Themes and Systems Safety Investigations (TSSI)

Proactively Investigating for System Safety Improvements

By Daniel Foley and Matthew Harris

Dan Foley (ISASI member: MO5732) *co-developed the Civil Aviation Authority of New Zealand's Themes and Systems Safety Investigation methodology. Dan's work acknowledges that complex systems such as aviation, need to be explored from a different perspective to those traditionally used. His work has enabled aviation system risks to be identified, providing clarity and understanding of the risks. Prior to his Themes and Systems work, Dan has spent 13 years as a Safety Investigator with the New Zealand CAA. He has a tertiary qualification in mechanical engineering, is a fixed wing aircraft instructor, Commercial Transport Pilot, and was an international calibration and commissioning pilot.*

Matt Harris *is one of the leads in the Civil Aviation Authority of New Zealand's Themes and Systems Safety Investigation function and co-developer of the function. A Safety Investigator of 8 years, he has a broad aviation engineering background, having experience in production, design and airworthiness. Matt is skilled at complex system safety, being actively involved in the investigation of socio-technical systems from a human factors perspective, taking a system-wide view to problem solving. Matt is currently undertaking a PhD in psychology with the University of Southern Queensland, Australia, focusing on supervisory practice, safety motivation and multilevel influenced, normalised risk-taking.*

Abstract "Hindsight is a wonderful thing but foresight is better, especially when it comes to saving life, or some pain!" William Blake

Aviation safety has seen major improvement over the last century due to the undertaking of safety investigations. The early focus was towards technical issues, with developments in design and manufacturing providing improved reliability.

As safety investigation matured, the focus shifted towards understanding human error, leading to crew resource management (CRM). We then began to understand that organisational latent factors were contributing to accidents. (Swiss cheese model).

Traditional investigation approaches are effective at identifying what barriers failed and what particular set of circumstances led to the accident.

As a risk-based regulator the CAA uses the themes and systems safety investigation (TSSI) methodology to help it understand complex problems.

The Civil Aviation Authority of New Zealand (CAA) conducts approximately 300 event-based safety investigations annually from a reported 9500 occurrences. The benefits that can be gained from these event-based safety investigations however, have their limitations. It is considered that greater safety benefits can be realised beyond the constraints of the causal chain of events. As such the CAA has developed a TSSI methodology.

Introduction

As a regulator, the ultimate aim of the CAA is to improve aviation safety before accidents happen, rather than retrospectively after they occur. As such, the safety investigation unit at the CAA has been developing an approach that is more proactive rather than reactive. To this end we have developed the themes and systems safety investigation (TSSI) which complements and works symbiotically with the traditional event-based, Annex 13 type investigation which still forms a crucial part of our work.

In this paper, we outline the process of initiating and conducting proactive themes and systems safety investigations, and the benefits such investigations can deliver. We describe the TSSI approach and explore the indicators that point to where such an approach is warranted. We conclude with a case study from New Zealand that showcases the TSSI process; the unravelling of a complex problem, the identification of the way the system is working in practice, and the tailored interventions[i] employed.

Traditional Safety

The CAA of New Zealand is slightly different to other regulators and accident investigation bodies around the world. All aviation accidents, serious incidents and a large number of other aviation occurrences, have to be reported to the CAA under the provisions of Civil Aviation Rule Part 12. Part 12 provides a level of protection to aviation participants who report their occurrences to the CAA, this is done in line with just culture principles. As such the CAA receives approximately 9500 reported occurrences a year. That makes the CAA data rich, with a relatively sterile pool of information. Out of the 9500 occurrences reported annually, the CAA conducts approximately 350 event-based safety investigations and upwards of 4 TSSI investigations annually. In New Zealand, this data has facilitated proactive engagement between the CAA and industry, enabling threats to the system to be tackled in a collaborative manner.

The CAA aims to be an intelligence driven, risk-based regulator and as such looks to identify and manage risks to the aviation system through its Regulatory Safety Management System. The TSSI dovetails into this work, providing the CAA with a way to examine and investigate complex problems, facilitate the implementation of tailored interventions, and provide the intelligence with which to measure the effectiveness of those interventions.

Taking a wider look at the global and historical context, we can see that world wide aviation safety has seen major improvement over the last century due to the undertaking of safety investigations. That's great news and a reflection of the commitment over the years that safety professionals have made. Early safety focused on technical issues, with developments in design and manufacturing providing improved reliability. As safety investigation matured the focus shifted towards understanding human error, leading to improvements like CRM. We then began to understand that organisational latent factors were contributing to accidents.

