A review of cognitive aids and their application to emergency management in Australia

Abstract

Decision-making in disasters and major crises faced by emergency services globally is a difficult combination of science and art to master. To assist decision-makers in these environments, a number of cognitive aids have been developed and subsequently adopted by individuals and organisations alike. However, these aids vary according to their intent and the context in which they are intended to be applied. This review explores the use of cognitive aids in the context of emergency management and explores how existing knowledge regarding the use of cognitive aids from other industries may be translated to emergency management. An iterative literature review of academic and industry material related to cognitive aids during incident and crisis response across a broad range of international emergency service and other industries within the last 20 years was completed. Ultimately, cognitive aids are not a silver bullet when it comes to decision-making in the emergency management context. The correct tool (that is correctly designed) must be correctly applied by trained and competent end users. The Australian emergency management sector may benefit from future research exploring how these existing tools adhere to the good practice principles identified in this study.

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Introduction

High-consequence decision-making during highly complex events is a difficult combination of science and art (Penney et al. 2022; Reale et al. 2023; Ingham 2009). Although emergency management practitioners and teams generally have good capability to respond and are adaptive to the demands placed on them, their cognitive resources will at times be stretched by dynamic, uncertain, time pressured and high-stakes events. Fundamental cognitive processes (such as perception, attention, memory, reasoning, judgement and decision-making) can become overloaded leading to task performance that is less fluid, slower and susceptible to errors or omissions. Good systems, training, planning and preparedness help practitioners respond effectively to these incidents. However, they are still very likely to find these events challenging. To assist practitioners in these environments, a number of cognitive aids have evolved and have been adopted by individuals and organisations alike.

The term 'cognitive aid' was first used in the 1970s and was initially used to describe decision-support systems (McLaughlin and Byrne 2020). In the 1980s, cognitive aid was used to describe various tools and systems that supported other cognitive processes (Reason 1987). For the purposes of this paper, we use an expanded version of the Marshall (2013) definition of cognitive aid to encompass a broad range of tools used to support the operational performance of individuals and teams working under pressure. This definition goes beyond Marshall's (2013) task focused aids to include decision models, frameworks and systems; checklists, aide memoires, standard operating procedures and standard operating guidelines.

This paper reviews the literature on the different cognitive aids that are or could potentially be used in emergency management with the aim of providing more clarity about what cognitive aids are and how they can be used to support complex task performance in emergency management.

Various attempts have been made to categorise cognitive aids, either based on the cognitive processes needed to complete the task at hand (McLaughlin and Byrne 2020) or based on their methods and target outcomes (Fletcher and Bedwell 2017; Burian et al. 2018). In this paper, we adopt a modified version of the Burian et al. (2018) taxonomy and classify cognitive aids according to their purpose and intended application (prior to, during or after an event). Figure 1 shows this taxonomy, with the distinction between the extent to which they are:

- primarily cognitive or behavioural in nature (vertical axis)
- primarily intended for individual or team application (horizontal axis)
- primarily intended for use prior to, during, or post an event (colour coding).

We acknowledge that these are artificial distinctions, but they are useful to discuss cognitive aids and can help direct emergency management practitioners to the right type of cognitive aid depending on their needs and circumstances. Each of the tools is discussed in relation to this taxonomy in 5 categories that emerged as the review was completed. The categories are:

- decision process and behavioural tools
- tools to support analysis
- checklists
- operational procedures and guidance
- cues and alarms.

Method

This study involved an iterative literature review to identify academic and industry material related to cognitive aids during incident and crisis response across international emergency services and other industries over the previous 20 years. The review provided a narrative synthesis of the use of cognitive aids within the context of emergency management as well as explored how existing knowledge regarding the use of cognitive aids from other industries translated to the emergency management context. The review used search terms including and synonymous with decision models, frameworks and systems, checklists, aide memoires, standard operating procedures and standard operating guidelines within emergency management and industry contexts. References of included works were reviewed for additional suitable material. Databases included those available through the research team's tertiary institutions, Google Scholar and Research Gate and open source material. Industry material was also reviewed from emergency services agencies where available. The search identified more than 6,000 titles published in the last 20 years. The papers were reviewed for relevance with 79 papers found to address the topic. Narrative synthesis of the 79 articles was conducted to provide a comprehensive picture of the subject matter and to guide new findings and conclusions (Fielding and Thomas 2001; McNeill and Chapman 2005).

