



**Network Manager**  
nominated by  
the European Commission



# Systems Thinking for Safety: Ten Principles A White Paper **Moving towards Safety-II**

**DNM Safety**



FIELD EXPERT INVOLVEMENT  
LOCAL RATIONALITY  
JUST CULTURE  
DEMAND & PRESSURE  
RESOURCES & CONSTRAINTS  
INTERACTIONS & FLOWS  
TRADE-OFFS  
PERFORMANCE VARIABILITY  
EMERGENCE  
EQUIVALENCE

# FOREWORD

In our industry, staff of all kinds constantly have to make decisions and trade-offs. For operational staff, safety is at the core of their work but at the same time the demands and pressure of the operational situation mean that there are conflicting options and decisions have to be made rapidly.

Thus, the 'safety management system' as we know it, with all its refinements, is not easy to grasp for a front-line person such as a controller or technician. On the front line, it may seem like safety management is "nothing to do with me". Safety is part of the work and is woven into the job. At the same time, they 'manage' safety – as well as efficiency – on a minute by minute basis.

So, safety versus efficiency – are we in a quandary? Not at all, I would say. If traffic levels and thus capacity issues could impinge on safety, improvement in safety is a prerequisite for any future capacity increase. The focus is not one or the other. The focus is on system effectiveness. This means doing the right things, and doing them right.

For that a new approach is needed. It is essential that we explore the gaps between the 'work-as-imagined' in the formal rules, regulations, SMS, etc, and the 'work-

as-done' in the operational world. Safety management must 'speak' to front-line actors, and promote and ensure the resilience of the system. There must be a continuous dialogue about how the system really works.

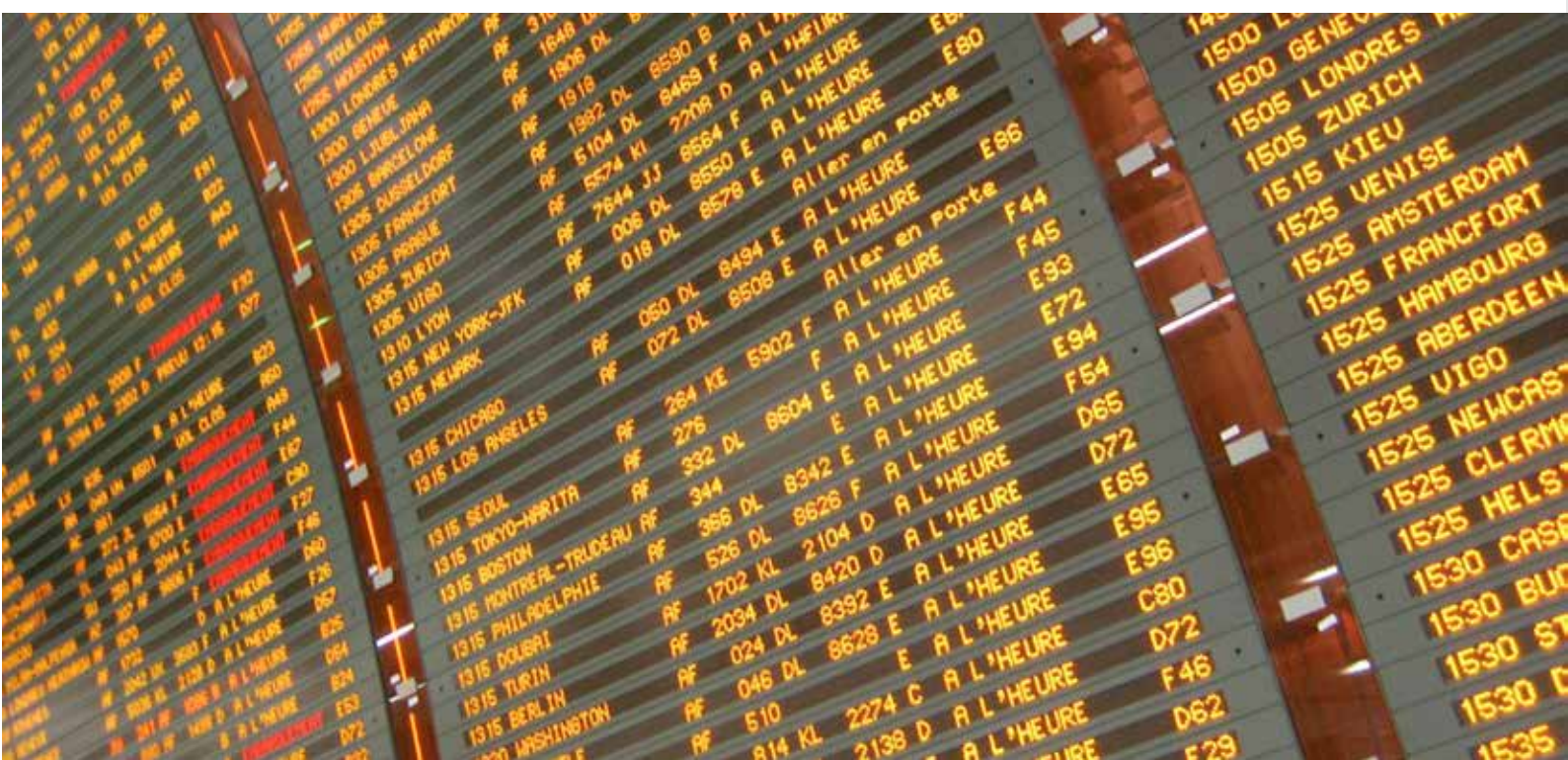
In order to have this dialogue, the message has to be clear and balanced. To meet demand and to balance conflicting goals in a complex and dynamic situation, staff need to make trade-offs and adapt to the situation. Performance will vary; it must vary to cope with varying demands and conditions. We still have to draw clear lines between what is and what is not acceptable, but a rigid regulatory environment destroys the capacity to adapt constantly to the environment. To understand the system, we need to see it from the perspectives of the people who are part of the system.

Like front-line staff, we must all adapt to the changing world and to new ways of thinking. I recommend this EUROCONTROL Network Manager White Paper to you and your colleagues to help make sense of how our systems really work.

**Jean-Marc Flon**

Chef du Service Exploitation

SNA-RP Paris Charles De Gaulle, DSNA, France





# EXECUTIVE SUMMARY

To understand and improve the way that organisations work, we must think in systems. This means considering the interactions between the parts of the system (human, social, technical, information, political, economic and organisational) in light of system goals. There are concepts, theories and methods to help do this, but they are often not used in practice. We therefore continue to rely on outdated ways of thinking in our attempts to understand and influence how sociotechnical systems work. This White Paper distills some useful concepts as principles to encourage a ‘systems thinking’ approach to help make sense of – and improve – system performance. It is hoped that these will give new ways of thinking about systems, work and safety, and help to translate theory into practice.

Principles 1, 2 and 3 relate to the view of people within systems – our view from the outside and their view from the inside. To understand and design systems, we need to understand work-as-done. This requires the involvement of those who do the work in question – the field experts. (**Principle 1. Involvement of Field Experts**). It follows that our understanding of work-as-done – past, present and future – must assimilate the multiple perspectives of those who do the work. This includes their goals, knowledge, understanding of the situation and focus of attention situated at the time of performance (**Principle 2. Local Rationality**). We must also assume that people set out to do their best – they act with good intent. Organisations and individuals must therefore adopt a mindset of openness, trust and fairness (**Principle 3. Just Culture**).

Principles 4 and 5 relate to the system conditions and context that affect work. Understanding demand is critical to understanding system performance. Changes in demands and pressure relating to efficiency and capacity, from inside or outside the organisation, have a fundamental effect on performance. (**Principle 4. Demand and Pressure**). This has implications for the utilisation of resources (e.g. staffing, competency, equipment) and constraints (e.g. rules and regulations) (**Principle 5. Resources and Constraints**), which can increase or restrict the ability to meet demand.

Principles 6, 7 and 8 concern the nature of system behaviour. When we look back at work, we tend to see discrete activities or events, and we consider these independently. But work-as-done progresses in a flow of interrelated and interacting activities (**Principle 6. Interactions and Flows**). Interactions (e.g. between people, equipment, procedures) and the flow of work through the system are key to the design and management of systems. The context of work requires that people make trade-offs to resolve goal conflicts and cope with complexity and uncertainty (**Principle 7. Trade-offs**). Finally, continual adjustments are necessary to cope with variability in system conditions. Performance of the same task or activity will and must vary. Understanding the nature and sources of variability is vital to understanding system performance (**Principle 8. Performance Variability**).

Principles 9 and 10 also relate to system behaviour, in the context of system outcomes. In complex systems, outcomes are often emergent and not simply a result of the performance of individual system components (**Principle 9. Emergence**). Hence, system behaviour is hard to understand and often not as expected. Finally, success and failure are equivalent in the sense that they come from the same source – everyday work, and performance variability in particular (**Principle 10. Equivalence**). We must therefore focus our attention on work-as-done and the system-as-found.

Each principle is explained briefly in this White Paper, along with ‘views from the field’ from front-line operational staff, senior managers and safety practitioners. While we are particularly interested in safety (ensuring that things go right), the principles apply to all system goals, relating to both performance and wellbeing. It is expected that the principles will be relevant to anyone who contributes to, or benefits from, the performance of a system: front-line staff and service users; managers and supervisors; CEOs and company directors; specialist and support staff. All have a need to understand and improve organisations and related systems.

# THE FOUNDATION: SYSTEM FOCUS

Safety must be considered in the context of the overall system, not isolated individuals, parts, events or outcomes

**Most problems and most possibilities for improvement belong to the system. Seek to understand the system holistically, and consider interactions between elements of the system**

When one spends any time in an organisation, it is clear that nothing works in isolation. Rather, things work within connected and interacting systems. In a tower and approach unit, for instance, controllers, assistants, engineers, supervisors, managers, and support staff routinely interact with each other and with others such as pilots, drivers and airport staff. People interact with various types of equipment, with much information, and with many procedures. The same applies in an area control operations room, in an equipment room, in an administrative centre, or in a boardroom. In a system, everything is connected to something; nothing is completely independent.

These connections and interactions, along with a purpose, characterise a system. More formally, a system can be described as *"a set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors, often classified as its 'function' or 'purpose'"* (Meadows, 2009, p. 188). In service organisations, this purpose must be understood from the customer's viewpoint. This means that the customer and their needs must be understood. System performance can then be evaluated against achievement of purpose.

In practice, what constitutes a system is relative, because the boundaries of systems are not fixed and are often unclear; essentially, they are where we choose to draw them for a purpose (e.g. safety investigation, system assessment, design), and people and information cross system boundaries. There are, therefore, multiple perspectives on a system and its boundary, and sometimes its purpose. In a sense, a 'system' is a social construct defined by what it does, not a thing 'out there' that is defined by what it is.

We might think about systems at various levels. Operationally, we may consider the working position or sector. At a higher level we may consider an Ops room, a centre, an organisation, airspace or the aviation

system. Systems exist within other systems, and exist within and across organisational boundaries.

While some system components are more visible, others are less visible to the observer. Less visible parts of the system include organisational elements (such as goals, rosters, incentives, rules), and political and economic elements (such as pressures relating to runway occupancy, noise abatement, and performance targets). Again, these interact to form a complex whole.

Despite these interactions, the way that we try to understand and manage sociotechnical system performance is often on a component level (a person, a piece of equipment, a unit, a department, etc). A focus on component performance is common in many standard organisational practices. At an individual level, it includes incident investigations that focus only on the controller's performance, behavioural safety schemes that observe individual compliance with rules, individual performance reviews, incentive schemes, etc. The assumption is that if the person would try harder, pay closer attention, do exactly what was prescribed, then things would go well. However, as the management thinker W. Edwards Deming observed, *"It is a mistake to assume that if everybody does his job, it will be all right. The whole system may be in trouble"*. Organisational theorist Russel Ackoff added that *"it is possible to improve the performance of each part or aspect of a system taken separately and simultaneously reduce the performance of the whole"* (1999, p. 36). A focus on components becomes less effective with increasing system complexity and interactivity.

The term 'complex system' is often used in aviation (and other industries), and it is important to consider what is meant by this. According to Snowden and Boone (2007), complex systems involve large numbers of interacting elements and are typically highly dynamic and constantly changing with changes in conditions. Their cause-effect relations are non-linear; small changes

can produce disproportionately large effects. Effects usually have multiple causes, though causes may not be traceable and are socially constructed. In a complex system, the whole is greater than the sum of its parts and system behaviour emerges from a collection of circumstances and interactions. Complex systems also have a history and have evolved irreversibly over time with the environment. They may appear to be ordered and tractable when looking back with hindsight. In fact, they are increasingly unordered and intractable. It is therefore difficult or impossible to decompose complex systems objectively, to predict exactly how they will work with confidence, or to prescribe what should be done in detail.