Figure 1 illustrates a traditional investigation approach which is effective at identifying what barriers failed and what particular set of circumstances led to an accident. We would typically see failed barriers such as inadequate oversight, poor procedures, human error and the list goes on. This type of accident investigation model is outcome focused, which makes sense, there has been an accident or an incident, so we want to know what caused it.

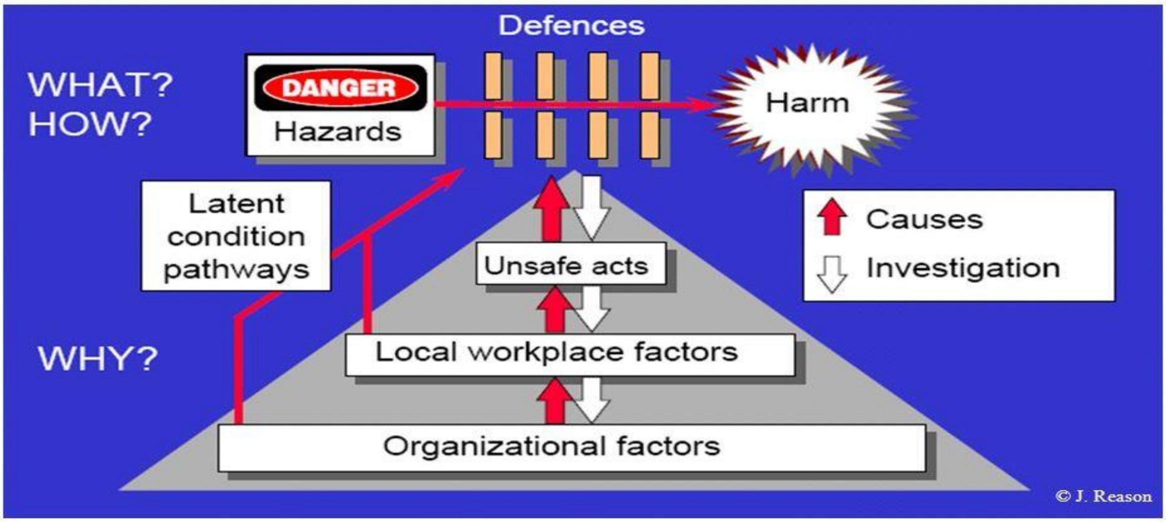

Figure 1 - James Reason's (1997, p. 17) model of organisational accidents

However, this outcome focus has led to a worldwide game of "whack-a-mole", reacting to problems as they pop up, focusing on individual events and only sometimes grouping outcomes together to look for trends. There is a heightened focus on human error, and the overly simplified view that if we control people's behaviour, and they pay attention and comply, all will go well. More recent thinking in the safety sector suggests that this view is outdated.

Professor Sidney Dekker, in his book a Field Guide to Understanding Human Error (2014), argues that human error is not a cause, but a symptom of wider system issues, and we would agree. If we want to move away from the reactive game of whack-a-mole, and gain a deeper understanding of what went wrong, we need to look at things differently. If we, as safety professionals, hear the term 'human error', that should raise a flag that we need to take a deeper look. This is where we can gain safety benefit. This is a starting point, not an end point.

As an industry we have, in theory, moved on from terms like pilot error or more generally, human error. This is in recognition of the fact that the term "error" is hindsight biased, it has no explanatory power, and fails to account for the fact that people do things that make sense to them at that time (Dekker 2014). An action can only be judged as an error after the fact and knowing that the outcome was adverse. We believe that the raw term human error, as well as terms like "should have", "could have" and "would have", are not helpful in safety investigation. They attribute blame or fault, and "blame is the enemy of safety" (Leveson 2011, p. 56). In practice however, terms such as "the pilot lost situational awareness", or "the PIC became complacent" still find their way into aircraft accident reports. Based on the criteria above, these phrases are essentially just another way of saying human error. A pilot can only be judged to have lost situational awareness retrospectively, and if the outcome was adverse.

A different perspective

Safety professionals need to take a more mature viewpoint and understand that individuals and teams will adapt to the dynamic environments that they work in and that people make decisions that make sense to them at the time. This is known as 'work-as-done'. To be a higher performing industry, we need to be mature enough to realise there is a difference or 'drift' between what we think should be happening (work-as-expected) and what is actually happening (work-as-done). And that this drift is due to system factors.

Figure 2 illustrates the overlap and, perhaps more importantly, the discrepancies between the way work is conducted in complex systems; work-as-expected[ii], work–as-prescribed, work-as-disclosed and work-as-done. Note the "messy reality" often sits somewhere near the intersection of all of these but may not cross into the "prescribed" area, suggesting that merely having the controls in place and expecting people to comply is unrealistic and insufficient for improving safety.

