data analysis follows a qualitative research approach.

The post positivistic acknowledgement that adaptive practices are contextual and dependent on the specific organizational settings being analysed (Johnson and Christensen, 2019) pushed for selecting Grounded Theory as a methodology for the analysis (Glaser and Strauss, 1967).

Such analysis needs to be interpretive by nature: adaptive practices are inherently present in socio-technical systems, and everyday operations are the expressions of multiple realities and points of view. Beyond those abstract dimensions, detailed ideas and concepts referred to specific complex adaptations are expected to emerge from otherwise unnoticeable facts. Accordingly, the coding strategy needs to be inductive and progressively reviewed to ensure higher granularity and abstraction. This pragmatical choice favours the attitude to openness, the attention to empirical evidence and the hermeneutic reduction of the distance between the process being investigated and the analysts (Age, 2011).

Figures 6-7 show the logic SECA uses to transfer Grounded Theory in action for multiple SECA interviews. One can note the need to have a team made up of Subject Matter Experts (e.g., ATCOs, or ATM safety managers) and analysts with expertise in qualitative research. While in principle the data analysis process is an exercise that could be conducted with pen and paper, it would benefit from the usage of computational qualitative tools, for both coding activities and descriptive analyses.

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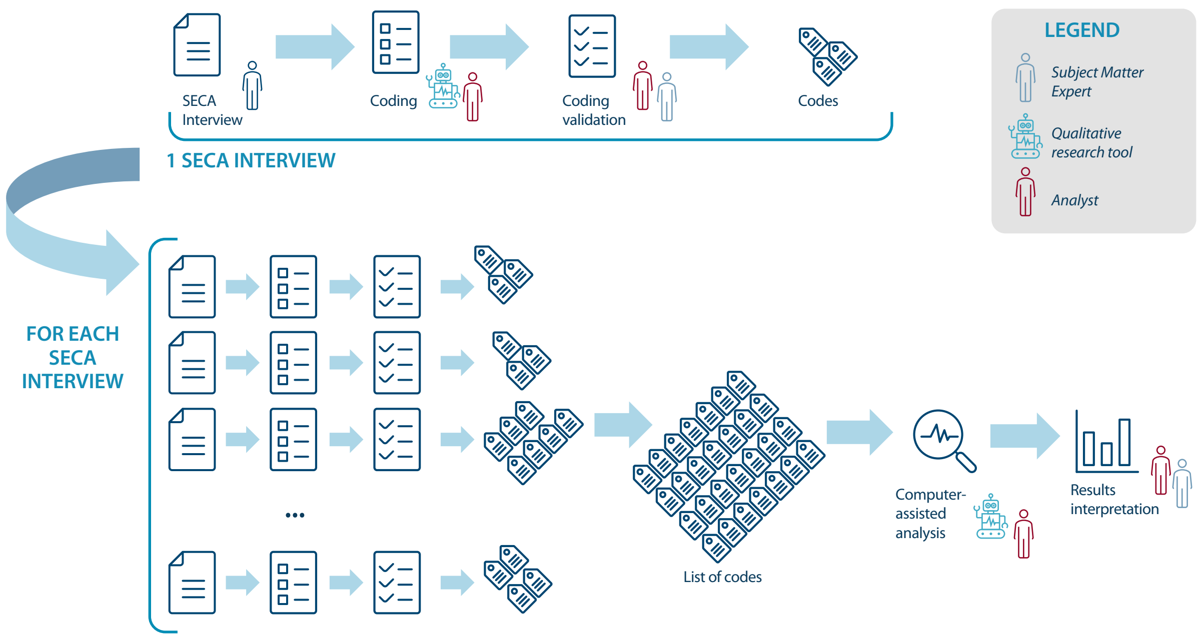
Figure 6. SECA data analysis flow, with the coding action being the central item.