This state of affairs differs from, say, an aircraft engine, which we might describe as 'complex' but is actually ordered, decomposable and predictable (with specialist knowledge). Some therefore term such systems 'complicated' instead of complex (though the distinction is not straightforward).

While machines are deterministic systems, organisations and their various units are purposeful 'sociotechnical systems'. Yet we often treat organisations as if they were complicated machines, for instance by:

- assuming fixed and universal goals;
- analysing components using reductionist methods;
- identifying 'root causes' of problems or events;
- thinking in a linear and short-term way;
- judging against arbitrary standards, performance targets, and league-tables;
- managing by numbers and outcome data; and
- making changes at the component level.

As well as treating organisations like complicated machines, we also tend to lose sight of the fact that our world is changing at great speed, and accelerating. This means that the way that we have responded to date will become less effective. Ackoff noted that *"Because of the increasing interconnectedness and interdependence of individuals, groups, organizations, institutions and societies brought about by changes in communication and transportation, our environments have become*

*larger, more complex and less predictable – in short, more turbulent"* (1999, p. 4). We must therefore find ways to understand and adapt to the changing environment.

Treating a complex sociotechnical system as if it were a complicated machine, and ignoring the rapidly changing world, can distort the system in several ways. First, it focuses attention on the performance of components (staff, departments, etc), and not the performance of the system as a whole. We tend to settle for fragmented data that are easy to collect. Second, a mechanical perspective encourages internal competition, gaming, and blaming. Purposeful components (e.g. departments) compete against other components, 'game the system' and compete against the common purpose. When things go wrong, people retreat into their roles, and components (usually individuals) are blamed. Third, as a consequence, this perspective takes the focus away from the customers/ service-users and their needs, which can only be addressed by an end-to-end focus. Fourth, it makes the system more unstable, requiring larger adjustments and reactions to unwanted events rather than continual adjustments to developments.

A systems viewpoint means seeing the system as a purposeful whole – as holistic, and not simply as a collection of parts. We try to *"optimise (or at least satisfice) the interactions involved with the integration of human, technical, information, social, political, economic and organisational components"* (Wilson, 2014, p. 8). Improving system performance – both safety and productivity – therefore means acting on the system, as opposed to 'managing the people' (see Seddon, 2005).

With a systems approach, different stakeholder roles need to be considered. Dul et al (2012) identified four main groups of stakeholders who contribute or deliver resources to the system and who benefit from it: system actors (employees and service users), system designers, system decision makers, and system influencers. These four groups are the intended readers of this White Paper. As design and management becomes more inclusive and participatory, roles change and people

span different roles. Managers, for instance, become system designers who create the right conditions for system performance to be as effective as possible.

The ten principles give a summary of some of the key tenets and applications of systems thinking for safety that have been found useful to support practice. The principles are, however, *integrative*, derived from emerging themes in the systems thinking, systems ergonomics, resilience engineering, social science and safety literature. The principles concern system effectiveness, but are written in the context of safety to help *move toward* Safety-II (see EUROCONTROL, 2013; Hollnagel 2014). Safety-II aims to 'ensure that as many things as possible go right', with a focus on all outcomes (not just accidents). It takes a proactive approach to safety management, continuously anticipating developments and events. It views the human as a resource necessary for system flexibility and resilience. Such a shift is necessary in the longer term, but there is

a transition, and different perspectives and paradigms are needed for different purposes (see Meadows, 2009).

Each principle is described along with some practical advice for various types of safety-related activities. 'Views from the field' are included from stakeholders – front-line to CEO – to give texture to the principles from different perspectives. There are some longer narratives to give an impression of how safety specialists have tried to apply some of the principles in their work. Since the principles interrelate and interact, we have tried to describe some interactions, but these will depend on the situation and we encourage you to explore them.

Ultimately, the principles are intended to help bring about a change in thinking about work, systems and safety. They do not comprise a method, but many systems methods exist, and these can be selected and used depending on your purpose. Additional reading is indicated to gain a fuller understanding.





**“In a system, everything is connected to something;  
nothing is completely independent.”**



## Practical advice

- **Identify the stakeholders.** Identify who contributes or delivers resources to the system and who benefits, i.e. system actors (including staff and service users), system designers, system decision makers, system influencers.
- **Consider system purposes.** Consider the common or superordinate purpose(s) that defines the system as a whole, considering customer needs. Study how parts of the system contribute to this purpose, including any conflicts or tension between parts of the system, or with the superordinate system purpose(s).
- **Explore the system and its boundary.** Model the system, its interactions and an agreed boundary, for the purpose, question or problem in mind (concerning investigation, assessment, design, etc.). Continually adapt this as you get data, exploring the differences between the system-as-imagined and the system-as-found.
- **Study system behaviour and system conditions.** Consider how changes to one part of the system affect other parts. Bear in mind that decisions meant to improve one aspect can make system performance worse.

## View from the field

**F/O Juan Carlos Lozano**

Chairman, Accident Analysis & Prevention Committee

International Federation of Air Line Pilots' Associations (IFALPA)

*“Flying a commercial aircraft at 35,000 feet might be perceived as working in a very expensive bubble. But bubbles are fragile. The aviation system cannot afford to be fragile. Aviation is a system that learns from experience, adapts and improves. Some think that improvements only come from technology. But it is people who make the system more resilient. Information sharing is good, but it is not enough. Knowledge and understanding are key. In the same way that pilots, controllers and technicians need to understand the technology that they work with, aviation professionals – including managers, specialists, support staff, researchers and authorities – must constantly seek to understand how the system works. With an understanding of the interactions between elements of the aviation system, we can make it more effective, enhancing safety and efficiency. The principles that follow in this White Paper can only help in this endeavour.”*

# PRINCIPLE 1. FIELD EXPERT INVOLVEMENT

The people who do the work are the specialists in their work and are critical for system improvement

**To understand work-as-done and improve how things really work, involve those who do the work**

To understand system behaviour, the most fundamental requirement is the involvement of the people who are part of the system. This first principle acknowledges that those who actually do the work are specialists in their work and a vital partner in improving the system. We refer to these people as 'field experts' to emphasise that they possess expertise of interest if we are to understand work-as-done. We need to understand people as part of the system, and understand the system with the people. So people are not simply subjects of study or targets of interventions, but rather partners in all aspects of improving the work. Seddon (2005) summarises: *"The systems approach employs the ingenuity of workers in managing and improving the system. It is intelligent use of intelligent people; it is adaptability designed in, enabling the organisation to respond effectively to customer demands."* Everyone therefore has two jobs: 1) to serve the customer and 2) to improve the work.

'Field experts' is meant as an inclusive term to consider people relative to their own work. Procedure writers, airspace designers, trainers, engineers, safety specialists, unit managers, regulation specialists, legal specialists, etc, are also specialists in *their* work, and need to be involved when trying to understand and improve the system. But they are not necessarily specialists in the work of front-line operational staff. What all need is a working understanding of the system, including the end-to-end flow of work.

In safety management and design activities, the involvement of front-line field experts varies widely. Experience suggests that, in conventional safety investigation for instance, there are several levels of involvement of relevant operational staff. The first is in raising the issue. There is almost universal involvement of field experts at this level because of mandatory reporting processes. In practice, the involvement sometimes stops here. The second level is the explanation of the event, for instance via interviews, discussions,

and commentary on replays and recordings. The third level is in analysis and synthesis, both for the specific event and for the work more generally. The fourth level is in safety improvement, where recommendations and improvements are proposed. As these levels progress, the involvement of operational field experts seems to decrease. But without such involvement, the validity and usefulness of data gathering, analysis, synthesis, and improvement will be limited.

A further level is learning. This comprises both formal and informal activities. Following an occurrence, operational and other field experts will learn through informal conversations and stories. There may also be more formal lesson-learning activity. But relevant field experts (which may include system actors, designers, influencers and decision makers), can most usefully be involved in learning about the *system*, perhaps using an event as an opportunity to get a better understanding of ordinary work and system behaviour (Principle 10).

For other activities that concern work (e.g. safety risk assessment, procedure writing, rostering, organisational change, technology design), the involvement of the right field experts helps to understand and reduce the tension and the gap between work-as-imagined (in documentation and the minds of others) and work-as-done (what really happens).

The perspectives of field experts need to be synthesised via the closer integration of relevant system actors, system designers, system influencers and system decision makers, depending on the purpose. The demands of work and various barriers (organisational, physical, social, personal) can seem to prevent such integration. But to understand work-as-done and to improve the system, it is necessary to break traditional boundaries.





**“We need to understand people as part of the system,  
and understand the system with the people.”**

### Practical advice

- **Enable access and interaction.** Managers, safety specialists, designers, engineers, etc., often have inadequate access and exposure to operational field experts and operational environments. To understand and improve work, ensure mutual access and interaction.
- **Consider the information flow.** Field experts of all kinds (including system actors, designers, influencers and decision makers), need effective ways to raise issues of concern, including problems and opportunities for improvement, and need feedback on these issues.
- **Field experts as co-investigators and co-researchers.** Field experts should be active participants – co-investigators and co-researchers – in investigation and measurement, e.g. via interviews, observation and discussions, data analysis, and synthesis, reconstruction and sense-making.
- **Field experts as co-designers and co-decision-makers.** Field experts need to be empowered as co-designers and co-decision-makers to help the organisation improve.
- **Field experts as co-learners.** All relevant field experts need to be involved in learning about the system.

### View from the field

**Yves Ghinet**

Air Traffic Control Specialist & Psychologist  
Belgocontrol, Belgium

*“Prescribed working methods and procedures never take account of all situations, and with time passing and the changing context, they can become obsolete. It is a jungle out there and local actors must adapt in order to make the system work. They know the traps and the tricks to find a way through. Without them you are lost; they are the only scouts able to guide you in their world. So go to them, humbly, because they are the experts and you are only trying to understand what’s going on. Observation and discussion are key to understanding the way people work.”*

## PRINCIPLE 2. LOCAL RATIONALITY

People do things that make sense to them given their goals, understanding of the situation and focus of attention at that time

**Work needs to be understood from the local perspectives of those doing the work**

It is obvious when we consider our own performance that we try to do what makes sense to us at the time. We believe that we do reasonable things given our goals, knowledge, understanding of the situation and focus of attention at a particular moment. In most cases, if something did not make sense to us at the time, we would not have done it. This is known as the 'local rationality principle'. Our rationality is local by default – to our mindset, knowledge, demands, goals, and context. It is also 'bounded' by capability and context, limited in terms of the number of goals, the amount of information we can handle, etc. While we tend to accept this for ourselves, we often use different criteria for everybody else! We assume that they should have or could have acted differently – based on what we know now. This counterfactual reasoning is tempting and perhaps our default way of thinking after something goes wrong. But it does not help to understand performance, especially in demanding, complex and uncertain environments.

In the aftermath of unwanted events, human performance is often put under the spotlight. What might have been a few seconds is analysed over days using sophisticated tools. With access to time and information that were not available during the developing event, a completely different outside-in perspective emerges. Since something seems so obvious or wrong in hindsight, we think that this must have been the case at the time. But our knowledge and understanding of a situation is very different with hindsight. It is the knowledge and understanding of the people *in situ* that is relevant to understanding work.

In trying to meet demand, it is the subjective goals of the people that are part of the system that shape human performance. These goals are situated in a particular context and are dynamic. They may well be different to the formal, declared system goals, which reflect the system-as-imagined (as reflected in policies, strategies, design, etc). Yet it is the formal goals that we tend to judge performance against. While bearing

these formal goals in mind (and questioning their appropriateness), analysis should seek to understand goals from the person's perspective at that time.

The person's focus of attention also requires our understanding. We might be baffled when a conflict is not detected by a controller, or an alarm is not spotted by an engineer. We might ask questions such as "How could he have missed that?" or say "She should have seen that!" What seems obvious to us – with the ability to freeze time – may not be obvious at the time, when multiple demands pull attention in different directions. Understanding these demands, the focus of attention, the resources and constraints is vital.

Trying to understand why and how things happen as they do requires an inside perspective, using empathy and careful reconstruction with field experts to make sense of their work in the context of the system.