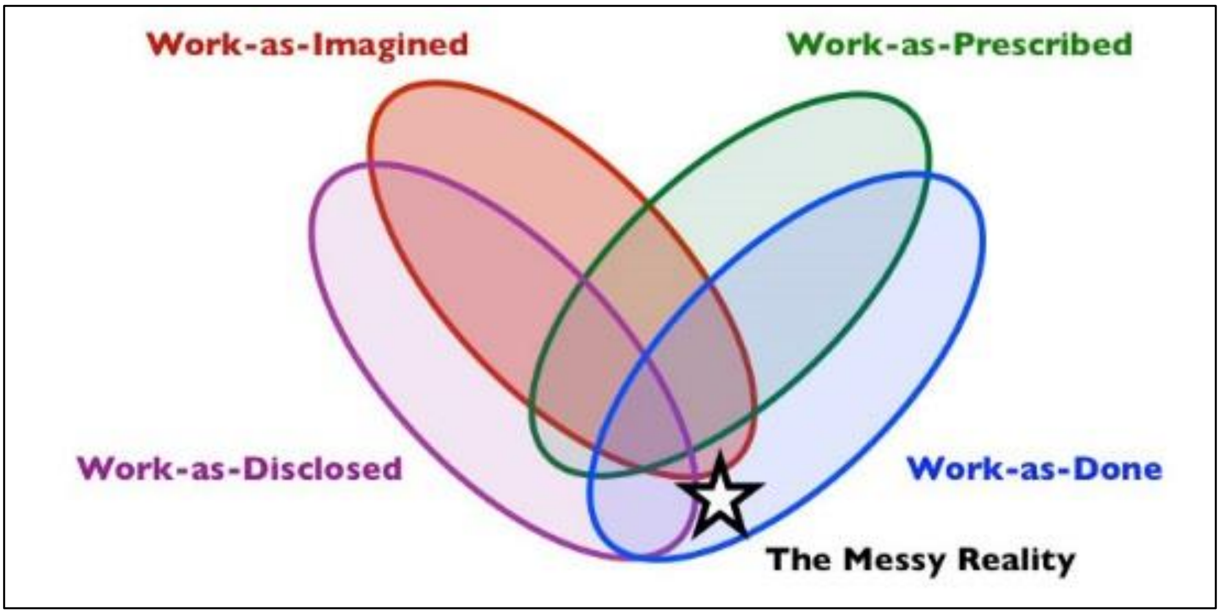

Figure 2. – Types and perception of work (Shorrock 2016)

We need to understand work-as-done from the point of view of the individual doing that work, not just what we think should have happened. This will help us gain a deeper understanding and provide us with an appropriate amount of clarity of what is actually happening, so that we can be proactive in our approach.

We can of course investigate and determine that people are not working as expected – 'not following the rules, etc.' and train them to do so next time, but maybe we need to begin to shift our perspective to gain a more comprehensive understanding of why they are not working as expected.

We have identified five themes underpinning the complex system safety thinking (Dekker 2011, EUROCONTROL 2013 and 2014, Leveson 2011) that have informed this approach:

1. Safety is created through practice and proactively equipping people to succeed.
2. People are both important safety barriers and sources of recovery.
3. The system is not inherently safe but people can create safety in complex systems.
4. Success and failure come from the same source – normal/ordinary work.
5. Accidents are often the result of interactions among components in complex systems that are all satisfying their individual requirements. This does not mean the components themselves have failed. Failure is an emergent property of the overall system factors.