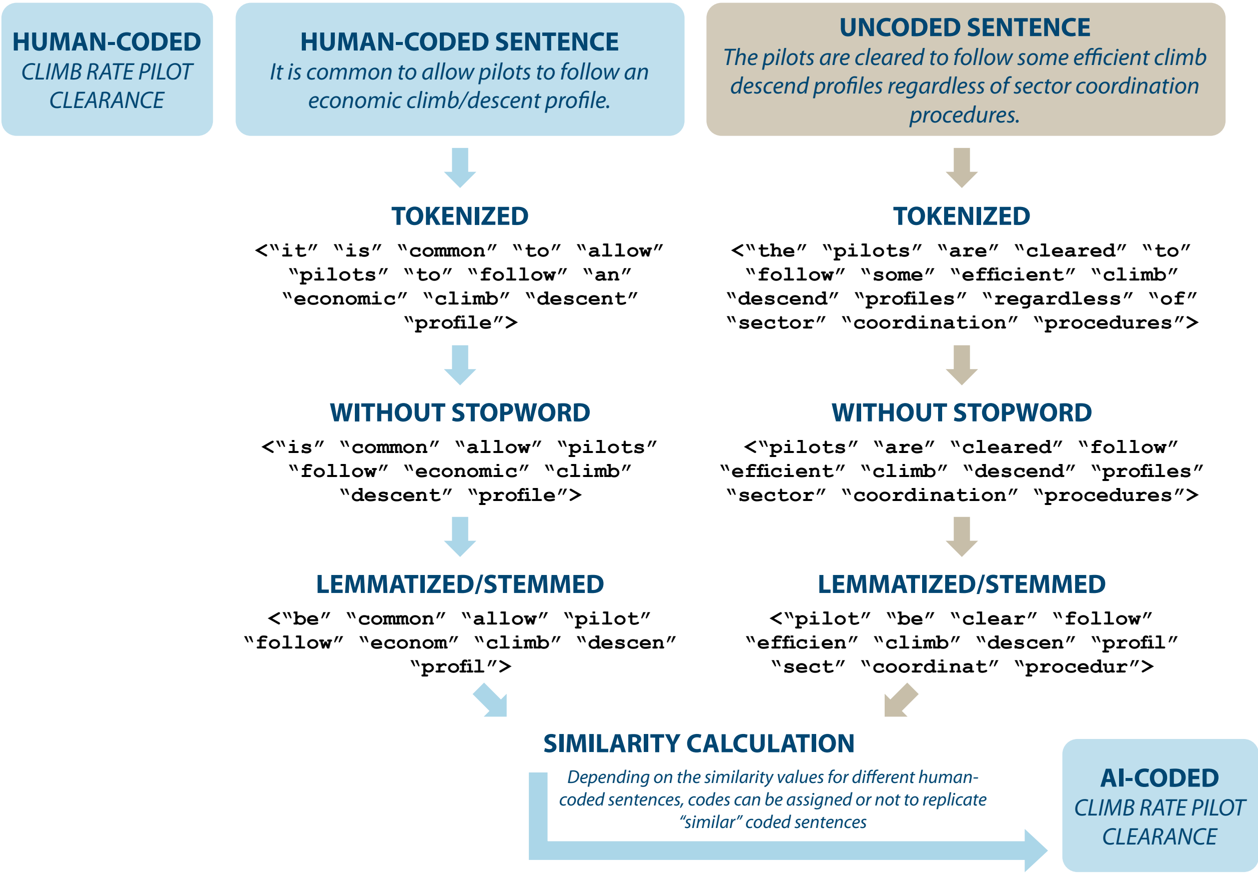


The SECA analysis is indeed conceived to be compatible with computer-assisted coding, replicating the initial codes assigned by humans. A code is here intended as a label to identify the content of a larger segment of data. In line with Grounded Theory, a substantive coding is used to conceptualize the empirical substance under study, i.e., the SECA interviews in which the theory will be grounded. Then an Artificial Intelligence (AI) pipeline can be set up to mimic human coding, based on these conceptual steps (cf. Figure 7):

- Firstly, it is necessary to ensure the AI engine recognizes the coding as done by human analysts
    - Each paragraph coded by an analyst is broken down into a list of words. Extremely common words are excluded to remove semantic noise in the text analysis (determiners, coordination conjunctions, prepositions), and simultaneously limit processing time.
    - Out of this list, words with the same stem are grouped together following stemming and lemmatization processes.
    - For each term, the term frequency (tf) and inverse document frequency (idf) are calculated, leading to the tf-idf statistics (Jones, 1972). These two values represent the relative importance of a term in a sentence in comparison with the importance for all coded paragraphs.
    - A vector including the terms, and their tf-idf value is then generated to map the features of each analysed sentence.
- Then the AI routine replicates this coding process to new text passages:
    - Each new paragraph is broken down into a list of words, and stop words are excluded as in the previous step.
    - Stemming and lemmatization are conducted on this list of words to generate terms.
    - For each term, the term frequency (tf) and inverse document frequency (idf) are calculated as above.
    - A vector including the terms identified by the AI, and their tf-idf value is made available to represent the feature of each analysed sentence.
    - Each text passage is compared against the coding vectors (coming from human-coding), in terms of similarity: the higher the value, the higher the degree of similarity. If the similarity metric of a given pair of text and coded vector is above a particular threshold, the text passage is coded to a previously identified node.

Human analysts are then required to assess the significance and validity of the AI codes, validating, or revising them where necessary. This leads to a virtuous cycle to progressively improve the AI-coded results.

Figure 7. Exemplary coding process (simplified).