Once one accepts this, it becomes clear that everyone will have their own local rationality; there will be multiple perspectives on any particular situation or event. This does not imply weak analysis, but acceptance that the same situation will be viewed differently. Performance cannot be necessarily understood (or judged) from any one of these. Making sense of system performance relies on the ability to shift between different perspectives and to see the interacting trajectories of individuals' experiences and how these interact.

Exploring multiple and differential views on past events and current system issues brings different aspects of the system to light, including the demands, pressure, resources and constraints that affect performance. We begin to see trade-offs, adjustments and adaptations through the eyes of those doing the work. This will help to reveal the aspects of the system that should be the focus of further investigation and learning.

**“Trying to understand why and how things happen as they do requires an inside perspective.”**



## Practical advice

- **Listen to people's stories.** Consider how field experts can best tell their stories from the point of view of how they experienced events at the time. Try to understand the person's situation and world from their point of view, both in terms of the context and their moment-to-moment experience.
- **Understand goals, plans and expectations in context.** Discuss individual goals, plans and expectations, in the context of the flow of work and the system as a whole.
- **Understand knowledge, activities and focus of attention.** Focus on 'knowledge at the time', not your knowledge now. Understand the various activities and focus of attention, at a particular moment and in the general time-frame. Consider how things made sense to those involved, and the system implications.
- **Seek multiple perspectives.** Don't settle for the first explanation; seek alternative perspectives. Discuss different perceptions of events, situations, problems and opportunities, from different field experts and perspectives. Consider the implications of these differential views for the system.

## View from the field

**Paula Santos**

Safety, Surveillance and Quality Expert  
NAV-P, Portugal

*“Facing an unexpected situation, what do you do? Do you try to understand what is going on and what has happened? What can be done to sort it out? Assess the possible consequences of acting versus delaying action? Do you go to look for instructions or manuals when there is time pressure? Do you ask for help? Do you apply what has worked before in similar circumstances? For technicians, apply the stop and start again solution? Depending on the individual, the environment, the time available, the time of day, and many other factors, the understanding of the situation will differ, and so will the response. But, whatever course of action you choose, you will consider it to be the right thing to do at that time. If this is valid for you, it is probably true for many. So why do we tend to forget this principle when analysing what others have done?”*



# PRINCIPLE 3. JUST CULTURE

People usually set out to do their best and achieve a good outcome

**Adopt a mindset of openness, trust and fairness. Understand actions in context, and adopt systems language that is non-judgmental and non-blaming**

Systems do not exist in a moral vacuum. Organisations, are primarily social systems. When things go wrong, people have a seemingly natural tendency to wish to compare against work-as-imagined and find someone to blame. In many cases, the focus of attention is an individual close to the 'sharp end'. Investigations end up investigating the person and their performance, instead of the system and its performance. This is mirrored and reinforced by systems of justice and the media.

The performance of any part of a complex system cannot neatly be untangled from the performance of the system as whole. This applies also to 'human performance', which cannot meaningfully be picked apart into decontextualised actions and events. Yet this is what we often try to do when we seek to understand particular outcomes, especially adverse events, since those are often the only events that get much attention.

'Just culture' has been defined as a culture in which front-line operators and others are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but where gross negligence, wilful violations and destructive acts are not tolerated. This is important, because we know we can learn a lot from instances where things go wrong, but there was good intent. Just culture signifies the growing recognition of the need to establish clear mutual understanding between staff, management, regulators, law enforcement and the judiciary. This helps to avoid unnecessary interference, while building trust, cooperation and understanding in the relevance of the respective activities and responsibilities.

In the context of this White Paper, this principle encourages us to consider our mindsets regarding people in complex systems. These mindsets work at several levels – individually, as a group or team, as an organisation, as a profession, as a nation – and they affect the behaviour of people and the system as a

whole. Do you see the human primarily as a hazard and source of risk, or primarily as a resource and source of flexibility and resilience? The answers may take you in different directions, but one may lead to the road of blame, which does not help to understand work.

Basic goal conflicts drive most safety-critical and time-critical work. As a result, work involves dynamic trade-offs or sacrificing decisions: safety might be sacrificed for efficiency, capacity or quality of life (noise). Reliability might be sacrificed for cost reduction. The primary demand of an organisation is very often for efficiency, until something goes wrong.

As mentioned in Principle 2, knowing the outcome and sequence of events gives an advantage that was not present at the time. What seemed like the right thing to do in a situation may seem inappropriate in hindsight. But investigation reports that use judgemental and blaming language concerning human contributions to an occurrence can draw management or prosecutor attention. Even seemingly innocuous phrases such as "committed an error", "made a mistake" and "failed to" can be perceived or translated as carelessness, complacency, fault and so on. While we can't easily get rid of hindsight, we can try to see things from the person's point of view, and use systems language instead of language about individuals that is 'counterfactual' and judgemental (about what they could have or should have done).

For all work situations, when differences between work-as-imagined and work-as-done come to light, just culture comes into focus. How does the organisation handle such differences? Assuming goodwill and adopting a mindset of openness, trust and fairness is a prerequisite to understanding how things work, and why things work in that way. When human work is understood in context, work-as-done can be discussed more openly with less need for self-protective behaviour.

**“Assuming goodwill and adopting a mindset of openness, trust and fairness is a prerequisite to understanding how things work, and why things work in that way.”**



### Practical advice

- **Reflect on your mindset and assumptions.** Reflect on how you think about people and systems, especially when an unwanted event occurs and work-as-done is not as you imagined. A mindset of openness, trust and fairness will help to understand how the system behaved.
- **Mind your language.** Ensure that interviews, discussions and reports avoid judgemental or blaming language (e.g. “You should/could have...”, “Why didn’t you...?”, “Do you think that was a good idea?” “The controller failed to...”, “The engineer neglected to...”). Instead, use language that encourages systems thinking.
- **Consider your independence and any additional competence required.** Consider whether you are independent enough to be fair and impartial, and to be seen as such by others. Also consider what additional competence is needed from others to understand or assess a situation.

### View from the field

**Alexandru Grama**  
Air Traffic Controller  
ROMATSA R.A., Romania

*“Sometimes it seems that organisations expect perfection from their imperfect employees; imperfect performance is considered unacceptable. This way, individuals are reluctant to come forward with their mistakes. They only become obvious to everyone when serious incidents or accidents occur, but then it is already too late. Punishing imperfect performance does not make the organisation safer. Instead it makes the remaining individuals less willing to improve the system. Just culture enables the transition from ‘punishing imperfect individuals’ to a ‘self improving system’. It supports better outcomes over time using the same resources, based on the trust and willingness of individuals to report issues. Through just culture we can look at the reasons that decisions made sense at the time. It is a continuous process that allows an organisation to become safer every day by listening to employees.”*

# PRINCIPLE 4. DEMAND AND PRESSURE

**Demands and pressures relating to efficiency and capacity have a fundamental effect on performance**

**Performance needs to be understood in terms of demand on the system and the resulting pressures**

Systems respond to demand, so understanding demand is fundamental to understanding how the system works. ATM demands are highly variable by nature, in type and quantity. Different units vary in their traffic demand, and traffic demand in the same unit varies enormously over the course of a day and year. Demand can come from customers (outside or inside the organisation) such as airlines and airports, or from infrastructure or equipment that provides a service.

A controller in a busy unit must meet demands from many pilots flying different types of aircraft, on various routes, using several procedures, in the context of dense traffic, to a tight schedule with little margin for disturbances. The controller must also meet demands from colleagues and technical systems. An engineer in the same unit may need to deal with various hardware and software with different maintenance schedules, as well as occasional unpredictable failures. All of this occurs under time pressure with variable resources.

Seddon (2005) outlines two types of demand. The first is 'value demand'. This is the work that the organisation wants; it is related to the purpose of the organisation and meets customer needs. Examples include a 'right first time' equipment fix, or training at the right level of demand to prepare staff for the summer peak in traffic. The second type is 'failure demand'. This is work that the organisation doesn't want, triggered when something has not been done or not done right previously. Often, failure demand can be seen where there is a problem with resources (e.g. inadequate staff, a lack of materials or faulty information). A temporary maintenance fix due to a missing spare part or lack of time will require rework. Training provided too soon in advance of a major system change may require repetition.

To understand system performance, it is necessary to obtain data about both demand and flow. Together, these measures will tell you about the system's capability – its performance in responding to demand and the


predictability of this performance. Some demand will be routine and predictable (in the short or long term) and there will often be good data already available (e.g. morning peak in traffic, the routine maintenance schedule). Other demand is less predictable (e.g. such as that associated with an intermittent fault on a network).

To respond to varying demand, people adjust and adapt. But, depending on resources, constraints, and the design of work, demand leads to pressure (e.g. from pilots, colleagues, supervisors, technical systems), and trade-offs are necessary, especially to be more efficient. Long-term or abstract goals tend to be sacrificed with increasing pressure to achieve short-term and seemingly concrete goals (such as delay targets).

For unusual events, it is important to get an understanding of demand (amount and variety) – both for the specific situation and historically. Understanding historical demand will give an indication of its predictability. But demand and pressure can only be analysed and understood with the people who do the work – the field experts. They can help you to get behind the numbers.

Designing for demand is a powerful system lever. To optimise the way the system works, the system must absorb and cater for variety, not stifle it in ways that do not help the customer (by targets, bureaucracy, excessive procedurisation, etc). It may be possible to reduce failure demand (which is often under the organisation's control), optimise resources (competency, equipment, procedures, staffing levels), and/or improve flow. All meet customer needs, including of course the need for safety, and so address the purpose of the system.





**“Systems respond to demand, so understanding demand is fundamental to understanding how the system works.”**

### Practical advice

- **Understand demand over time.** It is important to understand the types and frequency of demand over time, whether one is looking at ordinary routine work, or a particular event. Identify the various sources of demand and consider the stability and predictability of each. Consider how field experts understand the demands.
- **Separate value and failure demand.** Where there is failure demand in a system, this should be addressed as a priority as it often involves rework and runs counter to the system’s purpose.
- **Look at how the system responds.** When the system does not allow demand to be met properly, more pressure will result. Consider how the system adjusts and adapts to demand, and understand the trade-offs used to cope. Listen to field experts and look for signals that may indicate trouble.
- **Investigate resources and constraints.** Investigate how resources and constraints help or hinder the ability to meet demand.

### View from the field

**Massimo Garbini**

Chief Executive Officer  
ENAV, Italy

*“ENAV manages more than 1.8 million flights per year, with peaks of 6,000 flights per day. The demand on the ATM system is not to be under-estimated. With four area control centres, 40 control towers, 62 primary and secondary radars, and hundreds of navaids, it is a complex and demanding operation. But ENAV can count on about 3,300 employees, two thirds of which are in charge of operational activities. They enable us to cope with a variety of ever-changing demands – 24/7, 365 days a year. Demand is where everything starts, and so it needs to be understood carefully. But demand cannot be understood only from statistics. The field experts are the ones that understand demand and related pressures from a work perspective. So it is necessary to work together on the system in order to meet demand and achieve the best possible performance.”*

# PRINCIPLE 5. RESOURCES & CONSTRAINTS

## Success depends on adequate resources and appropriate constraints

**Consider the adequacy of staffing, information, competency, equipment, procedures and other resources, and the appropriateness of rules and other constraints**

Meeting demand is only possible with adequate resources and appropriate constraints. These are system conditions which help or hinder the work. Resources are needed or consumed while a function is carried out (Hollnagel, 2012), and include personnel, competence, procedures, materials, software, tools, equipment, information and time. Resources are provided by 'foreground' functions and activities (such as the production of a flight progress strip) and by 'background functions' such as the provision of documentation and procedures, materials, and equipment.

The quality of resources varies over the short- and long-term, and unavailable or inadequate resources make it difficult to meet demand effectively. For instance, a procedure may be out of date; flight strips may be produced for each waypoint, requiring an Assistant to sort them and keep only those that are relevant; an FDP system may be unreliable; lack of staff for an operational position may lead to a delay in opening a new sector until on-call staff arrive.

To cope with variable demand and variable resources, people make trade-offs and vary their own performance by adjusting and adapting. These are essential aspects of human performance in the context of the system. Occasionally, there may be unwanted performance variability, for instance in cases of competency gaps or fatigued staff. There may also occasionally be trade-offs with unwanted consequences. More often, though, the trade-offs and performance variability give the system the flexibility that is required in order to meet demand.

Resources, like demands and goals, are an important system lever for change. Improving resources improves the ability to meet demand, but this often takes time – sometimes too much time to be realistic in dynamic operational situations. In these cases, improving the flow of work in the short term may be a more effective system lever.