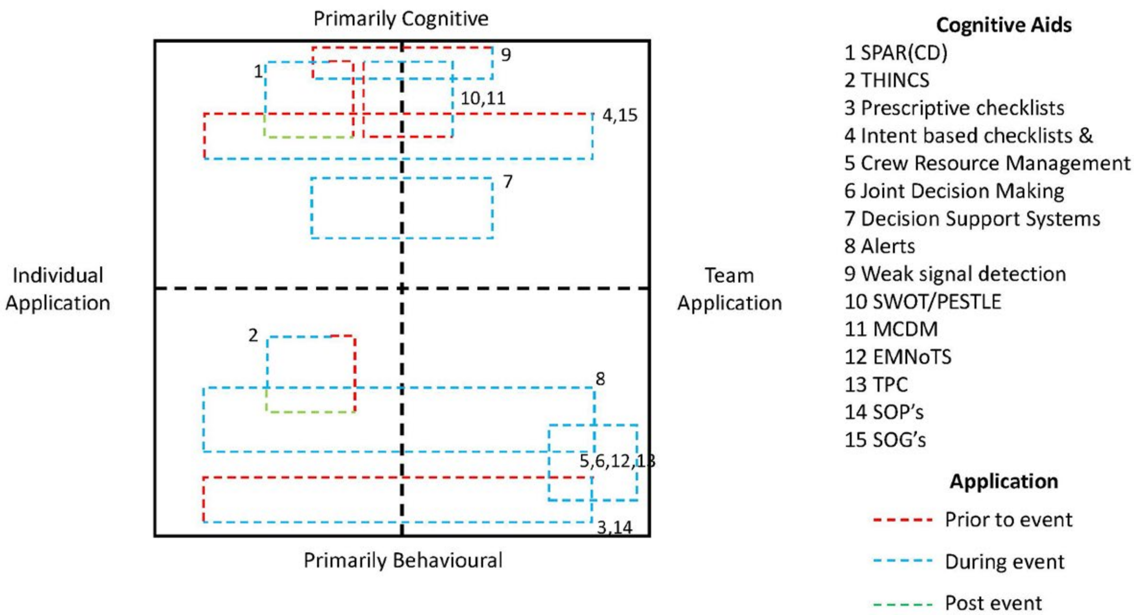

Figure 1: Depiction of cognitive aids based on the extent to which they are primarily cognitive or behavioural in nature (vertical axis), primarily intended for individual or team application (horizontal axis) or primarily intended for use prior to, during, or post an event (colour coding).

Source: Based on Burian et al. (2018)

Results

Decision process and behavioural tools

Cognitive aids are designed to:

- facilitate decision-making through structured and semi-structured non-technical processes such as decision frameworks and models
- facilitate enhanced analysis and sensemaking of multiple and complex criteria
- assist the development of a common operating picture where all personnel share a clear understanding of the situation, environment and actions or
- provide real-time intelligence and options.

They can be used prior to an event for planning or during an event in real time. They are key to the training of new personnel and once learnt, are designed to improve the process of decision-making during an incident. When applied correctly they can assist with a more consistent process of decision-making (Launder and Penney 2023a). However, they do not and cannot necessarily ensure that a correct decision is made in any particular circumstance. They require the user to be familiar, if not competent, with their application prior to use in real world situations.

At a tactical level, emergency management decision-making is typically driven by naturalistic intuitive processes (Klein et al. 1993; Penney et al. 2022; Reale et al. 2023). At the strategic level of emergency management, where there is often time and increased political and community consequences, more involvement of structured analytical processes in decision-making is generally required. Within military and emergency management contexts, established tools that facilitate structured analytical decision-making (e.g. decision ladders, step-based protocols) share common elements including extended situational analysis (e.g. risk identification, assessment and evaluation) and the identification and comparison of multiple options.

An example of a cognitive aid is the Situation Awareness – Context – Decision Strategy – Planning – Action – Review (S(CD)PAR) model developed by Launder and Penney (2023a). The model focuses on an individual decision maker, however, it could also be applied as a meta-level framework to help incident management teams understand the overall decision-making process. S(CD)PAR identifies 6 stages of an ideal decision-making process, which can be separated into pre-decision, decision and post-decision phases. The theoretical S(CD)PAR framework has been translated into a practical operational guide in the SPAR(CD) model (Launder and Penney 2023b) for use across industries and contexts allowing for consistent training, application and post-incident examination of high-risk, time-sensitive decisions and the identification of common decision errors.

Other examples of cognitive aids to assist decision-makers are crew resource management (CRM) and non-technical skills (NTS) frameworks. CRM was developed as a training program to reduce the incidence of human error in the aviation industry (Kanki et al. 2019; Gross 2014) but has also been applied to the field of emergency medicine (Kemper et al. 2017). Rather than decisions being made by an individual (the chief pilot), CRM involves the use of all available resources from information, equipment and especially other people. CRM is a systematic way of assisting a decision maker to make more accurate and robust decisions by using 'collective cognitive skills to gain and maintain situational awareness and develop our interpersonal and behavioural skills to establish relationships and communicate with everyone involved' (Mulenburg 2011, p.13). This helps to combat the issues of human error and failures of cognitive and social skills that were found to be the primary cause of accidents in complex socio-technical environments (Flin et al. 2003; Kanki et al. 2019; Gross 2014).

NTS frameworks are related to CRM and can help to improve performance and reduce error. Several NTS behavioural marker systems that have been developed for these are:

- The Incident Command Skills (THINCS), Butler et al. (2020)
- Team Process Checklist (TPC), Bearman et al. (2023)
- Emergency Management Non-Technical Skills (EMNoTs), Hayes et al. (2021).

THINCS is focused on the individual while EMNoTS and TPC are team-oriented. Unlike S(CD)PAR which is primarily cognitive in its purpose, CRM and NTS frameworks are more behavioural. EMNoTS, for example, identify 7 behavioural markers that index NTS performance, such as communication, coordination, cooperation, leadership, situation awareness, decision-making and coping with stress and fatigue (Hayes et al. 2021). These systems help people to understand what good performance looks like, allow better management of NTS performance in real time and provide a basis for continuous improvement programs (Butler et al. 2020; Hayes et al. 2021).