SECA roles

Adopting SECA into an organization envisages at least three user categories, who should interact tightly to ensure implementation success.

1. **SECA Interviewees:** the operators whose tacit knowledge and Socialization (intended as tacit-tacit conversions) constitute the primary target sources to be elicited. Considering the explorative nature of SECA, the sample size of respondents should be dimensioned following the principle of saturation, i.e. on the basis of the data already collected further data collection are unnecessary at some stage (Saunders et al., 2018).

2. **SECA Interviewers:** the ones who apply SECA to facilitate knowledge Externalization to transform knowledge from tacit to explicit, in line with SECA interview flow. They are expected to supply feedback on the SECA implementation and need for revisions to the SECA Masters. It would beneficial that the Interviewers could be themselves operators since sharing experiences might facilitate dialogue and mutual understanding. They should promote an informal and comfortable SECA application, and thus foster open conversations.

3. **SECA Masters:** those designing the tool, developing the guidelines, and instructing the Interviewers on their adoptions. They run the analyses on the externalized knowledge prepared by the Interviewers. In a continuous improvement cycle, the SECA Masters coordinate interviewers and interact with them to revise the tool and the guidelines in a way that remains representative and usable for the specific system at hand. They supervise the entire process and set the guidelines for Combination and Internalization of the elicited knowledge. SECA Masters are usually business analysts with a background in human factors and ergonomics, along with expertise in qualitative research. Some blunt-end operators should belong to this category to facilitate resource acquisition and program running.

SECA walkthrough

SECA was trialled by three teams of interviewers from two European ANSPs (i.e., 6 interviewers for a proof of concept of about 15 months). The most valuable insights gathered through SECA were the ones nobody would think about writing down a formal report, but that still provided some additional knowledge about the actual state of the ATM system. For example, ambiguous situations in which there is no dedicated handling procedure, so that ATCOs might be unsure about what to do: each individual response might be different, and even diverge from the simplified execution expected at the blunt end. This section aims to present SECA results, instantiated at three different resolution levels: macro, meso, micro.

At a macro level, main themes can be quickly identified. For example, after sampling the data for two units (Alpha and Bravo), the semantic frequency suggests Unit Alpha to be more concerned with Traffic-related issues, while Unit Bravo focusing more on Training aspects.

This analysis can be further extended encompassing more granular coding. See for example the meso-level of analysis where each theme is decomposed into its related sub-themes. Focusing on Traffic, high frequency refers to situations with limited volume, or special and additional traffic scenarios, along several more typical settings (IFR, VFR, civil, military, etc.). The high frequency of traffic is expected to define the context of all SECA interviews, being it a central element for any ATM operation.

Moving to more detailed analyses allows identifying specific weak signals. About Traffic, for example, evidence on vectoring and direct route management has been retrieved: especially in case of directs, ATCOs are expected to document them in the daily log. Unfortunately, a common topic from SECA interviews proved that in some units, ATCOs could not report it easily since some directs were unknown to the system. In one case, a SECA interviewee sat next to another ATCO, who experienced the reported situation, suggesting writing an entry into the daily log to get the entry added to their system for future use. They refused to do so, as there is no reported obligation. In the end, the interviewee decided to document the direct themselves.

This observation of a non-event motivated further reflections based on the other dimensions of SECA: What does prevent ATCOs from communicating directs? Why did they not want to do it? Is there an easier way for adding missing directs, or does the system require too much effort in comparison with the perceived importance of the documentation? Is it a signal of additional pressure in such unit only, or is it common practice in any unit, even if not appearing in SECA?

In other words, the identified situation becomes a weak signal for other additional unwanted events. While this event might lead to subsequent potential safety concerns, it is also related to productivity issues for ensuring a smoother management of directs.