One way to do this is to rationalise constraints. Performance is usually subject to various constraints or controls that supervise, regulate or restrict the flow of activity. Constraints usually seek to suppress variability or keep it within certain boundaries. Constraints are necessary for system stability, but can limit flexibility. Constraints may be exercised by people (e.g. supervision, inspection, checking), or be associated with procedures (e.g. standard operating procedures, checklists) and equipment (e.g. confirmation messages, dialogue boxes). A constraint may be a dynamic output from another activity (e.g. a check or readback-hearback), or may be relatively stable and relate to a resource.

Safety management is often characterised by the imposition of constraints. But this approach runs into limits. Constraints often restrict necessary performance variability, as well as unwanted variability, affecting the ability to achieve goals. If constraints run counter to the purpose and flow of work, they become problematic, and people work around constraints or 'game the system' in ways that are not visible from afar.

Any attempt to understand human work and safety needs to consider resources and constraints carefully. As said by Woods et al (2010), *"People create safety under resource and performance pressure at all levels of socio-technical systems"* (p. 249). Understanding how people create safety requires an understanding of the state of resources and constraints (for normal operations and at the time of any particular event), and their variability over time, since history will shape expectations and hence the local rationality of field experts. This understanding can only be gained with the involvement of the field experts, since what may seem adequate and appropriate from the outside may look very different from the inside.



**“Any attempt to understand human work needs to consider resources and constraints carefully.”**

### Practical advice

- **Consider the adequacy of resources.** With field experts, consider how resources (staff, equipment, information, procedures) help or hinder the ability to meet demand, and identify where there is the opportunity for improvement.
- **Consider the appropriateness of constraints.** Consider the effects of constraints (human, procedural, equipment, organisational) on flow and system performance as a whole. Reflect on the implications for individuals and the system when people have to work around constraints in order to meet demand.

### View from the field

**Mihály Kurucz**

Head of Safety Division  
Hungarocontrol, Hungary

*“Improving system performance requires a delicate interplay between resources. In all parts of the organisation, you will rely on the right people, procedures and equipment to run an effective system. But resources and constraints are closely linked. For instance, equipment should not over-constrain people, but rather allow the flexibility to meet demands and achieve goals. Safety-related regulations and procedures support the performance of the organisation, but I think over-regulation – be it external or internal – is a counterproductive constraint. In my view the best rules and procedures show the goals and principles, but don’t necessarily define directly and exactly the actions that you must do. Effective safety performance ultimately relies on the knowledge and sense of professionals at all levels, and their freedom to choose the most effective solution to a specific situation.”*



# PRINCIPLE 6. INTERACTIONS & FLOWS

## Work progresses in flows of inter-related and interacting activities

### Understand system performance in the context of the flows of activities and functions, as well as the interactions that comprise these flows

When looking at an organisation, we have a tendency to see it in terms of the organisational structure. This is how management normally works – managing resource in separate entities such as divisions, departments and units. This top-down perspective is problematic from an outside-in and end-to-end perspective – and this is the perspective of the customer. By managing individual functions, parts of the system compete. Goal conflicts are introduced and functions achieve their own goals at the expense of the whole, and to the expense of the customer. This ‘sub-optimisation’ is made worse when measurements are attached to functions or discrete activities, instead of focusing on system purpose.

When looking at an organisation as a system, it is necessary to see the flows of work from end to end through the system, and the interactions that make up these flows. The flow of work is not always obvious when we are only involved in a small part or a particular activity. But there is always flow. Flow in ATM is triggered and pulled by demand from external customers (e.g. airline pilots and dispatchers) and internal customers (within an ANSP, e.g. controllers, technicians, AIS, meteo staff). From a systems perspective, the task of management is to manage end-to-end flows, not functions. This means designing work according to purpose – to satisfy customer demands.

Acting on flow is a key system lever; it has a fundamental effect on performance. By studying, designing and managing flow, production and safety improvements emerge. Improving flow starts with designing against demand (Seddon, 2005). The variety and variability of demand needs to be understood. Improving flow also means paying attention to resources and constraints; when these are inadequate, they can be a particular problem for flow. Typical design-related flow blockers include poor interaction design (equipment and information), and unnecessary, overly complex or restrictive procedures. Designing these out requires a systems thinking approach. Bureaucracy of all kinds

hinders flow, especially when staff need to cut across organisational boundaries to get work done. When this happens, there are delays and the immediacy of need diminishes. For operational staff, the pressure builds up as time goes on.

To improve flow, you need measures of the nature and variability of demand and flow. The measures will give an idea of the capability of the system to handle demands and the predictability of work. This measurement of flow needs to be end-to-end. For each flow, you need data about achievement of purpose in customer terms. These measures need to be taken with the people who do the work – the field experts. They can help to understand the nature and predictability of flow. Measurement and analyses which dislocate decisions and actions from the demand, flow of work and context cannot explain performance or help to improve it. As noted by Seddon *“To manage clean flow, workers need to have the expertise required by the nature of demand. They also need to be in control of their work, rather than being controlled by managers with measures of output, standards, activity and the like”* (2005, p. 59).

Viewing the system as a whole, emerging patterns of activity become evident. These patterns, along with flows, can be seen using systems methods. The system interactions that make up these flows and patterns concern the integration of the human, technical, information, social, political, economic and organisational components of the system (Wilson, 2013). The nature of interactions, flows and patterns, along with purpose, characterise the system. There are many methods in human factors/ergonomics for studying interactions involving humans within systems (e.g. Stanton et al, 2013; Williams and Hummelbrunner, 2010; Wilson and Sharples, 2014). Considering interactions in the context of the flow of work, within the wider system, and from the viewpoints of those involved will help to improve the system, both for safety and productivity.



**“When looking at an organisation as a system, it is necessary to see the flows of work from end to end through the system, and the interactions that make up these flows.”**

### Practical advice

- **Understand and measure flow.** Investigate the flow of work from end to end through the system. Map the variability of flows and anything that obstructs, disrupts, delays or diverts the flow of work (e.g. preconditions not met, constraints, or unusual events). Consider how flow is measured, or could be measured, and the role of field experts in measuring and acting on flow.
- **Analyse and synthesise interactions.** Consider how to model past, present or future system interactions between human, technical, information, social, political, economic and organisational elements. Think about what systems methods to use and how to involve relevant field experts to help understand the interactions.

### View from the field

#### Dr Anthony Smoker

Manager Operational Safety Strategy (NERL), NATS

Former Air Traffic Controller

Graduate Tutor, Human Factors & System Safety, Lund University

*“Work can be described as the patterns of activity that characterise our daily working lives. We can see these patterns of activity as interactions with technology, procedures and equipment, situated in a wider system. The wider system is characterised by work flows that change as demand changes. Seen from a systems view, the patterns of activity can lead to new or infrequent interactions which the system may not support. New goal conflicts may be introduced that influence work with new priorities and new interactions, which technical systems (e.g. telephone or data processing) may not support. Procedures may not exist to support the new flows or interactions, and so flexibility is required to achieve a desirable outcome. Safe and efficient operation comes about by our adaptation to the changing patterns of flows and interactions. Understanding these – with the field experts – gives us the foresight to be able to manage operations intelligently.”*

# PRINCIPLE 7. TRADE-OFFS

People have to apply trade-offs in order to resolve goal conflicts and to cope with the complexity of the system and the uncertainty of the environment

**Consider how people make trade-offs from their point of view and try to understand how they balance efficiency and thoroughness in light of system conditions**

Work in complex systems is impossible to prescribe completely for all but fairly routine situations. Demand fluctuates, resources are often suboptimal, performance is constrained, and goals conflict. A busy airport that schedules traffic to a level near capacity leaves little room for disruption and requires consistently efficient performance. A lack of spare parts for equipment makes the functions vulnerable and may require workarounds. Often, the choices available to us are not ideal. We have to make trade-offs and choose among sub-optimal courses of action. This view contrasts with the simplistic view of prescribed work and non-compliance.

There are several different types of trade-offs, but a fundamental type is the 'efficiency-thoroughness trade-off' (ETTO; Hollnagel, 2009). Variations in system conditions (demand and pressure, resources, constraints) often create a need for efficiency over thoroughness. To achieve efficiency, we limit planning, quickly collect information and assess situations, make decisions on recognition of symptoms and 'gut feeling', enter data more rapidly, 'multitask', speak more quickly, reduce checking, and so on. The morning peak in traffic, limited time available for a software update or engineering work, or an urgent management decision, all call for greater efficiency. ETTO helps to frame how people and organisations try to optimise performance; people try to be as thorough as necessary, but as efficient as possible.

The efficiency-thoroughness trade-off has implications for understanding systems because it underlies all forms of work. It offers a useful alternative to 'human error' and is essential to help understand work-as-done. As an example, what we may call an 'expectation bias' in hindsight is actually just an expectation, and one that is probably valid most of the time. Taking away the 'bias' would also make the task almost impossible, at least at anything like an acceptable level. Imagine the effect on the readback-hearback process if a controller had no idea what to expect in the readback.

Readbacks are correct or acceptable in the majority of cases, so attention is split between the readback and other activities such as monitoring displays, recording flight data, and so on. The same can be said of rapid situation assessment and rapid decisions. If decisions in fast-paced environments were slow and deliberate, the task as we know it would be impossible. Trade-offs are essential for normal work.

Variable demands, production pressure and conflicting goals mean that people have to perform multiple activities in a given time frame, switching from one to another. This has several consequences. While some activities are sometimes amenable to 'multi-tasking', the conditions can make performance worse. Understanding how people switch between activities to achieve their goals is important to make sense of the situation from their points of view.

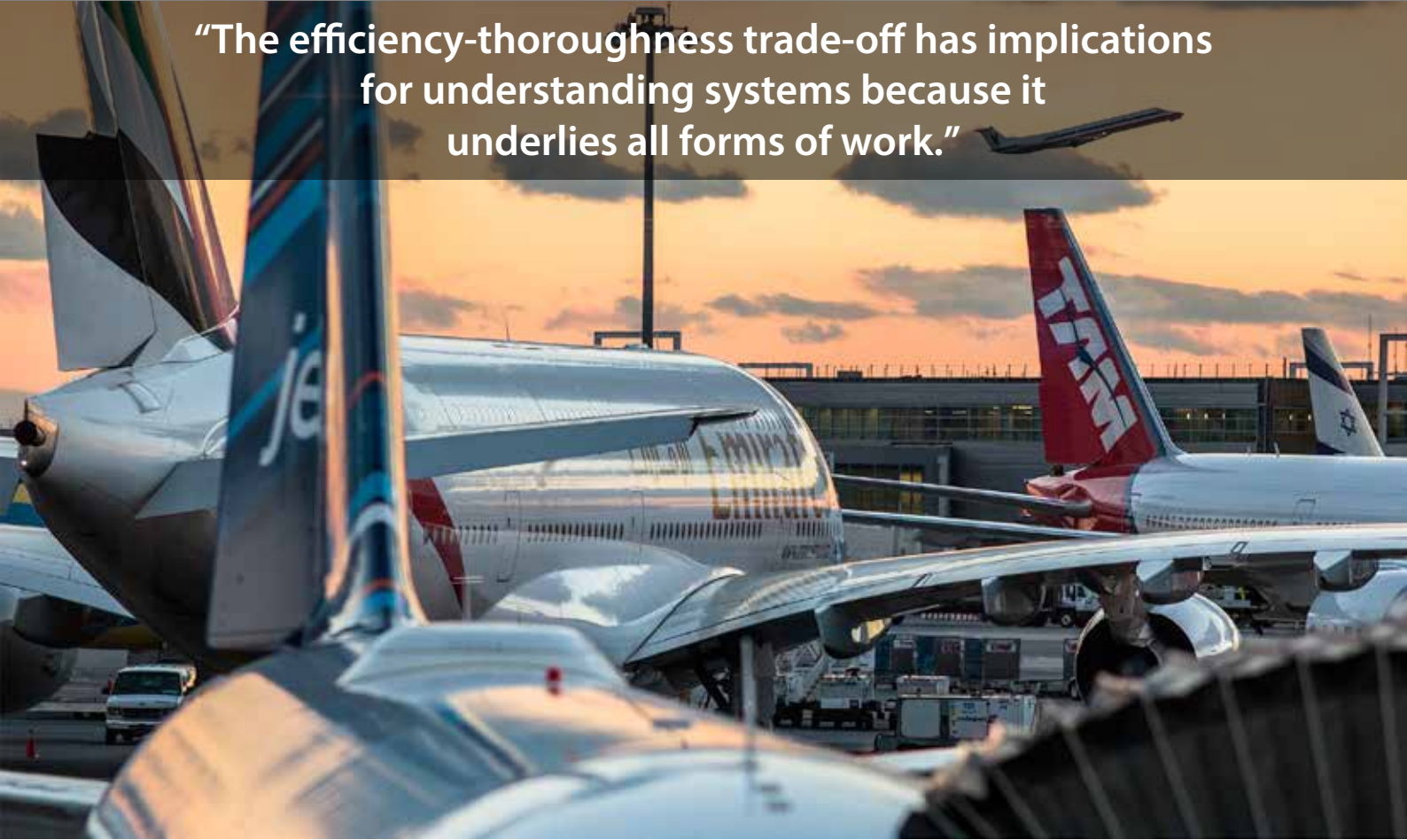
The possibility to switch successfully to a more efficient mode requires that at one time thoroughness was favoured over efficiency – a 'TETO' (thoroughness-efficiency trade-off). A system has to balance its resources and constraints dynamically to cope with complexity.