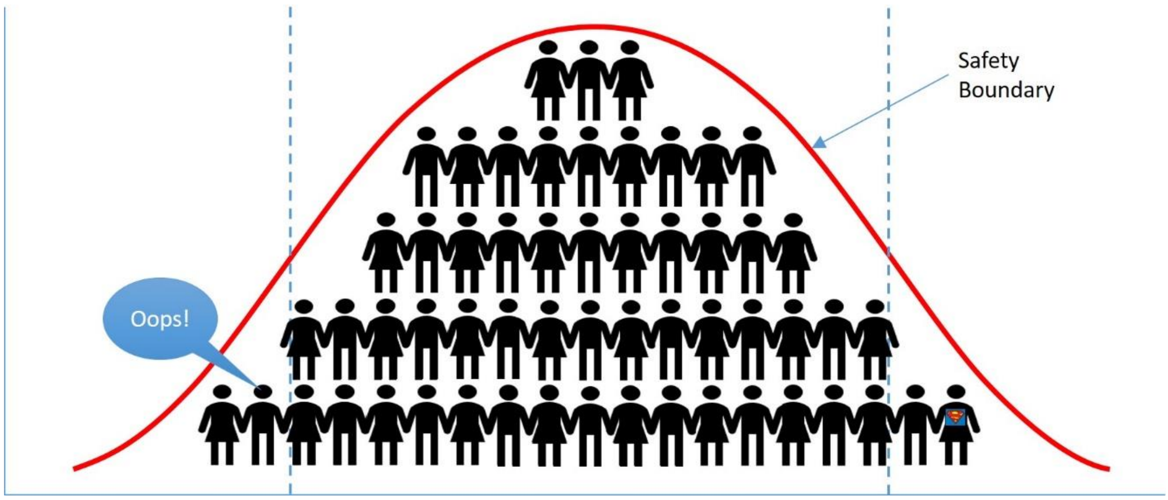

Figure 3. – Safety I to Safety II

Consider Figure 3, remembering that success and failure come from the same source - normal/ordinary work. We normally look at what went wrong on the left-hand side of this diagram. Or we consider the positive outcomes, on the right-hand side. Captain Sully is a prime example of this. However, both viewpoints are outcome focused. What we need to understand is the actual work-as-done and identify precursors to indicate whether things are moving left, towards failure, or right, towards success. We need to consider things from the point of view of those involved in the actual operation.

We stated previously that people do things that make sense to them at the time. This encapsulates what is known as the “local rationality principal” (Woods, Dekker, Cook, Johannesen and Sarter 2010) according to which people do the most reasonable thing in a given context according to their goals, knowledge and focus of attention. To understand why a person might have made a particular decision, we therefore need to understand:

- What the person was trying to achieve (and whether there were multiple goals in conflict with one another)
- What knowledge the person possessed at the time
- How the system influenced the assessments & actions being carried out.

"The Dekker pipe" (2014, p. 68), shown in figure 4, illustrates what we need to do to gain this crucial understanding of why a certain decision was made.

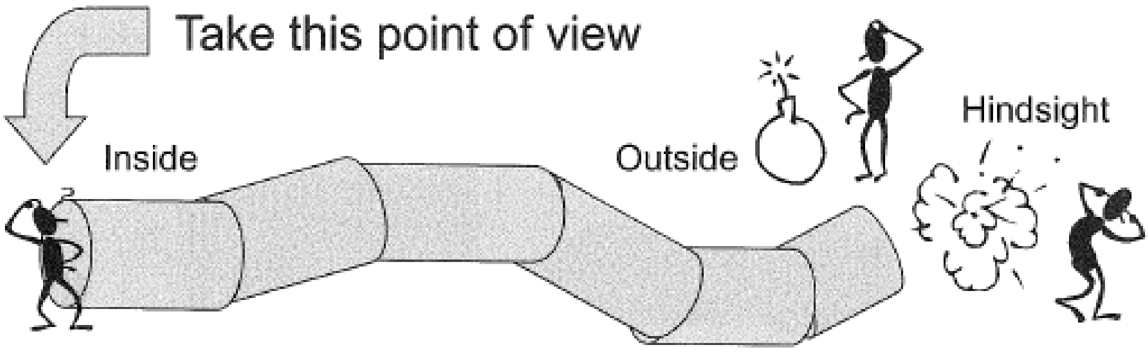

Figure 4. – Dekker's pipe (2014, p. 68)

For instance, after an accident we can look retrospectively at the event – taking the outside view in the top and bottom right side of the diagram. If we take this view, it leaves us susceptible to the two predominate biases: hindsight and outcome bias.

Hindsight bias is exemplified by questions such as: "They had all this information, why didn't they just do that?", while outcome bias is shown, for example, by categorising something as "a poor decision". It is easy to identify a decision as poor when we can also see the adverse outcome, however no one sets out to make a poor decision. Indeed they may have made similar decisions previously that did not have the negative outcome and thus, based on the evidence of their previous experience their decision may not appear to be "poor" at the time.

To understand the rationale behind a decision, we need to take the 'Inside' view. To do that, we must attempt to put ourselves in the person's position, to see things from their perspective. To find out what made sense to them at the time. We need to reconstruct the actual changing circumstances or environment that the person was working in. We need to be aware that there is a strong two-way relationship between circumstances & behaviour.

A different perspective in practice

The CAA Safety Investigators use these principles when conducting either an event or TSSI based safety investigation. When conducting an event-based investigation, we focus on what has happened and why for a specific event or events. This is similar to the Annex 13 approach and we acknowledge that this is the foundation of safety improvement. A TSSI compliments and builds on this approach.

During a TSSI investigation, the team of investigators take a holistic view, often without an accident occurring. A TSSI investigation can be commenced to understand what impact there may be if, for instance, the system is modified, and determine if there will be any unintended consequences. It will also allow the monitoring of the system change. This is proactive in nature.