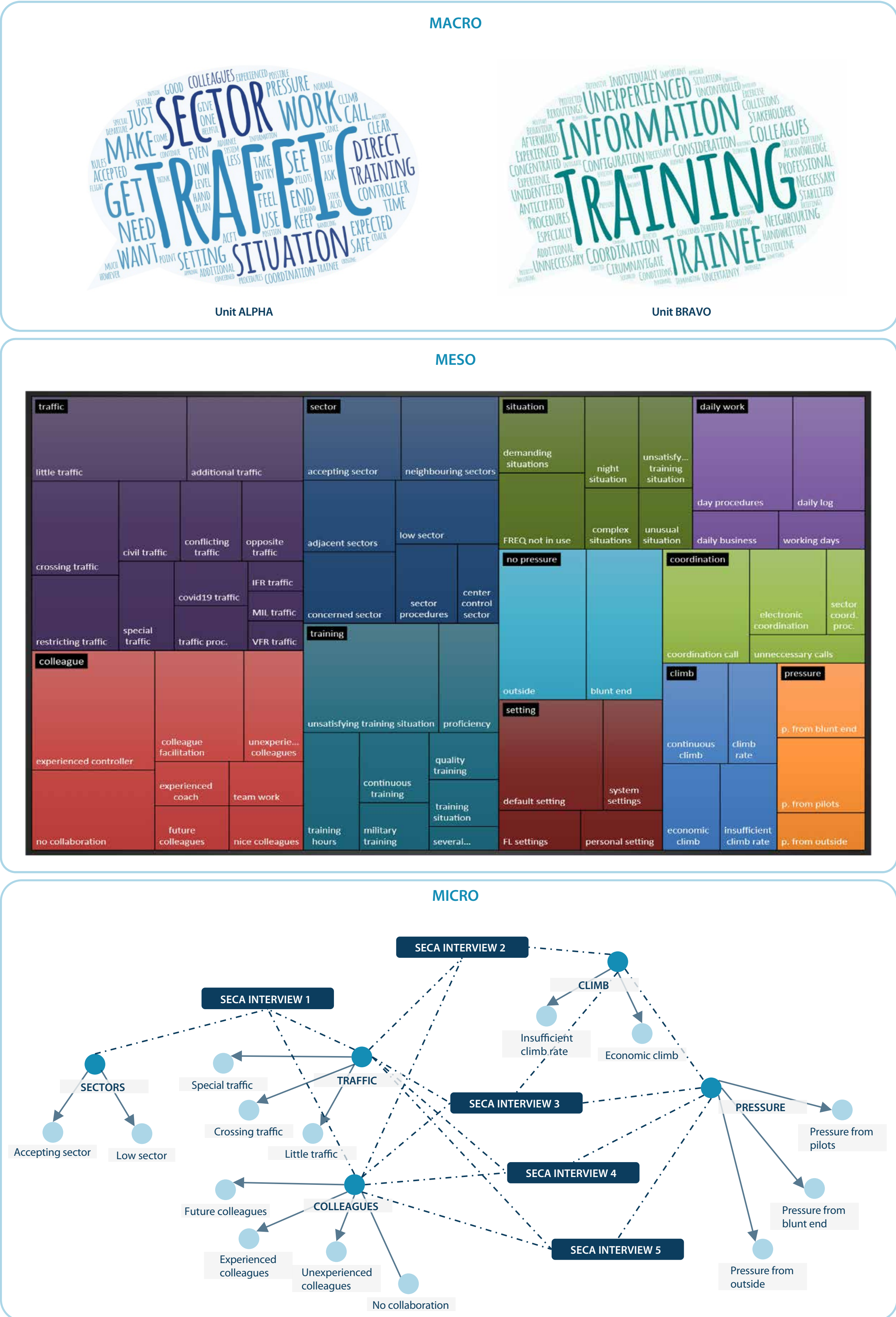
I work as an air traffic controller and a member of our local safety panel which focuses on enforcing proactive measures to maintain and increase our high safety standards.

Supporting the development of SECA and interviewing a few colleagues has had a great impact on how I understand the work of air traffic controllers. SECA helps making hidden knowledge visible, i.e., the trade-offs between safety and service, safety and workload, pressure from outside and within and so on. A lot of these trade-offs need to be actioned daily and almost automatically and are an inherent part of air traffic controllers' job. It is difficult but important to understand "work as imagined" and "work as done", and SECA has helped us in detecting such differences, embracing a different view than the one of incident investigation. SECA helped us focusing on pressures on the operator and the necessary trade-offs to solve the situation.

Most of the interviewees found it helpful to consciously think about their daily activity and having the opportunity to disclose pressures and trade-offs that are part of their daily work. It helps them to feel more confident about certain decisions but also to pinpoint weaknesses in procedures and work routines to contribute to organizational safety.

ATCO acting as a SECA interviewer

Figure 8. Three levels of SECA analysis, ranging from macro, meso, micro (simplified).



WAY FORWARD

A little knowledge that acts is worth more than much knowledge that is idle

Kahil Gibran

Many years of work on weak signals resulted in the theoretical formulation of complex working environments, and in the acknowledgement on the need of systemic approaches to transfer such theories into practicable applications (Hollnagel et al., 2021; Woods et al., 2021). With the completion of the second Weak Signals project, different methods were developed, used, and tested to allow a full understanding of work and operational success. Among them, SECA is a support tool to facilitate knowledge exploration starting from narratives on normal work at the sharp-end.