Other trade-offs involve short- vs long-term planning and sharp- vs blunt-end perspectives. For instance, additional resources may have to be deployed before the system runs out of capacity in face of rising demands. This may require shifting attention and resources to the longer term.

Trade-offs occur in all forms of work, in all organisational functions – including safety management (see Hollnagel, 2014). Trade-offs must be considered from a system perspective, with the right view of the person, especially in light of system conditions. Doing so will help to understand system behaviour and system outcomes.



**“The efficiency-thoroughness trade-off has implications for understanding systems because it underlies all forms of work.”**



## Practical advice

- **Take the field experts’ perspectives.** Data collection and interpretation are limited to what field experts can tell us. Assume goodwill and seek to understand their local rationality to consider how people make trade-offs from their point of view, balancing efficiency and thoroughness in light of system conditions.
- **Get ‘thick descriptions’.** A thick description of human behaviour (Geertz, 1973) is one that explains not just the behaviour, but its context as well, such that the behaviour becomes meaningful to an outsider. This comprises not only facts but also commentary and interpretation by field experts. Use these thick descriptions in investigations of routine work and adverse occurrences.
- **Understand the system conditions.** Use observation and discussion to understand how and when trade-offs occur with changes in demands, pressure, resources and constraints.

## View from the field

### Philip Marien

Incident Investigator EUROCONTROL &  
Editor of The Controller magazine, IFATCA

*“Controllers and other front-line staff constantly make very specific assessments of situations to meet the demands of the system: ‘If I do this, what will be the outcome?’ In doing this, they constantly balance different goals; a priority one moment may not be a priority the next. It is naive to believe that these judgements always place applicable procedures, including separation standards, above everything else. Demands and pressures from pilots, colleagues, supervisors, management, etc, mean trade-offs are necessary. Too often, demands from higher up within an organisation rely too much on the front-line being able to find the right balance under all circumstances. This places a controller between a rock and a hard place because compromises that satisfy all goals are not possible. When the outcome is outside agreed standards, it’s (too) easy to focus on one aspect of the trade-off. Instead, we should address why achieving balance between the different goals is not always possible.”*

# PRINCIPLE 8. PERFORMANCE VARIABILITY

Continual adjustments are necessary to cope with variability in demands and conditions. Performance of the same task or activity will vary

**Understand the variability of system conditions and behaviour. Identify wanted and unwanted variability in light of the system's need and tolerance for variability**

In organisations, demand is at least partly unpredictable, resources fluctuate, and goals and norms shift. System conditions and preconditions for performance are not completely knowable and they vary over time. This means the work cannot be specified precisely in procedures and so people must make continuous approximate adjustments in order to adapt to the system conditions. Performance variability, at the level of the organisation, airspace, team and individual, is both normal and necessary, and it is mostly deliberate. Without performance variability, success would not be possible. Variability is always there, even if the procedures do not account for it and if those at the blunt end are not aware of it. In order to understand work, one must understand how and why performance varies.

To respond to varying demand, we adjust and adapt. For operational staff, this involves moment-to-moment adjustment. Obvious examples are adjustments to spacing on final approach to reduce delay and optimise runway utilisation. Further away from the front-line, the time-scales for adjustments are longer.

Variability of any function does not exist in isolation – it is affected by the variability of other functions and the system as a whole. Therefore, the variability of all relevant functions needs to be considered.

The predictability, variability and adequacy of the various preconditions and conditions of performance relating to people, procedures, equipment and organisation affects the variability of these functions. These include system conditions or states (e.g. runway clear, aircraft at position, upload complete), previous task steps or activities (e.g. landing clearance, coordination, system input), and resources (information, staffing, procedures, working environment, equipment, etc).

Variability may be fairly predictable, or may be irregular, but with an historical experience base. Or it may be

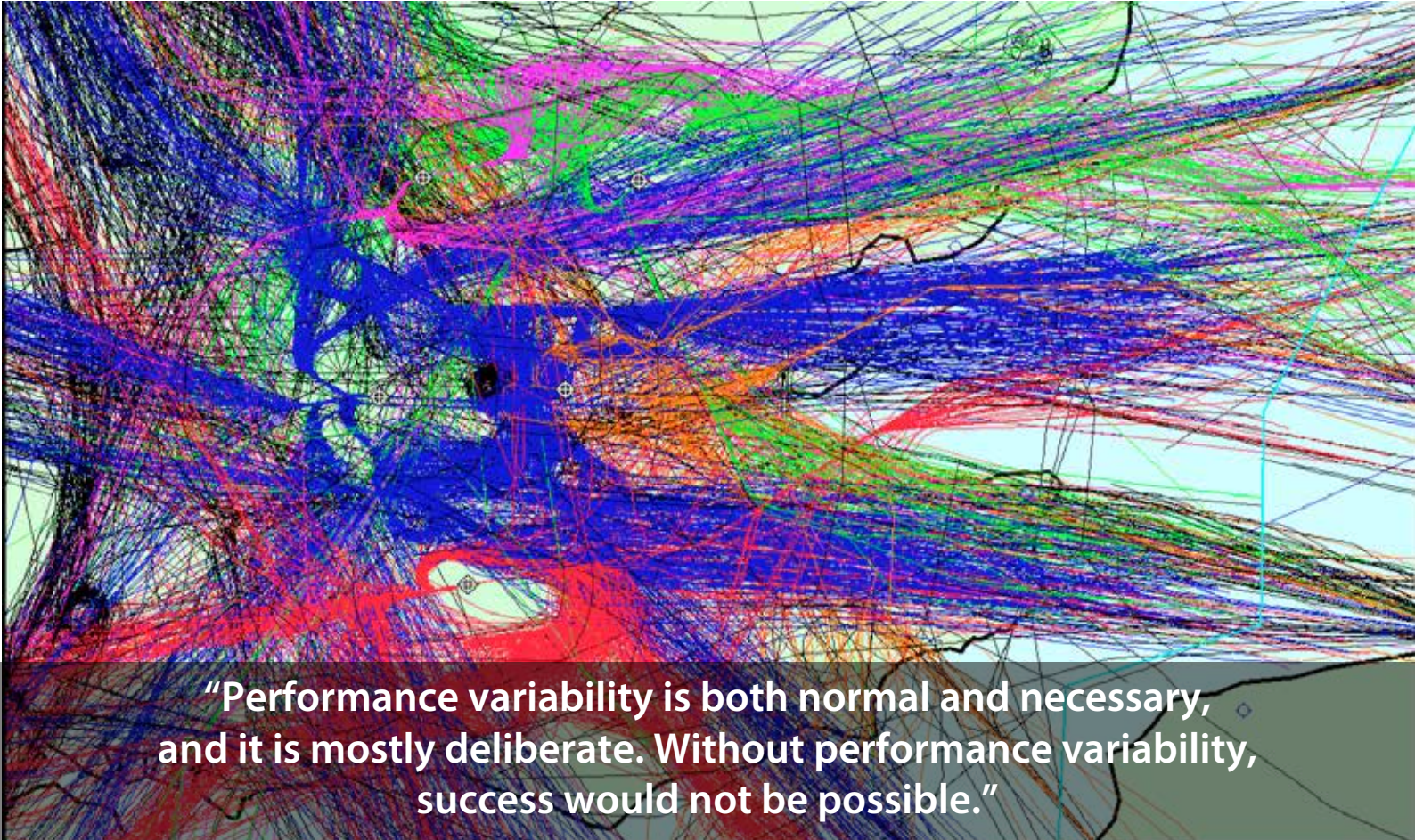
inherently unpredictable, and outside the historical experience base, including new, unanticipated, emergent variation, perhaps associated with abnormal or previously neglected issues within the system.

Performance variability has many reasons, and attempting to reduce variability without first understanding it may limit the degrees of freedom to select different options to deal with a situation. Hardening constraints, by introducing stricter rules and more procedures, may not be sustainable strategies. But by understanding variability, you increase your knowledge of the system.

To get this understanding, you cannot only ask why something goes wrong. You need to ask why things normally go right. For example, take a routine scenario in ATC: an aircraft gets airborne and is transferred from tower to approach. A situation like this is very likely to be handled in different ways, for lots of reasons. People will find ways to fill in the gaps in the system, with various adjustments to balance various goals.

From a higher level perspective, there are a few crucial questions: 1) Is performance variability within acceptable limits? Variability leads to success within a certain range of tolerance. But this tolerance is not fixed, and will itself vary over time with the system conditions (e.g. demand and constraints). 2) Is the system operating within the desired boundaries? Performance variability of various functions and flows of work will combine and interact at a system level and may approach certain boundaries. 3) Are adaptations and adjustments leading to drift into an unstable or unwanted system state? Drift happens slowly, and can be difficult to identify from the inside without appropriate measures. System level data on normal performance are needed to answer these questions. Where unwanted variability is identified, this will mean acting on the system (e.g. demand, resources and flows of work), not the person.





**“Performance variability is both normal and necessary, and it is mostly deliberate. Without performance variability, success would not be possible.”**

### Practical advice

- **Understand variability past and present.** Try to get a picture of historical variation in system performance. Consider what kind of variation can be expected given the experience base, how performance varies in unusual ways, and what is wanted and unwanted in light of the system's need and tolerance for variability.
- **Be mindful of drift.** Variability over the longer term can result in drift into an unwanted state. Consider what kind of measurements might detect such drift.
- **Understand necessary adjustments.** Operators must make continuous adjustments to meet demand in variable conditions. The nature of these adjustments and adaptations needs to be understood in normal operations, as well as in unusual situations.

### View from the field

**Marc Baumgartner**

ATCO, Skyguide, Switzerland

Former President and CEO, IFATCA

*“Air traffic management can be compared to the story of ‘Beauty and the Beast’. Front-line staff love to perform well. It is the nature of operational work that, in amongst the more routine work, we must respond to high demand situations that stretch the system's capability. In some cases, the beauty appears; demand is high but resources are good and the work flows. As a controller, this could mean working 90 movements on an airport where the declared capacity is 75 per hour. In such cases, operational staff feel very dynamic, flexible, and creative. But in other cases, the beast rears its ugly head. By surprise, unknown system features or behaviours emerge, turning our job into a real struggle. In both cases, it is necessary to make constant adjustments to developing situations. The fascinating thing is that the system can oscillate rapidly from beauty to beast to beauty again. The ATM system is intrinsically unstable and things only go right because we make them go right via our ability to vary our performance. It is the nature of our ordinary everyday work to transform the ‘beast’ into a more stable and safe system.”*



# PRINCIPLE 9. EMERGENCE

System behaviour in complex systems is often emergent; it cannot be reduced to the behaviour of components and is often not as expected

**Consider how systems operate and interact in ways that were not expected or planned for during design and implementation**

In the traditional approach to safety management (which may be characterised as Safety-I) the common understanding and theoretical foundations follow a mechanical worldview – a linear model where cause and effect is visible and wherein the system can be decomposed into its parts and rearranged again into a whole. This model is the basis for the ways that most organisations understand and assess safety.

Almost all analysis is done by decomposing the whole system into parts and identifying causes by tracing chains of events. For simple and complicated (e.g. mechanical) systems, this approach is reasonable because outcomes are usually resultant and can be deduced from component-level behaviour.

As systems have become increasingly complex, we have tended to extrapolate our understanding (and our methods) from our understanding of simple and complicated mechanical systems. We assume that complex system behaviour and outcomes can be modelled using increasingly complicated methods.