A different approach has been adopted by the Joint Decision Model (Lamb et al. 2021) that is designed to encourage responders to bring together available information and coordinate goals, decisions and actions to provide a common structure or frame to support responders to jointly consider single and interagency goals. As such, it is designed to facilitate team decision-making. The model's framework comprises 5 linear phases (Waring et al. 2020, p.632):

1. Gather information and intelligence to establish situational awareness and a multi-dimensional understanding of events.

2. Assess risks and develop a joint working strategy.
3. Consider powers, policies and procedures relevant to the situation, and whether these may assist or constrain decisions.
4. Identify options and contingencies.
5. Take action and review what has happened to feed into situation assessments and amend plans if necessary.

When applied correctly, the model can assist to engage all stakeholders, reduce potential blind spots through shared awareness and encourage buy-in to the decision-making process. However, to do this, all participants must be competent in the use of the framework and share common understandings and systems. This may be difficult to achieve (at least without extensive training) in the current Australian emergency management context where different functional command systems including the Australasian Inter-service Incident Management System™ (AIIMS) and the Incident Command and Control Structure Plus (ICCS Plus) (ANZPAA 2022) are applied and different levels of expertise and experience are present across jurisdictions and organisations (AIDR 2023).

Tools to support analysis

There are a number of cognitive aids that help people to analyse aspects of the situation to support decision-making. These are primarily cognitive in their application.

In industries that require the analysis of multiple opposing quantitative and qualitative criteria (e.g. oil spill response, airlines, airports and air traffic management) the application of multi-criteria decision-making methods have become standard practice (Wu et al. 2017; Dozic 2019; Wang et al. 2022; Li et al. 2022; Yang et al. 2021). Multi-criteria decision-making methods involve advanced algorithms and the use of fuzzy logic systems, which can account for uncertainty of outcomes within criteria (Dozic 2019; Wang et al. 2023). While such systems can facilitate enhanced analysis of complex information against multiple criteria, they have not (so far) been applied operationally in an emergency management context.

Decision-support systems are software or applications designed to assist decision-making through the provision of real-time intelligence, the prediction of potential outcomes or suggested courses of appropriate action. Examples include applications designed to evaluate a mortgage or plan a road trip (Becker et al. 2022). Within the context of emergency and military services, decision-support systems have been integrated into firefighting (e.g. Zarghami and Dumrak 2020; Tian et al. 2023; Nagarajan et al. 2023; Ujjwal et al. 2023; Wheatly et al. 2023; Xu et al. 2023; Kc et al. 2023), police operations (e.g. Theodosiadou et al., 2023; Sandhu and Fussey 2021; Wu 2021), emergency management (e.g. Kaur and Bhatia 2023; Sun et al. 2021; Bernabei et al. 2021) and military operations (e.g. Lee et al. 2023; Hunter and Bowen 2024; Johnson 2023). As decision-support systems become more commonplace and the integration of AI-supported decision-support systems into emergency management contexts occurs, the influence of trust and the relationship between decision-makers and decision-support systems becomes critical. Inappropriate levels of trust, both in terms of too little or too much, can result in the potential misuse or disuse of decision-support systems (Appelganc et al. 2022; Parasuraman and Riley 1997; Rieger et al. 2023).

Other simplistic, yet equally important tools such as SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) are embedded in business strategic decision-making (Koseoglu et al. 2019). Within emergency management, PESTLE (Political, Economic, Social, Technical, Environmental, Legal) is commonly applied (Penney et al. 2022; AFAC 2016; Sarwar et al. 2017) and is an analytical method best suited to complex systems that require extensive analysis (Christodoulou and Cullinane 2019). Tools such as SWOT and PESTLE provide predetermined and structured categories to assist users focus on relevant themes and categorise information, while continuing to allow freedom of analysis and interpretation within those categories.

Checklists and aide memoires

Checklists and aide memoires have likely been used informally for hundreds of years (Chapparo et al. 2019) but their formal use is attributed to the United States Airforce following a fatal crash in 1935 of a test flight in a new aircraft (Higgins and Boorman 2016; Hayes et al. 2020). An important distinction between types of checklists is between prescriptive checklists, which are primarily behavioural and specify tasks that must be completed and intent-based checklists, which are cognitive and guide decision-making. At a detailed level Chaparro et al. (2019) categorised checklists according to whether they are:

- sequential, where steps are expected to be completed in order
- laundry lists, where the order of task completion does not matter
- iterative, where the checklist is cycled through a number of times
- diagnostic, such as those commonly used in medicine or aviation to identify a medical condition or troubleshoot a systems malfunction
- criteria of merit, which assists the user to evaluate the performance of candidates under assessment.

Many of the checklists identified in this study were either sequential or laundry list checklists.