Scaled implementation

Following the prototypal SECA implementation in two major ANSPs, it is expected a workload for the SECA Interviewers of about 1-1.5 hour per interview, including the time to run the actual verbal interaction and to provide the data in a predetermined template. For example, interviewers running 3 interviews per month, would have an estimated workload of 4 hours/month. A learning curve is expected to speed up the process, also considering IT resources which could smooth the elicitation and analysis phases.

The three SECA roles identified so far (Interviewee, Interviewers, Masters) may become hard to manage for larger ANSPs, or even for larger-scale implementation in smaller ANSPs.

From the mentioned proof-of-concept in two different ANSPs, it has been recognized that SECA roles should not be static; accumulated experience with SECA encourages its scalability. It is expected that some SECA Interviewers might become progressively more experienced and aware of the strengths and weaknesses of the tool. As such, they might be promoted to a new role to oversee other interviewers and lessen the efforts of the SECA Masters, who could in turn concentrate only on the analysis of larger data samples. Accordingly, a fourth category of users could be addressed as SECA Champions, i.e., the most experienced SECA Interviewers, who have already conducted a few dozens of interviews. They recruit and train SECA Interviewers, coordinate them, collect criticalities on the tool and interact with the SECA Masters.

Incrementally speaking, selected SECA Champions may in turn become SECA Masters when they acquire enough confidence on queries development and data analyses techniques, as well as receive training on interpreting results. Similarly, selected SECA Interviewees may become SECA Interviewers at some stage. The entire implementation flow relies on delocalized training: early SECA adopters may train newcomers based on the feedback received and the experience gained during the proof-of-concept implementation (Figure 9).

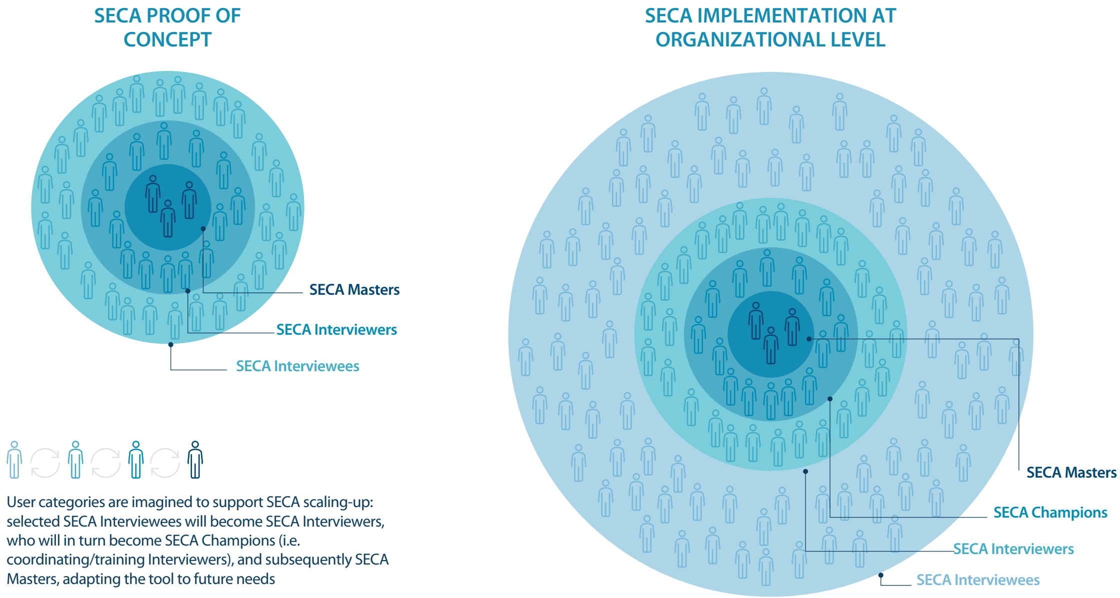
Analysts should not be discouraged by the increasing data size which could prevent from systematic analysis of narratives with traditional means. The development of natural language processing (NLP) tools offers sustainable solutions for large text management and semi-automatic analytics (Collobert et al., 2011; Devlin et al., 2019). Similarly, digital platforms for editing, sharing, and commenting documents as well as running business intelligence are widespread. To this regard, the Weak Signal project team has tested the possibility to have interviews recorded and automatically transcribed for further analyses.

Initially, we had a hard time figuring out how to do the interviews in the beginning of the project. During the project meetings, we understood more about an interview setup, and the need for questions to be specific. Later in the project, we started learning more about pragmatical aspects of patterns, and how to make extract knowledge from interviews.

From the beginning of the project and to the point where it is today, we feel much more confident that it is possible to find patterns in daily work; patterns that might lead to an occurrence if not dealt with proactively. We would also say that the results of SECA show that the best outcome will be when you have many interviews from similar sectors or workplaces. These resources are needed to move from reactive to the latest stage of proactive safety management.