However, in complex sociotechnical systems, outcomes increasingly become emergent. Woods *et al* (2010) describe emergence as follows: *“Emergence means that simple entities, because of their interaction, cross adaptation and cumulative change, can produce far more complex behaviors as a collective and produce effects across scale.”* System behaviour therefore cannot be deduced from component-level behaviour and is often not as expected.

From this point of view, organisations are more akin to societies than complicated machines. Similar to societies, adaptations are necessary to survive. Small changes and variations in conditions can have disproportionately large effects. Cause-effect relations are complex and non-linear, and the system is more than just the sum of its parts. Considering the system as a whole, success and failure are increasingly understood

as emergent rather than resultant. As variability and adaptation is necessary and there are interactions between parts of the system, variability can cascade through the system and can combine in unexpected ways. Parts of the system that were not thought to be connected can interact, and catch us by surprise.

These emergent phenomena can be seen in the 1999 Mars Polar Lander crash, or in the 2002 Überlingen mid-air collision. In both examples, there were cross-adaptations and interactions between system functions, and major consequences. These effects cannot be captured by simple linear or sequential models, nor by the search for broken components. Further examples can be seen in stock market and crowd behaviour.

Emergence is especially evident following the implementation of technical systems, where there are often surprises, unexpected adaptations and unintended consequences. These force a rethink of the system implementation and operation. The original design becomes less relevant as it is seen that the system-as-found is not as imagined (see Bainbridge, 1983).

Emergence is reflected in systems theory, but less so in safety management practice, or management generally. As systems become more complex, we must remain alert to the adaptive and maladaptive patterns and trends that emerge from the interactions and flows, and ensure a capacity to respond.

Systems thinking and resilience engineering provide approaches to help anticipate and understand system behaviour, to help ensure that things go right. They have in common a requirement to go ‘up and out’ instead of going ‘down and in’, understanding the system-as-found (structure, boundaries, interactions) and work-as-done (adaptations, adjustments) before trying to understand any specific event, occurrence, or risk.



**“As systems become more complex, we must remain alert to the positive and negative emergent properties of systems and system changes.”**

## Practical advice

- **Go ‘up and out’ instead of going ‘down and in’.** Instead of first digging deep into a problem or occurrence to try to identify the ‘cause’, look at the system more widely to consider the system conditions and interactions.
- **Understand necessary variability.** Try to understand why and where people need to adjust their performance to achieve the goals of the organisation. Instead of searching for where people went wrong, understand the constraints, pressures, flows and adjustments. Integrate field experts in the analysis.
- **Make patterns visible.** Look for ways to probe and make visible the patterns of system behaviour over time, which emerge from the various flows of work.
- **Consider cascades and surprises.** Examine how disturbances cascade through the system. Look for influences and interactions between sub-systems that may not have been thought to be connected, or were not expected or planned for during design and implementation.

## View from the field

**Alfred Vlassek**

Safety Manager & Head of Occurrence Investigation  
Austro Control GmbH, Austria

*“The modern ATM system is a highly complex environment. To assess any impact on safety in such systems, you have to understand – more or less – not only the components, but how they interact. Unfortunately, system interactions and outcomes are not always linear. Outcomes are often ‘emergent’ rather than ‘resultant’, and so they take us by surprise. For this reason, we need to address safety not only systematically but also in a systemic way – looking for desirable and undesirable emergent properties of the changing system. So we must adapt our safety processes to address this complexity. This does not mean that we stop using common methods (investigations, survey, audits, assessments, etc) but it does mean that we need to combine our safety data sources and supplement them with more systemic approaches that allow us – together with the field experts – to ‘see’ this emergence.”*

# PRINCIPLE 10. EQUIVALENCE

## Success and failure come from the same source – ordinary work

**Focus not only on failure, but also how everyday performance varies, and how the system anticipates, recognises and responds to developments and events**

When things go wrong in organisations, our assumption tends to be that something or someone malfunctioned or failed. When things go right, as they do most of the time, we assume that the system functions as designed and people work as imagined. Success and failure are therefore thought to be fundamentally different. We think there is something special about unwanted occurrences. This assumption shapes our response. When things go wrong, we often seek to find and fix the 'broken component', or to add another constraint. When things go right, we pay no further attention.

Looking back, what makes performance look different is time for scrutiny, deconstruction and hindsight. Everyday work is not subject to examination because things are going well, and that is thought to be unremarkable. It is assumed that people are behaving as they are supposed to according to rules, procedures and standard working methods, i.e. work-as-imagined.

This bimodal view of performance (function vs. malfunction) underlies Safety-I, and may be well-suited to mechanical systems, but less so to complex socio-technical systems (see EUROCONTROL, 2013). In such systems, success and failure emerge from ordinary work – they are equivalent. When wanted or unwanted events occur in complex systems, people are often doing the same sorts of things that they usually do – ordinary work. What differs is the particular set of circumstances, interactions and patterns of variability in performance. Variability, however, is normal and necessary, and enables things to work most of the time.

Ordinary work occurs within the context of system conditions – demand and pressure, and resources and constraints. System conditions influence system behaviour, including patterns of interactions and flows, trade-offs, and performance variability. Success and failure therefore emerge from system behaviour, which is shaped or influenced by system conditions.

While we tend to focus our safety efforts and resources on things that go wrong (occurrences and risks), we need to shift more towards system behaviour and system conditions in the context of ordinary work. In practice, this means understanding how the work really works, how the system really functions, and the gaps between work-as-imagined and work-as-done. On this basis, it would be more effective to investigate the system, not just an occurrence. As Seddon (2005) put it, *"How does the work work? How do current system conditions help or hinder the way the work works?"*

System behaviour reveals itself over time. This means that understanding ordinary work is especially important, because performance can change quickly or drift into an unwanted state over time. Performance variability may propagate from one activity or function to others, interacting in unexpected ways, with non-linear and emergent effects. This may occur with or without component failures.

Whether variability is short- or longer-term, stable, fluctuating or drifting, it can be difficult to anticipate and recognise unless attention is being paid to normal work. When relying on reactive safety data concerning malfunctions, developments may occur too quickly to notice or so slowly that no-one notices. The causation may be complex and hard to understand. It may be difficult or impossible to respond.

A proactive approach involves continuously monitoring the system and its capability. The aim is to improve system effectiveness by improving the system's ability to anticipate, respond and learn. This may involve working on demand, providing better resources, adjusting interactions, improving flow, or increasing flexibility and responsiveness by removing unnecessary constraints. By improving the number of things that go right, safety improves, and other important objectives are met.





**“When wanted or unwanted events occur in complex systems, people are often doing the same sorts of things that they usually do – ordinary work.”**

### Practical advice

- **Understand everyday work.** To understand success and failure, we need to understand ordinary work and how work is actually done. Consider end-to-end flows and interactions, trade-offs and performance variability in the context of the demands and pressures, and the resources and constraints. Use a safety occurrence as an opportunity to understand how the work works and how the system behaves.
- **Observe people in context.** This can be done using a variety of observational approaches, formal and informal. It is not about checking compliance with work-as-imagined, but rather seeing and hearing how work is done (including how people adjust performance and make trade-offs), in a confidential and non-judging context.
- **Talk to field experts about ordinary work.** Observation is important, but alone it is insufficient to understand work-as-done. Talking to people in discussion (e.g. talk-through sessions, focus groups) helps to understand the how and why of work-as-done.
- **Improve resilience with systems methods.** Use systems methods to understand how the system anticipates, recognises and responds to developments and events.

### View from the field

**Fernando Marián de Diego**

Air Traffic Controller, Spain

Head of the Technical Office: Spanish ATCO Professional Association (APROCTA)

*“We ATCOs and pilots work with procedures and technology that are designed to be invariable. But with variable demands, people are the only part of the system that provide the needed flexibility to absorb and handle this variety. We need to predict, recognise and respond to the constantly changing situation at the right time and in the right way. Whenever a difficult or unusual situation arises, a natural instinct for helpful cooperation shows up with great intensity on both sides of the radio. Every request, advice, or instruction affects the outcome of the event. Success or failure come from same thing – everyday work and our ability to ‘see’, adjust and adapt. And looking at the safety of aviation operation, it works!”*

# PRINCIPLES IN ACTION

The principles in this White Paper encourage a different way of thinking about complex systems, in the context of both ordinary work and unusual events or situations. Anyone can use the principles in some way, and you may be able to use them in different aspects of your work. It is helpful to have working knowledge of some methods for data collection, analysis and synthesis that focus on some of the principles. Some specialists will already have knowledge of these (e.g. human factors specialists, systems engineers, safety investigators). These methods will tend to be of the following sorts.

**Systems methods** allow the consideration of the wider system and its interactions. These include many methods that can be used for describing, analysing, changing, and learning about situations and systems. You may wish to research the following methods: system maps and influence diagrams (see Open University, 2014); causal loop diagrams (see Meadows and Wright, 2009); activity theory/systems (see Williams and Hummelbrunner, 2010); seven samurai (Martin, 2004); FRAM (functional resonance analysis method; Hollnagel, 2012); AcciMaps (Rasmussen, 1997); and STAMP (systems theoretic accident model and processes; Leveson, 2004, 2012).

**Observation** of ordinary work with field experts, with or without a particular method, is important to understand how work really works (even, or especially, where an unusual event has occurred). By observing interactions over time, the flow of work becomes clearer, along with performance variability and the trade-offs used to manage complexity and deal with uncertainty. The focus of observation is work and system behaviour, not the individual. Work must be understood in the context of system conditions – demand and pressure, resources and constraints. Observation is non-judgemental and focuses only on what is observable. Alone, however, observation is insufficient to understand work.

**Discussion** with field experts is essential to understand why things work in the way that they work. Discussion may follow an observed period of work, or may relate to work and the system more generally, including activities, situations, occurrences or scenarios. This

can be in the context of a one-to-one or group discussion. The principles may be especially useful in the context of team resource management (TRM) training, which involves strategies for the best use of all available resources – information, equipment and people. Discussion of the principles enables a better understanding of system behaviour.

**Data and document review**, in partnership with field experts, looks at data that exist in documents, information systems, and so on. This can help, for instance, to highlight patterns, trends and variability in interactions and demand over time.

**Survey methods**, such as questionnaires and interviews, may be used to collect data from a larger number of people, for instance concerning trade-offs used in practice, the adequacy of resources and appropriateness of constraints.

These and other methods are detailed in several books (e.g. Williams and Hummelbrunner, 2010 on systems thinking methods; Stanton et al, 2013, and Wilson and Sharples, 2014 on human factors methods).

The principles do not operate in isolation; they interrelate and interact in different ways, in different situations. This is illustrated in the following scenario.

## Scenario: Alarm management

Imagine an engineering control and monitoring position. There is variability in the way that alarms are handled, and some important alarms are occasionally missed. This must be understood in the context of the overall ATM/CNS system (*Foundation: System Focus*). Since success and failure come from the same source – everyday work – it is necessary to understand the system and day-to-day work in a range of conditions over time (*Principle 10: Equivalence*). This can only be understood with the engineers and technicians who do the work (*Principle 1: Field Experts*). They will view their work from their own (multiple) perspectives, in light of their experience and knowledge, their goals at their focus of attention, and how they make sense of the work (*Principle 2: Local Rationality*).

In particular, it is necessary to understand how performance varies over time and in different situations (*Principle 8: Performance Variability*). For this, we must understand demand over time (e.g. the number, pattern and predictability of alarms) and the pressure that this creates in the system (time pressure; pressure for resources) (*Principle 4: Demand and Pressure*). Through observation and discussion, it is possible to understand the adequacy of resources (e.g. alarm displays, competency, staffing, procedures), and the effect of constraints and controls (e.g. alarm system design) (*Principle 5: Resources and Constraints*) on interactions and the end-to-end flow of work (*Principle 6: Interactions and Flow*) – from demand (alarm) to resolution in the field.

It will likely become apparent that engineers must make trade-offs (*Principle 7: Trade-offs*) when handling alarms. Under high pressure, with limited resources

and particular constraints, performance must adapt. In the case of alarms handling, engineers may need to be more reactive (tactical or opportunistic), trading off thoroughness for efficiency as the focus shifts toward short-term goals.

Through system methods, observation, discussion, and data review, it may become apparent that the alarm flooding emerges from particular patterns of interactions and performance variability in the system at the time (*Principle 9: Emergence*), and cannot be traced to individuals or components. While the alarm floods may be relatively unpredictable, the resources, constraints and demand are system levers that can be pulled to enable the system to be more resilient – anticipating, recognising and responding to developments and events.