Checklists commonly used in emergency and crisis management are the suite of AIIMS and Emergency Management Professionalisation Scheme[1] functional role aid memoires. Other checklists in emergency management identify key tasks for regional and state coordination centres (Hayes et al. 2020) and seek to reduce biases (Brooks et al. 2020). Studies from a range of industries have demonstrated the potential effectiveness of checklists in improving team adherence to critical steps, increasing standardisation of performance, reducing mental workload and assisting fault-finding and trouble-shooting (Koseoglu et al. 2019; Greig et al. 2023; Torre-Concha et al. 2020; Hales and Pronovost 2006; Higgins and Boorman 2016).

Good checklists are simple, applicable to different settings and provide the potential for measurement when reviewing performance (Torre-Concha et al. 2020). They can also be beneficial for training purposes especially when the task is complex or requires extensive or detailed sequences of actions (Marshall 2013). However, checklists also have limitations. Checklists that duplicate other guidance, are too complex or are considered inappropriate for the task at hand may lead to reduced rather than improved performance and may be rejected by the intended users (Chaparro et al. 2011; Torre-Concha et al. 2020; Anthes, 2015; Reijers et al. 2017; Marshall 2013). Checklists that are too prescriptive or too long may likely inhibit operational discretion required for adjustment and decision-making in complex environments. Organisationally, even a good checklist that is poorly implemented, not supported by appropriate training or poorly integrated with existing processes can result in poor outcomes and user rejection (Anthes 2015; Reijers et al. 2017; Guy et al. 2022; Rose and Bearman 2013). Finally, completing checklists can provide a false impression that work is well done and the associated tasks are well understood by people completing them (Reijers et al. 2017).

Operational procedures and guidance

Standard Operational Procedures (SOPs) are documented rules and steps that must be followed when a specific incident is encountered (Butler et al. 2021). By comparison, Standard Operational Guidelines (SOGs) are not prescriptive, provide principle-based guidance with inherently greater flexibility and can be considered a 'starting point' for operations (Weinschenk et al. 2008). Both SOPs and SOGs serve a purpose to facilitate effective coordinated response to disasters (Taber et al. 2008) allowing different teams to follow predefined steps through SOPs or working towards a unified intent through SOGs.

Effectively an operational equivalent to checklists, SOPs are prone to being inappropriately abandoned in favour of operational discretion (Butler et al. 2021) where fire services commanders disregard required processes and actions in favour of their own strategies and priorities. By comparison, where SOGs were implemented, it was found that firefighters would comply with the SOGs in 90% of situations (Weinschenk et al. 2008). Across military and emergency service environments SOPs are typically used as training tools and are more likely to be stringently followed by novices, whereas experienced practitioners prefer to use operational guidelines and personal discretion (Penney et al. 2022).

Outside of fire services operations, SOPs are extensively used within controlled medical and laboratory settings where they can bring compliance with best practice, harmonise laboratory practices, reduce user errors and can be used as training tools (Barbé et al. 2016; Guerra-Farfan et al. 2023). SOPs are not without fault. Sasangohar et al. (2018) found that 'an abundance of outdated procedures and procedures plagued by information overload' were common in the offshore drilling industry. Within dynamic and complex environments inappropriate protocols restrict reasonable and necessary flexible situational action and can become a hindrance to effective coordinated action (Taber et al. 2008).

Cues and alarms

Cues are signals that prompt personnel to execute a specific action. Within the emergency management context they include establishing operational and reporting timelines and rhythms. By comparison, alarms are audible or visual (or a combination of both) warnings used to alert people to critical changes to their environment. Common fire service examples at a tactical level include the low-pressure warning whistle on a self-contained breathing apparatus set, the motion sensitive personal distress alarm carried by search crews and the atmospheric or chemical alarms of chemical and gas detection equipment. At the broader emergency management level, examples include community warnings involving threat levels and required responses (AIDR 2013, 2021). For emergency managers, alarms can be used for purposes such as warning of impending decision and trigger points, the approach of reporting deadlines as well as upcoming meetings. For maximum effect, Omori et al. (2017) report that alarms and alert signals should involve flashing lights accompanied by clear, consistent, concise and candid warning messages (auditory and visual), although the potential for distraction and sensory overload needs to be carefully considered.

An alternate form of alarm is the use of early and weak signal detection design to identify and alert emergency management practitioners to impending natural disasters before they would typically be identified (Jongman et al. 2015). A potential problem with alarms is that people can become attenuated to or complacent of alarms. For

1. Emergency Management Professionalisation Scheme, www.emps.org.au.

example, the frequent sounding of the motion sensitive personal distress alarms during large fires when firefighters leave breathing apparatus sets unattended often leads to complacency. It is also the case that people don't immediately comply with alarms, even in situations where speed is of the essence. Instead, people typically consider the false alarm rate and other potential reasons why the alarm may have occurred before responding (Endsley et al. 2003; McLeod et al. 2005). As Bearman (2013) noted, it is important to remember that 'alarms occur in an ongoing stream of events in the operational environment, where the operator is constantly building an understanding of their current situation and responding to external stimuli' (p.13).

Discussion and conclusion

This study included a literature review and narrative synthesis of cognitive aids within emergency management and industry contexts. It was useful to draw distinctions between the cognitive aids based on whether they were decision process and behavioural tools, tools to support analysis, checklists, operational procedures and guidance or cues and alarms. Decision processes and behavioural tools help people through the process of decision-making and interactions with others. Checklists, protocols and guidelines assist decision-makers step through tasks that will help them resolve an incident. Cues and alarms prompt attention to aspects of the situation. Each of these cognitive aids can be described in terms of the extent to which they are primarily cognitive vs behavioural, team vs individuals and whether they are used prior to, during or after an emergency.