There is no standard road map for a TSSI investigation. The beginning of a TSSI starts with designing the approach or structure to be employed in each case. It also involves using historic data, reclassifying the data to make it consistent and relevant in today's context.

Moving now from the theoretical to the practical, we will explore the ways in which the CAA conducts investigations or, more specifically, how we solicit information to provide clarity about a problem, which is then applied to our risk-based principles.

When faced with a problem, we have three possible lenses we can apply to it, as seen in Figure 5. These are an Event lens, a Themes lens, and a Systems lens. We can employ any or all of these lenses to a given problem in order to provide clarity on how that problem has emerged.

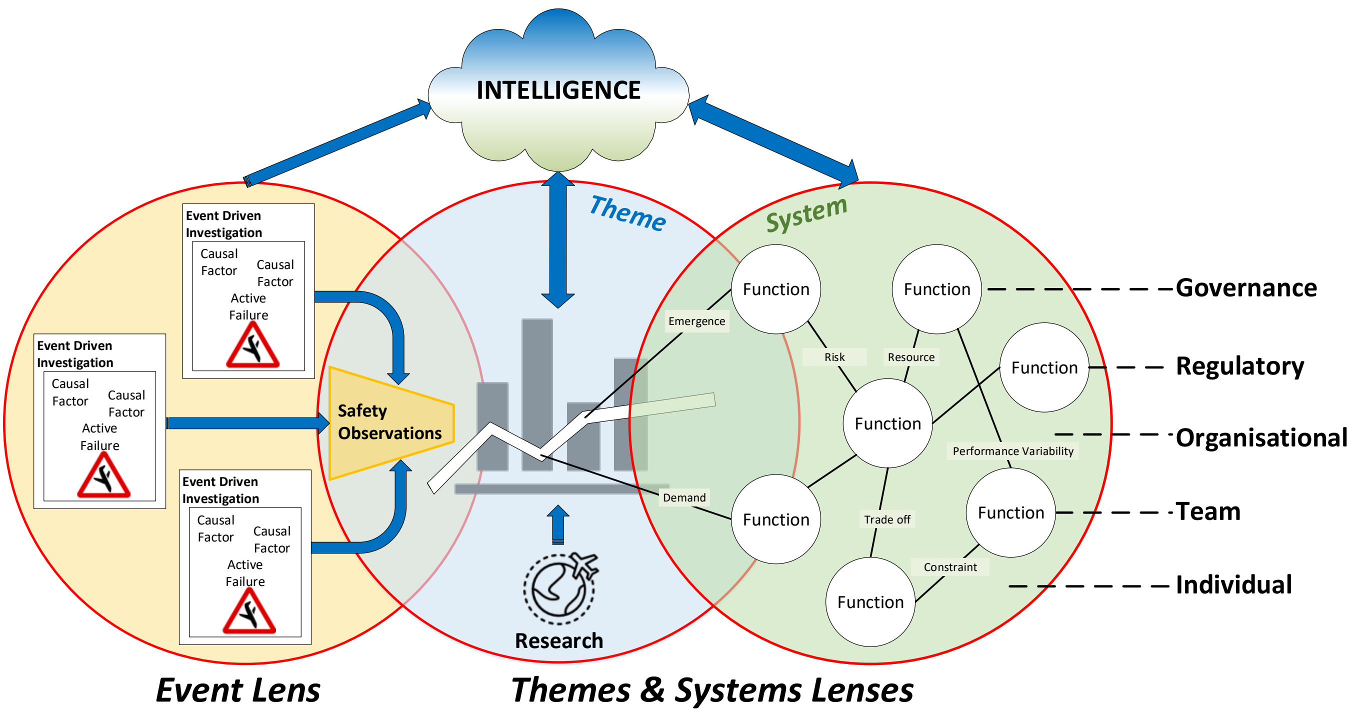

Figure 5. – Emergent problem investigation lenses.

Let us first look at the event lens. Following an occurrence, the team will conduct a safety investigation, in a similar manner to the traditional, Annex 13 type of investigation. We would typically look at the human, the machine and the environment, how these pieces of the puzzle interact and the potential survivability of the occurrence. We identify the active failure and any latent failures that may have been present. Any safety deficiencies are addressed through safety actions or interventions to fix the problem. Where we may differ to other investigating agencies is that we also seek to identify precursors. Precursors can be defined as those factors which preceded an event and may have adversely affected an element, or elements involved in the event, but on their own may not necessarily cause the event. Precursors are generally grey in nature and as such are harder for safety investigators to deal with. They lack the black and white evidential level that safety investigators base their conclusions on.