# THE TEMPORARY OPERATING INSTRUCTION

In early 2014, the UK experienced a prolonged period of low atmospheric pressure. At the same time, there was an unusual cluster of level busts at the transition altitude, which were thought to be linked to incorrect altimeter setting on departure into the London TMA.

Level busts have been, and remain, a key risk in NATS operation. Longer-term strategic projects, such as the redesign of the London TMA and the raising of the Transition Altitude, are expected to provide some mitigation. However, to respond tactically to the perceived trend in the short-term, it was decided to issue a Temporary Operating Instruction (TOI) to controllers.

The TOI required the inclusion of additional phraseology when an aircraft was cleared from an altitude to a Flight Level during low pressure days. The additional phraseology was “standard pressure setting” e.g. “BigJet123, climb now FL80, standard pressure setting”. The change was designed to remind pilots to set the altimeter to the standard pressure setting (1013 hPa) and so reduce level busts associated with altimeter setting. As this phrase was deemed to be an instruction, it was mandatory for flight crews to read back this phrase.

The TOI was subject to the usual procedural hazard assessment processes and implemented on 20 February 2014 on a trial basis, with a planned end date of 20 May 2014, after which the trial results would be evaluated. The change was detailed in Notices to Airmen (NOTAMs).

During the first day of implementation, several occurrence reports were received from controllers, who noted that flight crews did not understand the meaning of the phraseology, and did not read back as required. This led to additional radio telephony to explain the instruction, and therefore additional workload and other unintended consequences.

These reports prompted us to consider the level bust problem, the TOI and the response to its introduction as events unfolded, consistent with a Safety-II perspective. We used some systems thinking techniques and reflected on the ten principles. The results highlighted that the

TOI was a simple, locally rational, but unfortunately ineffective solution to a more complex problem.

We started with the systems thinking perspective of going ‘up and out’, to make sense of the issue in the context of system. First, we drew a system map (Open University, 2014). This describes the structure of a system under consideration from a particular perspective and for a particular purpose (in this case, to prevent level busts associated with incorrect altimeter setting). The main elements of the system were people, equipment, rules and procedures, information, operational environment and training. Each of these elements had sub-elements, some of which had further sub-elements.

We then considered the interactions between sub-elements using influence diagrams. For instance, the atmospheric pressure (operational environment) influences the transition level (rules and procedures). The controller (people) influences the pilot (people) via RT instructions (information). Many interactions were identified, and those that were considered most influential in the context of the TOI were considered further. The ten principles were used to help examine the interactions between the TOI and altimeter setting.

Considering first the view of the person, the pilots and controllers are field experts, but in this case time was constrained, which limited the normal level of involvement in the development of the procedure. In terms of the pilot’s local rationality, many pilots would fly into the London TMA only infrequently. To these, the goal of the instruction may have been unclear, and interpretation variable. Of course, none intended to deviate from their level (just culture).

Moving on to system conditions and considering demand and pressure, the nature of work changes in low atmospheric pressure; there is a need to pay closer attention. The NOTAM acts as a resource, but not necessarily an effective one, since time to listen and interpret is limited (a constraint), as is time for RT to clarify the “standard pressure setting” instruction. On the ATC side, the initial TOI was published following



standard process, but this may not have been the most effective means of communicating the need for change or to ensure clarity of understanding by the user.

When considering system behaviour, the interactions and flows are more complex than might appear. For many pilots (especially frequent users of the TMA), there is an expectation regarding RT phraseology. Deviations from this can be confusing and trigger requests for clarification, which disrupt flow. When reading briefings, there is a trade-off between efficiency and thoroughness. Reading all briefings very thoroughly might delay arrival into the ops room. Similarly, in radio-telephony under time pressure, efficiency is prioritised; attention to the readback may be reduced to attend to other information, such as radar. Performance variability, both intended and unwanted, is relevant. RT was already deliberately tailored, for example to pilots who might be unfamiliar with the London TMA and the transition altitude, based on perceived language proficiency, country of origin or operator. Requiring that all instructions contain the additional phraseology removed an element of flexibility.

In terms of the outcome, what occurred could be seen as a case of emergence. The TOI was associated with increased workload from confusion, additional RT, delays and incomplete readbacks. Our analysis was based on normal work, as the source of both success and failure (equivalence). The initial analysis was of work-as-imagined, but from a systems perspective. The next planned stage was to consider work-as-done via observation in the ops room. However, it became clear

by the end of the first week of implementation that the 'one size fits all approach' taken in the TOI was not sustainable, and the TOI was cancelled.

Subsequently, a safety notice was issued highlighting the level bust issue and the range of operating techniques which were already being applied in day-to-day work to protect against the issue. The notice included a range of phraseology options, changes to controller style, circumstances known to contribute to level busts, consideration of the cockpit workload at the time of an instruction, and other techniques.

This experience is probably very familiar to many readers. Procedures are a common way to solve problems, but can have unintended consequences. In this case, the system map and influence diagram showed that the TOI was linked only very indirectly to the altimeter setting (a stronger link being the airline SOPs). This insight, along with consideration of the principles, showed that problems, as well as solutions, are often far more complex than imagined, and require a systemic approach.

**Craig Foster** Future Safety Specialist, NATS, UK

**Anthony Smoker** Manager Operational Safety Strategy, NATS, UK

**Christine Deamer** Safety Assurance Advisor, NATS, UK

**Bill Leipnik** Manager Swanwick Operational Safety Improvement, NATS, UK  
with

**Steven Shorrock** Safety Development Project Leader, EUROCONTROL

# THE MINIMUM RADAR VECTORING ALTITUDE

For my work as a safety manager and investigator for ATC incidents it is vital to understand why practitioners make their decisions, why their actions make sense to them, whether the outcome later on is positive or negative. To see their work through their eyes helps to support the system, ensuring that things go right while also preventing things from going wrong. What makes sense to one controller or engineer most of the time usually makes sense to others at the time.

Our controllers make decisions based on their local rationality and in 99.9% the outcome is positive. One example was when a controller came to us and reported that he had taken an aircraft below the minimum radar vectoring altitude (MRVA). This is normally prohibited. The procedures do not allow this because the MRVA is the lowest safe altitude, which is clear of obstacles. Within controlled airspace in most cases this absolutely makes sense.

In this special case the pilot of a small aircraft had navigational difficulties and was running short on fuel. He wanted to land at a nearby aerodrome but his instruments no longer worked properly for an IFR approach. He requested to descend below the MRVA to come below the clouds and approach the aerodrome visually. Without waiting for permission by the controller he descended below the minimum on his own. According to procedures a controller cannot tolerate that and has to advise the pilot to climb back to the MRVA. But on the other hand, such constraints sometimes do not apply in an emergency.

In this case the controller considered within seconds the obstacle situation and decided not to instruct the pilot to climb, but rather to assist him by giving position information and pointing out the location of the aerodrome.

The pilot finally managed to land safely. The first thought of readers might be: "How can he break a procedure and tolerate a descent below the minimum altitude?" But once

you look at the situation from the inside perspective, you understand that it made sense to the controller: he did not want to make the pilot more nervous by instructing him to climb in this emergency situation. He knew the obstacle situation and he wanted to assist the crew to land as soon as possible. With these quick decisions, the controller possibly saved the life of the crew.

And here is a close link to another principle: because the controllers knew about our just culture policy they were able to report this case for other controllers to learn from it. They did not have to fear consequences and knew that safety management would look at this case in context and not only for rules and procedures that might be involved and broken.

**"To see their work through their eyes helps to support the system, ensuring that things go right while also preventing things from going wrong."**

Another example can be seen in infringements of separation when a controller did not recognise traffic on the radar screen. We have had the experience that sometimes

the relevant traffic was displayed in different colours for various reasons (level band filter, warning colour, group code, etc). We then ask "Why did the controller not recognise the traffic displayed and why were colours not perceived in the way that the designers expected." Then we are able to investigate the colour settings further.

Sometimes system and procedure designers, managers and investigators have their own vision of how things will work – work-as-imagined. But these cases show that it is most important to see what makes sense to the field experts in practice, how they make their decisions, and how they see their world.

**Christiane Heuerding**

Safety Manager, ACC Bremen  
DFS, Germany



# CALLSIGN SIMILARITY

Besides some other aircraft, the ATCO of the HIGH-Sector had two aircraft on frequency that had almost the same callsigns (A/C1 and A/C2). A/C1 was a flight at FL360 to a nearby aerodrome and therefore had to be descended soon. A/C2 was an overflight at FL370 whose destination was still over 1000 miles away.

The ICAO-3-letter abbreviations of the two callsigns differed only by one letter and both tripnumbers ended with the letter “B” – spoken “Bravo”. The opportunity of a callsign mixup on either side – cockpit and/or ATC – was high, and this turned out to be the case.

First, the ATCO instructed A/C1 to call the LOW-Sector because the LOWEr controller had to perform the descent. During that instruction the HIGH-controller wanted to send away A/C1 but inadvertently used the callsign of A/C2 with the tripnumber of A/C1.

The wrong callsign (and most probably the tripnumber ending “Bravo”) was enough for A/C2 to answer that call (with its correct callsign). A/C2 left the frequency of the HIGH-Sector and called in on the LOWEr’s frequency.

When A/C2 called in (again with its correct callsign) the LOWEr controller was focused on A/C1, which he expected to descend. In addition, he had a potential conflict concerning A/C1 and another flight in his sector, for which the planned descent of A/C1 was the solution. The actual flight that called in (A/C2) was about 70NM away from the point where the ATCO’s focus was at that time. The controller thought, “I have to solve that potential conflict and I have to descend A/C1 anyway. So why wait?”

After identifying A/C1 visually, the ATCO instructed what he thought was A/C1 to descent to FL340 – but this instruction was made to A/C2. This clearance prompted some discussions between the A/C2 pilot and ATCO; the pilot wanted to continue at his cruising level. During this discussion neither the ATCO nor the pilot used the correct callsign anymore. The A/C2 pilot expressed his

astonishment and asked the ATCO if he could stay at FL370. The answer of the ATCO was surprising. The ATCO was still fixated on A/C1 and answered: “You are at FL360 and negative! You have to descent now due to traffic”. The pilot didn’t argue, and left his cruising level.

The result was that A/C2, which wanted to fly at FL370 to its destination, performed an uncoordinated descent to FL340 whilst A/C1 still was at FL360. The conflict had to be solved by turning the other aircraft. Luckily no other traffic was below A/C2. When all participants recognised the evolving situation, A/C2 was offered to climb back to FL370.

This illustrates the local rationality principle. For the LOWEr controller it made sense to act as he did. Part of his mental picture was the expectation of the initial call of A/C1. He had no knowledge about A/C2 because it was never planned to enter his airspace. In addition, he had a potential conflict between A/C1 and another flight in his sector. The ATCO planned to descend the inbound A/C1 according to the procedures after initial call. The next call on his frequency from a flight with a similar callsign fit his plan perfectly. After ‘identification’, he issued the descent clearance. Even the short discussion about the actual level did not help to identify the mix up.

This case also illustrates an interesting fact about the equivalence of success and failure in ordinary work; the same sorts of processes that enable efficient performance can also contribute to unwanted events. It is not feasible or desirable to avoid adaptive processes (e.g. expectation) and ways of working. What matters most is to work with field experts to improve the system.

**Thomas Jaekel**

Safety Manager, UAC Karlsruhe  
DFS, Germany

# INDEPENDENT PARALLEL NEW DEPARTURES PROCEDURES

“Stick to the procedures”, “Use standard phraseology”, “Maintain situational awareness”, “Avoid complacency”. Phrases such as these are the watchwords for many managers, including a lot of safety managers in the aviation industry and especially in air traffic control. The implication is that the system is basically safe if everybody behaves and acts accordingly.

As a sharp-end operator in the approach control for one of the busiest airports in Continental Europe (Frankfurt Approach Control) I find this disturbing. It is as if I would go to work every day carelessly undermining the system. Needless to say the opposite is true. I try to deliver the best performance every day, for the good of the system and my own job satisfaction.

Managing heavy air traffic in a dynamic environment can be very fulfilling. One source of this satisfaction is my discretionary space – my room for manoeuvre. To successfully cope with daily challenges, my room for manoeuvre needs to be as large as possible. Only then can I balance efficiency and thoroughness well (trade-offs) and handle traffic in a safe, orderly and fluent way.

Don't confuse this with 'whatever-ism'. There are some basic principles, which must never be abandoned. But not everything can be or needs to be ruled right down

to the last detail. This approach can have unintended consequences.