The implications of this review are fourfold. First, emergency management agencies and practitioners need to identify the outcome they are seeking to achieve and then select the correct cognitive aid that will assist to achieve this outcome. Figure 1 can be used to help think through the different ways that cognitive aids can support decision-making. Second, emergency management practitioners need to acknowledge that poorly designed cognitive aids may cause more harm than good regardless of whether they are applied in the right context. Third, to improve the use of cognitive aids during emergency events, agencies need to ensure practitioners are appropriately trained in the aid's selection and use. Finally, emergency services agencies need to recognise the different needs of their staff depending on their expertise and cater for this in the tools they provide. Critically, there is a difference between the way tools are applied between novices and experts with novices tending to adhere strictly to defined steps and protocols while experts desire greater discretion to apply principles within the dynamic nature of an individual event.

Ultimately, cognitive aids are not a silver bullet when it comes to decision-making in the emergency management context. The correct tool (that is correctly designed) must be correctly applied by trained and competent users. Cognitive aids that seek to extend and support the cognitive limitations of individuals and teams to facilitate skilled performance in demanding conditions are a critical but often under-used aspect of decision-making.

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References

AIDR (Australian Institute for Disaster Resilience) (2013) *Communicating with People with a Disability: National Guidelines for Emergency Managers,* Australian Disaster Resilience Handbook Collection. https://knowledge.aidr.org.au/media/1762/handbook-5-communicating-with-people-with-a-disability-kh-final.pdf

AIDR (Australian Institute for Disaster Resilience) (2021) *Public Information and Warnings.* Australian Disaster Resilience Handbook Collection. https://knowledge.aidr.org.au/media/9104/aidr_handbookcollection_publicinfoandwarnings_2021.pdf

AIDR (Australian Institute for Disaster Resilience) (2023) *Incident Management.* Australian Disaster Resilience Handbook Collection. https://knowledge.aidr.org.au/media/10161/handbook_incidentmanagement_2023.pdf

AFAC (Australasian Fire and Emergency Service Authorities Council) (2016) *A Risk Framework for Ecological Risks Associated with Prescribed Burning. National Burning Project: Sub-project 3.* https://knowledge.aidr.org.au/media/4865/a-risk-framework-for-ecological-risks-associated-with-prescribed-burning.pdf

Anthes E (2015) 'The trouble with checklists', *Nature,* 523:516–519. https://users.cs.northwestern.edu/~robby/courses/395-495-2017-winter/checklists/Anthes%20The%20Trouble%20with%20Checklists.pdf

ANZPAA (Australia New Zealand Policing Advisory Agency) (2022) ICCS Plus – *A common approach to incident management.* Australia New Zealand Policing Advisory Agency. Melbourne.

Appelganc K, Rieger T, Roesler E and Manzey D (2022) 'How Much Reliability is Enough? A Context-Specific View on Human Interaction with (Artificial) Agents from Different Perspectives', *Journal of Cognitive Engineering and Decision Making,* (16)4:207–221. https://doi.org/10.1177/15553434221104615

Barbé B, Verdonck K, Mukendi D, Lejon V, Lilo Kalo JR, Alirol E, Gillet P, Horié N, Ravinetto R, Bottieau E, Yansouni C, Winkler AS, van Loen H, Boelaert M, Lutumba P and Jacobs J (2016) 'The art of writing and implementing standard operating procedures (SOPs) for laboratories in low-resource settings: Review of guidelines and best practices', *PLOS Neglected Tropical Diseases,* 10(11):e0005053. https://doi.org/10.1371/journal.pntd.0005053

Becker F, Skirzynski J, van Opheusden B and Lieder F (2022) 'Boosting Human Decision-making with AI-Generated Decision Aids', *Computational Brain and Behavior,* 5:467–490. https://doi.org/10.1007/s42113-022-00149-y

Bearman C (2013) 'Key technology-related human factors issues of introducing new technology', in Bearman, C., Naweed, A., Dorrian, J., Rose, J., and Dawson, D. (Eds.). *Evaluation of Rail Technology: A Practical Human Factors Guide,* pp.9–2, Ashgate.

Bearman C, Hayes P and Thomason M (2023) 'Facilitating teamwork in emergency management: The team process checklist', International Journal of Disaster Risk Reduction, 94:103775. https://doi.org/10.1016/j.ijdrr.2023.103775

Bernabei L, Mochi G, Bernardini G and Quagliarini E (2021) 'Seismic risk of Open Spaces in Historical Built Environments: A matrix-based approach for emergency management and disaster response', *International Journal of Disaster Risk Reduction,* (65). https://doi.org/10.1016/j.ijdrr.2021.102552

Brooks B, Curnin S, Owen C and Bearman C (2020) 'Managing cognitive biases during disaster response: the development of an aide memoire', *Cognition, Technology and Work,* 22:249–261. https://doi.org/10.1007/s10111-019-00564-5