ATCOs acting as SECA Interviewers

Figure 9. Key roles and scalability of SECA.



SECA for wider goal conflicts management

The identification of a weak signal via SECA is meant to provide *stimuli* for deeper investigations of organizational performance at large. Accordingly, the interpretative results of SECA require a scope enlargement, via functionalist approaches. A continuous iterative performance management profile is expected to integrate SECA results (Figure 10, phase 1) with two additional stages:

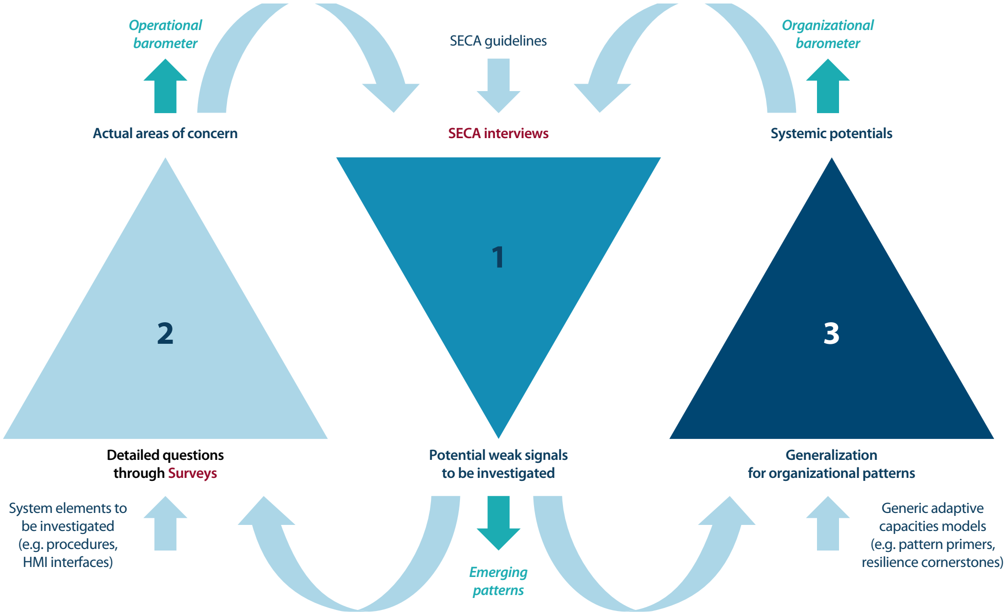
- The identified emerging patterns need to be checked in larger organizational contexts, to make emerge more detailed information from other respondents. This action can be conducted via surveys to be ran via more or less sophisticated apps (e.g., using the case described above: "Did it ever happened to you to deal with a missing direct?", "Is it a common practice to have missing directs?").

  The results of the survey are actual areas of concerns about normal work (see Figure 10, phase 2), obtained from an investigation that is disconnected from usual reporting and which is focusing on actual performance variability. This action results into developing an operational barometer for *ad hoc* concerns.

- Both the weak signals obtained through SECA, and the operational barometer are bottom-up and interpretative by nature. Nonetheless, these signals can be seen as specific instantiation of more general patterns (e.g.), reciprocity, initiative, trade-offs, workload (Woods et al., 2021). An iterative activity spanning through pattern finding and priming may thus be beneficial. If on one hand, the previously mentioned operational barometer is meant to focus on operational details for a detailed adaptation emerged into practice, the organizational barometer is meant to identify different adaptive practices which recall adaptive mechanisms like the ones already identified (see Figure 10, phase 3). In our example, the priming would be to identify (e.g.) other workload-based patterns related to missing information, or similar bottlenecks (Woods, 2019; Woods and Branlat, 2011).

Figure 10 synthesizes the whole iterative knowledge management cycle for learning from normal operations.

Figure 10. SECA at organizational level.



Towards a cultural mindset

The trigger of a failure investigation is straightforward. The same does not apply to investigations of normal work and to explorations of complex adaptations: *When can an action be interpreted as adaptive? What are the nuances that matter? What are the aspects of normal work that are not so normal?*

The relevance for acquiring weak signals exceeds the scope of heroic recoveries and focuses more on what could be seen as everyday unremarkable practices. Operators should be encouraged to critically reflect on their routines to answer these interrogatives. They should be invited to discuss their adaptive practices, and the ways they favoured success in a non-deterministic world.

To this scope, SECA is a means, not the result. It is part of a process to de-bureaucratize safety management, to disconnect compliance from actual practices and achieve fruitful understanding of system performance. Implementing SECA is indeed a way forward to drive operators talking about their work, to encourage managers having conversation with their people, to have discussions about practices rather than bureaucratized risks.