Unfortunately this is what happens in the aftermath of a serious incident. Even though the incident might never reoccur because of the uniqueness of the circumstances that contributed to the situation, new rules are implemented to prevent 'reoccurrence'. This is the find-and-fix approach, and it is often implemented in haste.

Whether such rules serve to reassure the public or the management (“We did something”), or if they really do serve safety, is hard to tell. But since the “hastened stroke often goes astray” such quick fixes often curtail the performance and reduce flexibility (performance variability) rather than enhance the system.

The ‘independent parallel new departures procedures’ at Frankfurt Airport is a good example of this. Together with the new runway, the procedures were introduced to ensure the capacity of the two departure runways (25C and 18), which are interdependent with the landing runway 25L. Although the procedures were heavily criticised by many controllers (field experts) from the beginning, the safety assessment concluded that the procedures were basically safe if a VOR were constructed for a certain standard instrument departure (SID) route.



It didn't take long until a serious incident occurred between a missed approach on RWY25L and a Departure on RWY25C, the latter of which turned exactly (and as designed) into the flight path of the Missed Approach Procedure. Work-as-done did not turn out as imagined, but was as designed.

Eventually, the independent parallel new departures procedures were withdrawn. For the original problem, this a reasonable decision (local rationality), but now created more serious problems. Departure capacity was decreased by the withdrawal of the procedures and a night curfew still existed. The tower controllers now faced the problem to bring all aircraft into the air in a shorter period of time, namely in the final 90 minutes before the airport closes for the night, due to restriction and noise abatement. This demand created pressure. On the departure radar side, this felt like the air being released of a balloon, and we had some "Close-Calls" because of this depletion.

Frequently, new rules are introduced for political or environmental reasons, like noise abatement. After the opening of the new runway at Frankfurt Airport, the public outcry because of the aircraft noise was tremendous. There is a goal conflict between noise and safety, but the pressure from the system environment was on reducing noise.

During the last 12 month, many procedures have been implemented to mitigate the situation and to calm down the public, without necessarily reducing noise. These procedures (resources) actually act as constraints – they constrain my handling of the traffic but, at the same time, capacity must not be reduced. This seemingly simple example illustrates the complexity of the system; procedures to avoid noise over certain areas or during certain times of day had interactions with other parts of the system and affected the flows of work. Ultimately, unexpected phenomena observed later (emergence).

At the sharp end, this dilemma can only be dissolved by removing some constraints and looking for new 'freedoms'. These freedoms could be more time to

evaluate the situation, new workarounds, etc. Here is an example how that works: When I send an aircraft on final to the Tower by using standard phraseology, "Lufthansa A/C one two tree contact Tower on one one niner decimal niner", this takes including the pilot's read-back about 8-10 seconds. When I use a much shorter but equally understandable phrase, "DLH A/C one two tree Tower nineteen nine", I save 2-4 seconds. This does not seem to be much. But if you take into account that there are about 60 aircraft per hour during an average inbound rush this adds up to 2-4 minutes – a lot of time for a thorough traffic analysis.

This is only one example of how 'cutting a corner' can help to cope with a complex and dynamic environment. And looking at the (very low) number of incidents we have, we are not too bad at coping.

I avoid saying 'safe' or 'safety' here because in my view safety is different from absence of serious incidents. Safety is rather implicitly present because aviation and especially air traffic control is not a system that is designed and works 'as designed' but which functions well because of the day-to-day interactions involving human beings, who all try to cope the best they can.

And in the end it is because of this permanent interaction that progress and safety evolves. New rules and procedures on the other hand, no matter how well-intentioned they might be, too often constrain the adaptive powers of the people interacting and do not necessarily enhance safety.

Despite this, it goes without saying that I am responsible and, if you will, accountable for my actions and decisions within my radius of operation (just culture). And you can rest assured that I am the worst critic of my actions and decisions and, like my colleagues, I will always FEEL responsible for the outcome.

**Andreas Conrad**  
Supervisor ACC Langen  
DFS, Germany



# REFERENCES AND FURTHER READING

- 
- Ackoff, R. (1999). *Ackoff's best: His classic writings on management*. John Wiley.
- 
- Amalberti, R. (2001). The paradoxes of almost totally safe transportation systems. *Safety Science*, 37, 109-126.
- 
- Bainbridge, L. (1983). The ironies of automation. *Automatica*, 19(6), 775-779
- 
- Dekker, S. (2011). *Just culture: Balancing safety and accountability*. Ashgate.
- 
- Dekker, S. (2014). *A Field guide to understanding 'human error'*. Third edition. Ashgate.
- 
- Deming, W.E. (2000). *Out of the crisis*. MIT Press.
- 
- Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W.S., Wilson, J.R., & van der Doelen, B. (2012). A strategy for human factors/ergonomics: Developing the discipline and professions. *Ergonomics*, 55(4), 377-395.
- 
- EUROCONTROL (2013). *From Safety-I to Safety-II: A White Paper*. EUROCONTROL.
- 
- Geertz, C. (1973). Thick description: Toward an interpretive theory of culture. In *The interpretation of cultures: Selected essays*. New York: Basic Books. pp. 3-30.
- 
- Hollnagel, E. (2009). *The ETTO principle: Efficiency-thoroughness trade-off. Why things that go right sometimes go wrong*. Ashgate.
- 
- Hollnagel, E. (2012). *FRAM: Functional resonance analysis method*. Ashgate.
- 
- Hollnagel, E. (2014a). *Safety-I and Safety-II. The past and future of safety management*. Ashgate.
- 
- Hollnagel, E. (2014b). Human factors/ergonomics as a systems discipline? "The human use of human beings" revisited. *Applied Ergonomics*, 41(1), 40-44.
- 
- Hollnagel, E., Paries, J., Woods, D.D. & Weathall, J. (2011). *Resilience engineering in practice: A guidebook*. Ashgate.
- 
- Hollnagel, E., Woods, D.D. & Leveson, N.G. (2006). *Resilience engineering: Concepts and precepts*. Ashgate.
- 
- Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science*, 42(4), 237-270.
- 
- Leveson, N. (2012). *Engineering a safer world: Applying systems thinking to safety*. MIT Press.
- 
- Martin, J.N. (2004). The seven samurai of systems engineering: Dealing with the complexity of 7 interrelated systems. *Symposium of the international council on systems engineering (INCOSE)*.
- 
- Meadows, D. & Wright. (2009). *Thinking in systems: A primer*. Routledge.
-

---

Rasmussen, J. (1997). *Risk management in a dynamic society: A modelling problem*. *Safety Science*, 27(2-3), 183-213.

---

Rasmussen, J. & Svedung, I. (2000). *Proactive risk management in a dynamic society*. Swedish Rescue Services Agency.

---

Seddon, J. (2005). *Freedom from command and control (Second edition)*. Vanguard.

---

Snowden, D.J. & Boone, M.E. (2007). A leader's framework for decision making. *Harvard Business Review*, November, pp. 76-79.

---

Stanton, N. A., Salmon, P.M., Rafferty, L.A., Walker, G.H., Baber, C. & Jenkins, D.P. (2013). *Human factors methods: A practical guide for engineering and design (Second Edition)*. Ashgate.

---

Open University. (2014a). *System maps and influence diagrams (basic tutorial)* <http://bit.ly/1u8HKm1>.

---

Open University. (2014b). *System maps (detailed guidance)* <http://bit.ly/1n4cbH9>.

---

Open University. (2014c). *Influence diagrams (detailed guidance)* <http://bit.ly/1oNEVa8>.

---

Williams, B. & Hummelbrunner, R. (2010). *Systems concepts in action: A practitioner's toolkit*. Stanford University Press.

---

Wilson, J.R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics*, 41(1), 5-13.

---

Wilson, J.R. & Sharples, S. (2014). *Evaluation of human work*. Taylor and Francis.

---

Woods, D.D., Dekker, S., Cook, R., Johannsen, L. & Sarter, N. (2010). *Behind human error*. Ashgate.

---

## PHOTO CREDITS

p. 1. NATS Press Office <https://flic.kr/p/cwfQQL> CC BY-NC-ND 2.0  
p. 2. Pawel Loj <https://flic.kr/p/2fHLQv> CC BY 2.0  
p. 7. NATS Press Office <https://flic.kr/p/eHUA3u> CC BY-NC-ND 2.0  
p. 9. EUROCONTROL © <https://flic.kr/p/8VCAJj> (All rights reserved)  
p. 11. NATS Press Office <https://flic.kr/p/cwfK51> CC BY-NC-ND 2.0  
p. 13. Douglas Sprott <https://flic.kr/p/5orYgw> CC BY-NC 2.0  
p. 15. autowitch <https://flic.kr/p/nTTX> CC BY-NC-SA 2.0

p. 17. Randomwire <https://flic.kr/p/7u6jhM> CC BY-NC-SA 2.0  
p. 19. \_chrisUK <https://flic.kr/p/cxTU91> CC BY-NC-ND 2.0  
p. 21. Angelo DeSantis <https://flic.kr/p/dSbG9V> CC BY 2.0  
p. 23. NATS Press Office <https://flic.kr/p/dA481J> CC BY-NC-ND 2.0  
p. 25. Rafael Matsunaga <https://flic.kr/p/JmU2w> CC BY 2.0  
p. 27. Naviar © <http://naviir.dk> (All rights reserved)  
p. 31. NATS Press Office <https://flic.kr/p/cwfyq7> CC BY-NC-ND 2.0  
p. 34. Christian Schnettelker [www.manoftaste.de](http://www.manoftaste.de) CC BY 2.0

# AUTHORS



**Steven Shorrock** is Project Leader, Safety Development at EUROCONTROL and the European Safety Culture Programme Leader. He has a Bachelor degree in psychology, Master degree in work design and ergonomics and PhD in incident analysis and performance prediction in air traffic control. He is a Registered Ergonomist and a Chartered Psychologist with a background in practice and research in safety-critical industries. Steve is also Adjunct Senior Lecturer at the University of New South Wales, School of Aviation. [steven.shorrock@eurocontrol.int](mailto:steven.shorrock@eurocontrol.int)

•



**Jörg Leonhardt** is Head of Human Factors in Safety Management Department at DFS – Deutsche Flugsicherung – the German Air Navigation Service provider. He holds a Master degree in Human Factors and Aviation Safety from Lund University, Sweden. He co-chairs the EUROCONTROL Safety Human Performance Sub-Group and is the Project leader of DFS-EUROCONTROL “Weak Signals” project. [joerg.leonhardt@dfs.de](mailto:joerg.leonhardt@dfs.de)

•



**Tony Licu** is Head of Safety Unit within Network Manager Directorate of EUROCONTROL. He leads the support of safety management and human factors deployment programmes of EUROCONTROL. He has extensive ATC operational and engineering background and holds a Master degree in avionics. Tony co-chairs EUROCONTROL Safety Team and EUROCONTROL Safety Human Performance Sub-group. [antonio.licu@eurocontrol.int](mailto:antonio.licu@eurocontrol.int)

•



**Christoph Peters** spends half his time as an Air Traffic Controller for Düsseldorf Approach and the other half as a Senior Expert in Human Factors for the Corporate Safety Management Department at DFS – Deutsche Flugsicherung. He completed a degree in psychology and is member of the EUROCONTROL Safety Human Performance Sub-Group and the DFS-EUROCONTROL “Weak Signals” project. [christoph.peters@dfs.de](mailto:christoph.peters@dfs.de)

# ACKNOWLEDGEMENTS

These principles have been derived from the work of key thinkers in the field of systems thinking, resilience engineering, systems ergonomics, social science and safety – too many to acknowledge here. The material is necessarily shortened and summarised at a very high level. Readers are strongly encouraged to read some of the original works in the References. The contents of the White Paper are the result of cooperation between EUROCONTROL and a number of air navigation service providers, via the EUROCONTROL Safety Human Performance Sub-Group, Safety Improvement Sub-Group, RAT User Group, and Safety Team. We particularly would like to thank the contributors to the views from the field and the narratives, and also the reviewers of this White Paper.

## Graphic design

Steven Shorrock



## NOTES

[illegible]



© August 2014 – European Organisation for the Safety of Air Navigation (EUROCONTROL)

This document is published by EUROCONTROL for information purposes. It may be copied in whole or in part, provided that EUROCONTROL is mentioned as the source and it is not used for commercial purposes (i.e. for financial gain). The information in this document may not be modified without prior written permission from EUROCONTROL.

[www.eurocontrol.int](http://www.eurocontrol.int)