Butler PC, Honey RC and Cohen-Hatton SR (2020) 'Development of a behavioural marker system for incident command in the UK fire and rescue service: THINCS', *Cognition, Technology and Work,* 22(1):1–12. https://doi.org/10.1007/s10111-019-00539-6

Butler PC, Bowers A, Smith A, Cohen-Hatton S, Honey R (2021) 'Decision making within and outside Standard Operating Procedures: Paradoxical use of Operational Discretion in Firefighters', *Human Factors Society.* 65. DOI:10.1177/00187208211041860

Burian B, Clebone A, Dismukes K and Ruskin K (2018) 'More than a tick box: Medical Checklist Development, Design, and Use', Anesthesia and Analgesia, 126(1):223 –232. https://doi.org/10.1213/ANE.0000000000002286

Chaparro A, Keebler J, Lazzara E and Diamond A (2019) 'Checklists: A Review of Their Origins, Benefits, and Current Uses as a Cognitive Aid in Medicine', *Ergonomics in Design,* 27(2):21–26. https://doi.org/10.1177/1064804618819181

Christodoulou A and Cullinane K (2019) 'Identifying the Main Opportunities and Challenges from the Implementation of a Port Energy Management System: A SWOT/PESTLE Analysis', *Sustainability,* 11(21):6046. http://dx.doi.org/10.3390/su11216046

Dozic S (2019) 'Multi-criteria decision making methods: Application in the aviation industry', *Journal of Air Transport Management,* 79:101683. https://doi.org/10.1016/j.jairtraman.2019.101683

Endsley MR, Bolte B and Jones DG (2003) *Designing for Situation Awareness: An Approach to User-Centered Design* (1st ed.). CRC Press. https://doi.org/10.1201/9780203485088

Fielding N and Thomas H (2001) 'Qualitative interviewing', in: Gilbert N (ed), *Researching social life, 3rd edn*., pp.123–144. Sage.

Fletcher KA and Bedwell WL (2017) 'Cognitive aids in emergency medical services', in JR Kebbler, EH Lazzara, and P Misasi (Eds.), *Human Factors and Ergonomics of Prehospital Emergency Care* pp.123–139. CRC Press.

Flin R, Martin L, Goeters K-M, Hörmann H-J, Amalberti R, Valot C and Nijhuis H (2003) 'Development of the NOTECHS (non-technical skills) System for Assessing Pilots' CRM Skills', *Human Factors Aerospace Safety,* 3:97–119.

Greig P, Zolger D, Onwochei D, Higham H and Desai N (2023) 'Cognitive aids in the management of clinical emergencies: a systematic review', *Anaesthesia,* 78(3):343–355. https://doi.org/10.1111%2Fanae.15939

Gross B (2014) Crew Resource Management – A concept for teams in critical situations. Conference: 5th International Conference of Integrated Natural Disaster Management.

Guerra-Farfan E, Garcia-Sanchez Y, Jornet-Gilbert M, Nunez J, Balaguer-Castro M and Madden K (2023) 'Clinical practice guidelines: The good, the bad, and the ugly', *Injury,* 54:26–29. https://doi.org/10.1016/j.injury.2022.01.047

Guy I, Kerstein R and Brennan P (2022) 'How to WHO: lessons from aviation in checklists and debriefs', *Annals of the Royal College of Surgeons of England,* 104(7):510–516. https://doi.org/10.1308/rcsann.2021.0234

Hales B and Pronovost P (2006) 'The checklist—a tool for error management and performance improvement', *Journal of Critical Care,* 21(3):231–235. https://doi.org/10.1016/j.jcrc.2006.06.002

Hayes P, Bearman C, Butler PC and Owen C (2021) 'Non-technical skills for emergency incident management teams: A literature review', *Journal of Contingencies and Crisis Management*, 29(2):185–203. https://doi.org/10.1111/1468-5973.12341

Hayes P, Bearman C, Thomason M and Bremner P (2020) 'Staying on task: a tool to help state and regional-level emergency management teams', *Australian Journal of Emergency Management,* 35(1):38–44. https://knowledge.aidr.org.au/media/7453/ajem_11_2020-01.pdf

Higgins WY and Boorman DJ (2016) 'An analysis of the Effectiveness of Checklists when Combined with Other Processes, Methods and Tools to Reduce Risk in High Hazard Activities', *Boeing Technical Journal.* www.flighttestsafety.org/images/BTJ_Checklist_full1.pdf

Hunter C and Bowen BE (2024) 'We'll never have a model of an AI major-general: Artificial Intelligence, command decisions, and kitsch visions of war', *Journal of Strategic Studies,* 47(1):116 –146. https://doi.org/10.1080/01402390.2023.2241648

Ingham V (2009) T*he Art of Multimodal Decision Making by Incident Controllers on the Fireground.* Thesis – PhD dissertation. Western Sydney University website https://researchdirect-dev.westernsydney.edu.au/islandora/object/uws%3A7084.

Jongman B, Wagemaker J, Romero BR and De Perez EC (2015) 'Early Flood Detection for Rapid Humanitarian Response: Harnessing Near Real-Time Satellite and Twitter Signals', ISPRS *International Journal of Geo-Information,* 4(4):2246–2266. https://doi.org/10.3390/ijgi4042246

Johnson J (2023) 'Automating the OODA loop in the age of intelligent machines: reaffirming the role of humans in command-and-control decision-making in the digital age', *Defence Studies,* 23(1):43–67. https://doi.org/10.1080/14702436.2022.2102486

Kanki BG, Anca J and Chidester TR (Eds.) (2019) *Crew resource management* (3rd ed.). Academic Press, London UK.