In a themes investigation we start to group precursors together and look for patterns. We are not outcome focused. For example, say we investigate a runway excursion and find it occurred as a result of the pilots being distracted due to ATC tasking. During another safety investigation we found that a pilot was distracted while conducting a deer recovery operation, and the helicopter's main rotor blades contacted a shrub. The outcome of these occurrences is totally different, yet the precursor that led to them was almost identical, the pilot's distraction. This leads to the questions; why were pilots distracted and what were the trade-offs the pilots were dealing with. The distraction may be another symptom of a deeper problem, e.g. both pilots were fatigued having little sleep opportunity over the last 48 hours.

Once we have grouped the occurrences and precursors, and sliced and diced them using analytical tools, we look for common themes. A theme might be: In New Zealand a helicopter pilot is 7 times more likely to depart a controlled airport without a departure clearance than a fixed wing pilot. If the CAA has enough clarity about why this occurs, then an intervention may be applied at this stage. If there isn't sufficient clarity about why this is occurring, or if there is a concern that an intervention that is to be employed may have unintentional consequences, then a systems investigations is commenced.

A systems investigation could be viewed as the real "deep dive" methodology of the three investigative lenses. As such, it provides the highest level of clarity about a problem. Systems investigations involve identifying who the system players are and working with them on system influences and relationships. The problem becomes clear over the course of the investigation, appropriate interventions become obvious, and are adopted by those system players. In this way, the people who are actually part of the system, that is, those that have the most potential to influence safety in everyday work, have buy-in to the interventions. During the process of conducting a TSSI, it is important to get input from all of the system players. When faced with a problem, diversity of thought with multiple views will allow you to truly identify the problem. This kind of deep-dive methodology is so effective in aviation safety because we are so often dealing with complex systems. As we saw previously, problems and risks often emerge out of complexity. It is not one individual part of the system but the complexity of the system as a whole that is causing the problem to emerge and the solution to complex problems can be considered that of having transparency of the system factors.

Some of the tools that are utilised in a TSSI may be quite different to those traditional investigation tools. These tools may include word pictures, surveys, focus groups, and also engaging in observational tools such as LOSA. This helps gain industry buy in, diversity of thought, and understand work-as-done. We have diversified our skill set and work closely with a group of CAA analysts to turn data into intelligence.

Another element of a TSSI investigation is mapping the system players as well as the influences within the system, to determine the emergent properties. Figure 6 depicts a system influence map.