This cultural shift takes more than the implementation of a tool and the respective technicalities. It demands for humility and openness to the reasons people have for not following a particular procedure, to deal with a process differently, to revise actual working practices. It demands for courage to reverse a long-established bureaucratized safety perspective (Dekker, 2018).

I am the Safety Manager at an Area Control Center (ACC). We are always trying to improve our safety knowledge and the detection of weak signals is a way to transform retrospective safety management towards a proactive perspective. This is a challenge, as the information which gets to the safety management is in most cases fragmented and disconnected from other information and collected in an unstructured way. This could be a canteen talk between colleagues over lunch or ATCOs reporting their stories via mail, or just drop into our office to talk about certain situations. Another weakness is that many aspects in this information which might be interesting and reflect "work as done" never find their way to colleagues and management who live in a "work-as- imagined" world. The questions are: how can we collect stories from real life in a structured way and how can we extract meaning and connect this data to identify patterns?

SECA helped us providing the logic to connect weak signals without losing the individual story. In its early adoption stage, its application required some time to fully understand the scope and the way to conduct interviews, but it went significantly easier when we start practising. The SECA aspects and analysis opened our mind for understanding daily operations and communicate them across our organization. It really became a practical tool to get more into systems thinking. And even most importantly: You do not have to wait until something goes wrong. It is possible to collect daily work, make situations and background processes transparent that make work successful, and explore adaptive practices, otherwise remaining opaque.

Safety Manager acting as a SECA Interviewer

CONCLUSION

A vision without a plan is just a dream. A plan without a vision is just drudgery.
But a vision with a plan can change the world.

Old proverb

The safest ship is the one that never leaves the harbour, the safest flight is the aircraft that does not takes off. Socio-technical systems are affected by intrinsic risks and hazards that must be incurred to achieve the functional purposes systems are designed for. In ultra-safe systems, spectacular failures are just seldom preceded by the factors that get reported (Amalberti, 2001). Most of the time innocuous variability, pressures, and conflicting goals exist in time and space well behind from the immediacy of a reported failure.

Traditional mechanisms for incident reporting and analysis share a great difficulty to pick up the subtle signs of a drift, the weak signals that expose a system to failures (Dekker 2014). The consequent disenchantment with linear cause-effect explanations due to new non-recurring types of accidents motivates investments on studying complex adaptations, as they are put in practice in everyday work (Provan et al., 2020). Narratives of normal operations become thus an efficient knowledge elicitation support. They do not structure work as a mechanistic execution of predetermined actions; they rather envisage a recontextualization of adaptive practices, fostering the exploration of how stories may move off in a direction not previously conceived from an individual perspective (Tsoukas and Hatch, 2001).

Originated from Resilience Engineering and the SECI model, this White Paper suggests SECA as a technique to understand and elicit knowledge – otherwise inert – on complex adaptations performed at the sharp-end. At certain granularity, all events are unique; at more abstract levels, they may reveal common patterns. SECA is not about finding the root cause of an event. It is about understanding non-events; explicating the nuances of real-world operations as seen from the eyes of those who are doing the job; collecting bookends on which the second stories experienced at the sharp-end can be told.

Nonetheless, SECA is not an on-the-shelf approach, still requiring a supportive organizational mindset and a solid training, avoiding trivialization and unnecessary safety bureaucratization.

During the Weak Signals projects led by EUROCONTROL, it has become clear how for High Resilient Organizations focus should span on the entire value chain: safety management is not just about safety, but it involves aspects of capacity, training, operational staff, automation, and digitalization, among others. Achieving safety is more about system management than safety management in isolation. This transformation is important to lead organizations out of pre-established data silos and to prepare them for future challenges, especially referred to automation. Knowledge of normal operations, adjustments and trade-offs must be made available to develop and implement different automation solutions successfully. Otherwise, the gap between operator and automation will widen and the hoped-for benefit will never be achieved. Cross-disciplinary cooperation is needed between different disciplines. This requires resources and time.

In summary, this White Paper promotes a disconnection between the outcomes of a decision and the hindsight judgments about its correctness. It suggests supplementing/complementing retrospective critiques and acknowledge the intrinsically complex nature of systems in which practitioners act. It favours rejecting a trivialization of real situations and of the continuous dilemmas that characterize normal operations. It empowers operators' knowledge and expertise to create safer, more efficient, and more workable distributed cognitive system. It enables analysts to access and use data on performance variability, fostering organisational resilience and intelligence capacities.

SECA is not about finding the root cause of an event. It is about understanding non-events; explicating the nuances of real-world operations as seen from the eyes of those who are doing the job; collecting bookends on which the second stories experienced at the sharp-end can be told.