Kaur A and Bhatia M (2023) 'Stochastic game network based model for disaster management in smart industry', *Journal of Ambient Intelligence and Humanized Computing,* 14:5151–5169. https://doi.org/10.1007/s12652-021-03090-3

Kemper P, van Dyck C, Wagner C and de Bruijne M (2017) 'Implementation of Crew Resource Management: A Qualitative Study in 3 Intensive Care Units', *Journal of Patient Safety,* 13(4):223–231. https://doi.org/10.1097/pts.0000000000000145

Klein G (1993) 'A Recognition-Primed Decision (RPD) 'Model of Rapid Decision Making', in G. Klein, J. Oransu, R. Calderwood, and E. Zsambok C, *Decision making in action: Models and Methods.* Ablex Publishing, New Jersey.

Koseoglu M, Tetteh I and King B (2019) 'Decision tools: A systematic literature review, co-citation analysis and future research directions', *Nankai Business Review International,* 10(4):591–617 https://doi.org/10.1108/NBRI-07-2018-0045

Lamb K, Farrow M, Olymbios C, Launder D and Greatbatch I (2021) 'Systematic incident command training and organisational competence', *International Journal of Emergency Services,* 10(2):222–234. https://doi.org/10.1108/IJES-05-2020-0029

Launder D and Penney G (2023a) 'Towards a common framework to support decision-making in high-risk, low-time environments', *Journal of Contingencies and Crisis Management,* 31(4):862–876. https://doi.org/10.1111/1468-5973.12487

Launder D and Penney G (2023b) 'An operator's guide to SPAR(CD): a model to support decision-making', *Australian Journal of Emergency Management,* 38(4):1–15. https://doi.org/10.47389/38.4.59

Lee CE, Baek J, Son J and Ha Y (2023) 'Deep AI military staff: cooperative battlefield situation awareness for commander's decision making', *The Journal of Supercomputing,* 79:6040–6069. https://doi.org/10.1007/s11227-022-04882-w

Li X, Zhu Y, Abbassi R and Chen G (2022) 'A probabilistic framework for risk management and emergency decision-making of marine oil spill accidents', *Process Safety and Environmental Protection,* 162:932–943. https://doi.org/10.1016/j.psep.2022.04.048

Marshall S (2013) 'The Use of Cognitive Aids During Emergencies in Anesthesia: A Review of the Literature', Anesthesia and Analgesia, 17(5):1162–1171. https://doi.org/10.1213/ane.0b013e31829c397b

McLaughlin AC and Byrne VE (2020) 'A fundamental cognitive taxonomy for cognition aids', *Human Factors,* 62(6):865–873. https://doi.org/10.1177/0018720820920099

McLeod R, Walker G and Mills A (2005) 'Assessing the human factors risks in extending the use of AWS', in Wilson, J, Norris, B, Clarke T and Mills A (eds). *Rail human factors: Supporting the integrated railway.* Aldershot, Ashgate.

McNeill P and Chapman S (2005) *Research methods.* Routledge.

Mulenburg J (2011) 'Crew Resource Management improves decision making', *Ask Magazine,* 42. NASA website https://appel.nasa.gov/2011/05/11/crew-resource-management-improves-decision-making/.

Nagarajan M, Ganapathy S and Cheatham M (2023) 'Model-Based Decision Support System for Improving Emergency Response', *International Journal of Human–Computer Interaction,* 39(3):659–666. https://doi.org/10.1080/10447318.2022.2041912

Omori H, Hughes J, Kuligowski E, Butler K and Gwynne S (2017) ‘Human Response to Emergency Communication: A Review of Guidance on Alerts and Warning Messages for Emergencies in Buildings’, *Fire Technology,* 53:1641–1668. https://doi.org/10.1007/s10694-017-0653-3

Parasuraman R and Riley V (1997) ‘Humans and Automation: Use, Misuse, Disuse, Abuse’, *Human Factors,* 39(2):230–253. https://doi.org/10.1518/001872097778543886

Penney G, Cattani M and Ridge S (2022) 'Enhancing fire service incident investigation – Translating findings into improved outcomes using PIAM', *Safety Science,* 145:105488. https://doi.org/10.1016/j.ssci.2021.105488

Reale C, Salwei ME, Militello LG, Weinger MB, Burden A, Sushereba C, Torsher LC, Andreae MH, Gaba DM, McIvor WR, Banerjee A, Slagle J and Anders S (2023) ‘Decision-Making During High-Risk Events: A Systematic Literature Review’, *Journal of Cognitive Engineering and Decision Making,* 17(2). https://doi.org/10.1177/15553434221147415

Reason J (1987) ‘Cognitive aids in process environments: prostheses or tools?’, *International Journal of Man-Machine Studies,* 27(5–6):463–470. https://doi.org/10.1016/S0020-7373(87)80010-X

Reijers H, Leopold H and Recker J (2017) ‘Towards a science of checklists’, in Bui, T and Sprague Jr, R (Eds.) *Proceedings of the 50th Hawaii International Conference on System Sciences.* University of Hawaii, United States of America, pp.5773–5782.