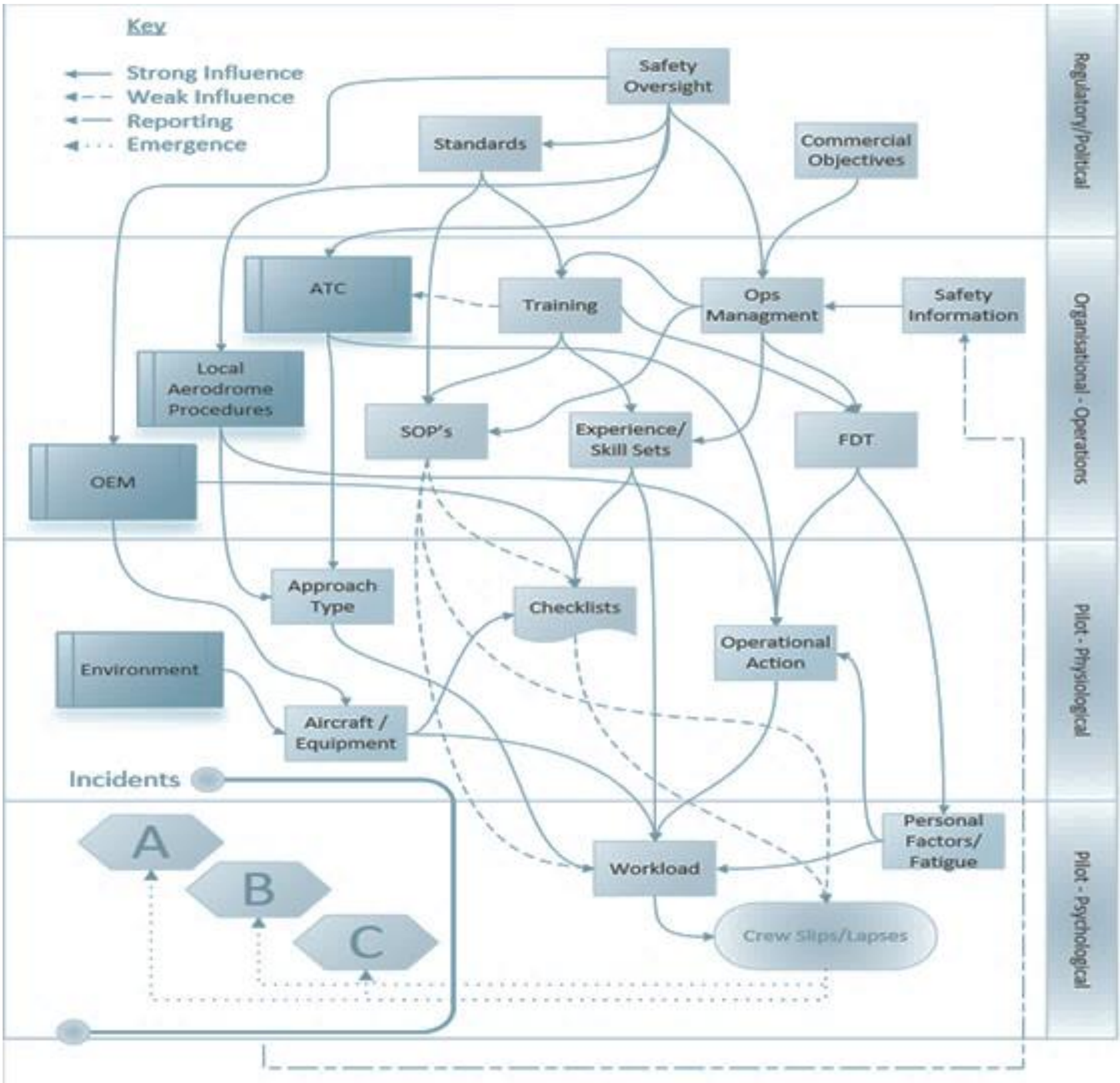

Figure 6. – System influence map

The system is explored from an individual, team, organisation, regulatory and governance level perspective. Typically, this is done by getting a proportion of representatives together in a workshop forum. The diagram shown in Figure 6 depicts the complex system influences generating high workload on the crews in a New Zealand organisation. This high workload led to crews dynamically adapting to the situation, making trades-off to accomplish tasks. Due to the complexity of the situations, slips and lapses were made and different incidents emerged. What this shows us is that the errors are not the root cause of any occurrences that may have resulted, but rather the symptom of a deeper system problem – the high workload.

Following a TSSI investigation, the CAA has significant clarity around a problem, has identified the system factors that need to be modified, and will be able to monitor the system to make sure that the changes have indeed had the desired effect.

In practice, the Safety Investigation Unit at the CAA recently identified an operator who was having multiple serious incidents. Over a short period they had 10 serious incidents, which could have led to accidents. The operator had tried multiple interventions and had erected more safety barriers, yet these serious incidents kept occurring. When approached, it became evident that the operator was trying to address each occurrence in isolation and had not identified the precursors. They were playing a game of whack-a-mole, with a limited understanding of the actual problem.

Collaborating with the operator's safety team, a TSSI was conducted which identified the precursors, grouped them and derived two underling themes. This provided clarity about the actual problem. Gaining the intelligence of the system factors and understanding how the system is operating has led to the reduction of serious incidents in this case. This is a clear example of working proactively to prevent accidents.