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APPENDIX 1. EXEMPLARY SECA QUESTIONS

The dimensions of SECA (i.e., Context, Responses, Pressures, Conflicts) can be explored during an interview through questions similar to the ones suggested in this table.

Code	Dimension	Element	Exemplary questions
1	Context	Description of the situation	*Tell me something you experienced that stood out to you or something from your everyday work that you or someone from the outside would find remarkable.*
2a	Responses	Personal response	*How did you act in the situation and managed it? What actions did you put in place?*
2b	Responses	Procedures (written rules)	*How would you have acted strictly following the procedures?*
2c	Responses	Units' normal way of working	*How does most of your unit normally act in such a situation?*
2d	Responses	Less experienced colleagues' response	*How would someone new to your unit act in such a situation?*
2e	Responses	Experienced colleagues' response	*How would someone who works in your unit for a long-time act in such a situation?*
3a	Pressures	Pressures from Management in the organization (blunt end)	*Was there any pressure or expectations from your management that could or did influence the situation?*
3b	Pressures	Pressures from the outside the unit (work related environment)	*Was there any pressure or expectations from the outside (airport, pilot, regulator, etc.) management that could or did influence the situation?*
3c	Pressures	Pressures from colleagues	*Was there any pressure or expectations from your colleagues that could or did influence the situation?*
4a	Conflicts	Goal conflicts	*Which goals did you have to balance between?*
4b	Conflicts	Trade-offs	*How did you in the end decide on what to actually do in the situation?*

APPENDIX 2. INTERVIEW BEST PRACTICES WITHIN SECA

A key aspect for SECA is being non-judgmental, authentic, and trust-worthy during any interview. Asking follow-up questions and probing, when needed, for greater depth and detail proves interest and facilitates an open dialogue, at least as much as smooth transitions between SECA dimensions and interview elements. Based on the evidence from literature (Patton, 2014), some best practices can be identified as follows.

Interview principle	Example
Ask open-ended questions. SECA questions should invite a thoughtful and in-depth response to ensure a representative Externalization of tacit knowledge	*What is an event that you recall as critical or relevant, but where no reporting should be mandatory?* Rather than: *Were you involved in any incident in your career?*
Be clear. Questions should be clear, focused, understandable and answerable by the operators.	*Who was giving you this pressure?* Rather than: *What was important that you'll remember and can use and that made it even more important at least as you think about it now?*
Listen. Responses should be attended carefully, letting the interviewees knowing that they have been heard (i.e., their Externalization efforts matters).	*That's very helpful. You've shared a clear description that made me understand the context and the pressure in actions.*
Probe as appropriate. When appropriate, follow-up should be suggested to give the interviewee a complete understanding of what is needed and expected.	*It would be helpful to hear more about that. Tell me more about what happened afterwards and how the pilot reacted.*
Observe. Watch the interviewees to guide the interactive process and adapt to fit the reactions of the interviewees themselves.	*I can see that this question could be very specific. Take your time, or if you like, we can come back to this later.* Note that this aspect should be adjusted in case of remote digital interviews (usually not recommended).
Be both empathic and neutral. Interest should be shown, offering non-judgmental encouragement. This will facilitate the Externalization and in turn the Combination process.	*I appreciate your willingness to provide this narrative. Every event is unique, and we have heard dozens of stories. There is no right or wrong answer to any of these questions. What matter is to explore the context and actions you provided from which we can all learn something.*
Make transitions. The interviewee should be guided through the interview process.	*You have been describing how you were pressured from management. I would also like to know if you were subjected to any other questions, for example from pilots? Or from airport operators?*
Distinguish types of questions. The interviewer should make explicit distinction between questions purely descriptive and questions about interpretations and judgments	*Descriptive behaviour question: what did it happen during that day? Was there any relevant weather?* *Interpretative opinion question: How would a less experienced colleague react to the same traffic situation, in your opinion?*
Manage the unexpected. During an interview, external events may affect the way the interview can be conducted in practice. Therefore, the interviewer requires flexibility and responsiveness.	*Despite a commitment to a one-hour interview, maybe giving the possibility to explore multiple stories, only a half-hour may be available. Make the most of it.*
Be present throughout. Interviewees can understand if an interviewer is distracted, inattentive or uninterested.	*Checking the time regularly, glancing at your text messages, looking around instead of staying engaged with the person talking, these things are noticed by the interviewee. So, take simple notes, which you will refine later in the SECA template.*

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ACKNOWLEDGMENTS

A project of this kind, which extends over several years and involves the development of initially theoretical approaches, their communication and implementation in practical applications through suitable methods and tools, needs a lot of staying power. On this path, we have continuously and committedly Diana Alexandra Stefan, Sebastian Däunert, Thomas "Snoopy" Jäckel and Christoph Peters. They deserve our special thanks.

NOTES

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