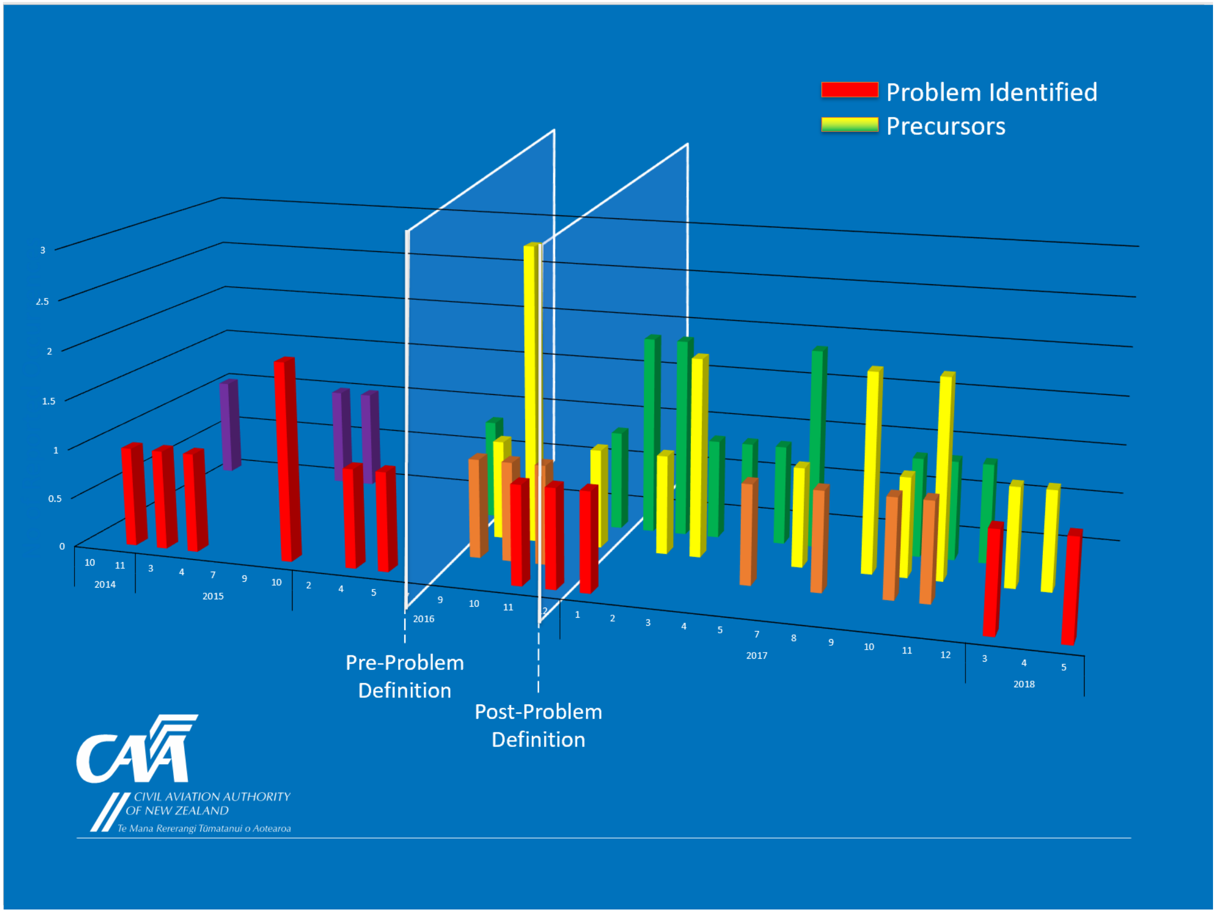

Figure 7. – Operator's occurrences pre- and post- TSSI implementation monitoring.

Figure 7 presents some of the actual data from that TSSI investigation. The colour bars represent reported occurrences. The simplest way of looking at the data presented here is to look at it by the colour groupings. The red bars are the serious incidents which could have led to accidents. The purple and brown bars are less critical incidents but emergent outcomes of the same precursors as the serious incidents. The yellow and green bars are the precursors - the two themes leading to the problem.

This shows that leading up until early 2016, the serious incidents kept occurring, even though each of the serious incidents had been investigated and safety actions had been put in place. In mid-2016 a TSSI was initiated. From this time you can see that we began to identify the precursors and understand the themes behind the serious incidents and other incidents reported. By the end of 2016 we had a thorough understanding of the problem and the system factors generating the emergent outcomes. From here, tailored interventions were put in place to influence the emergent properties and mitigate the problem.

You may notice that in early 2018 there were two further serious incidents reported. This demonstrates the concept of emergence quite well. These two serious incidents again emerged from the complex interactions and system factors, including those factors changed as part of the outputs from the TSSI. However, having clarity and understanding of the system factors enabled further refinements to be made ensuring that these unintended consequences were addressed. Since mid-2018 there have been no serious incidents of this type reported by the operator, even though reporting in general has increased significantly, with the number of flights steadily increasing.

This is the first time that the CAA has been able to conduct a full TSSI Investigation, implement an intervention, and monitor the effectiveness of that intervention. Today we are still actively monitoring this operator and the interventions.

Conclusion

In conclusion, we, as an industry of safety professionals need to look deeper than human error, and challenge ourselves when we may be using hindsight bias. We are a mature industry and should not encourage terms like “should have”, “could have” and “would have”. It is important to remember that blame is the enemy of safety, but also to put this into practice by searching for deeper understandings of how problems emerge. We have the potential to lead the world in a more proactive and positive manner. As William Blake said “Hindsight is a wonderful thing but foresight is better, especially when it comes to saving life, or some pain”. Complex system safety improvements need a proactive approach to understanding how the system operates.

For further information on TSSI, or to conduct the first TSSI training module which is free and online please visit this link: https://www.caa.govt.nz/resources/TSSI/index.html

We welcome any feedback or thoughts you may have on the model. You can contact us at Dan.Foley@caa.govt.nz and Matt.Harris@caa.govt.nz.

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Footnotes:

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[i] Interventions is a collective term used for all safety related actions and recommendations resulting from an investigation.

[ii] For our purposes, work-as-expected is comparable to work-as-imagined, this is what people think “should” be happening.