Rieger T, Kugler L, Manzey D and Roesler E (2023) ‘The (Im)perfect Automation Schema: Who is Trusted More, Automated or Human Decision Support?’, *Human Factors,* 66(8):1995–2007. https://doi.org/10.1177/00187208231197347

Rose J and Bearman C (2013) ‘Resistance to technology’, in Bearman, C., Naweed, A., Dorrian, J., Rose, J., and Dawson, D. (Eds.) Evaluation of rail technology: *A practical human factors guide,* pp.23–54. Ashgate.

Sandhu A and Fussey P (2021) ‘The ‘uberization of policing’? How police negotiate and operationalise predictive policing technology’, *Policing and Society,* 31(1):66–81. https://doi.org/10.1080/10439463.2020.1803315

Sasangohar F, Peres SC, Williams JP, Smith A and Mannan MS (2018) ‘Investigating written procedures in process safety: Qualitative data analysis of interviews from high risk facilities’, *Process Safety and Environmental Protection,* 113:30–39. https://doi.org/10.1016/j.psep.2017.09.010

Sarwar D, Ramachandran M and Hosseinian-Far A (2017) ‘Disaster Management System as an Element of Risk Management for Natural Disaster Systems Using the PESTLE Framework’, in Jahankhani, H., et al. Global Security, Safety and Sustainability - The Security Challenges of the Connected World. ICGS3 2017. *Communications in Computer and Information Science,* pp.191–204. https://doi.org/10.1007/978-3-319-51064-4_16

Sun H, Dai X, Shou W, Wang J and Ruan X (2021) ‘An Efficient Decision Support System for Flood Inundation Management Using Intermittent Remote-Sensing Data’, *Remote Sensing,* 13(14):2818. https://doi.org/10.3390/rs13142818

Taber N, Plumb D and Jolemore S (2008) ‘“Grey” areas and “organized chaos” in emergency response’, *Journal of Workplace Learning,* 20(4):272–285. https://doi.org/10.1108/13665620810871123

Theodosiadou O, Chatzakou D, Tsikrika T, Vrochidis S and Kompatsiaris I (2023) ‘Real-time threat assessment based on hidden Markov models’, *Risk Analysis,* 43(10):2069–2081. https://doi.org/10.1111/risa.14105

Tian S, Zhang Y, Feng Y, Elsagan N, Ko Y, Mozaffari MH, Xi DDZ and Lee C-G (2023) ‘Time series classification, augmentation and artificial-intelligence-enabled software for emergency response in freight transportation fires’, *Expert Systems with Applications,* 233:120914. https://doi.org/10.1016/j.eswa.2023.120914

Torre-Concha A, Alonso Y, Blanco S, Allende A, Mayordomo-Colunga J and Barrio B (2020) ‘The checklists: A help or a hassle?’, *Anales de Pediatria,* 93(2):135–145.

Ujjwal KC, Garg S, Hilton J and Aryal J (2023) ‘An adaptive quadtree-based approach for efficient decision making in wildfire risk assessment’, *Environmental Modelling and Software,* 160:105590. https://doi.org/10.1016/j.envsoft.2022.105590

Wang X, Liang X, Li X and Luo P (2022) ‘An Integrated Multiattribute Group Decision-Making Approach for Risk Assessment in Aviation Emergency Rescue’, *International Journal of Aerospace Engineering,* 9713921. https://doi.org/10.1155/2022/9713921

Wang X, Xu B and Guo Y (2023) ‘Fuzzy logic system-based robust adaptive control of AUV with target tracking’, *International Journal of Fuzzy Systems,* 25:338–346 https://doi.org/10.1007/s40815-022-01356-2

Waring S, Moran JL and Page R (2020) ‘Decision-making in multiagency multiteam systems operating in extreme environments’, *Journal of Occupational and Organizational Psychology,* 93(3):e12309. https://doi.org/10.1111/joop.12309

Weinschenk C, Ezekoye O and Nicks R (2008) ‘Analysis of Fireground Standard Operating Guidelines/Procedures Compliance for Austin Fire Department’, *Fire Technology,* 44:39–64. https://doi.org/10.1007/s10694-007-0025-5

Wheatley M, Wotton BM, Woolford DG, Martell DL and Johnston JM (2023) 'Modelling decisions concerning the dispatch of airtankers for initial attack on forest fires in Ontario, Canada', *Canadian Journal of Forest Research,* 53(4):217–233. https://doi.org/10.1139/cjfr-2022-0225

Wu B, Yan X, Wang Y, Zhang D and Soares C (2017) 'Three-Stage Decision-Making Model under Restricted Conditions for Emergency Response to Ships Not under Control', *Risk Analysis,* 37(12):2455–2474. https://doi.org/10.1111/risa.12815

Wu C-K (2021) 'A game theory approach for risk analysis and security force deployment against multiple coordinated attacks', *Environmental Research,* 194:110737. https://doi.org/10.1016/j.envres.2021.110737

Li X Zhu Y, Abbassi R and Chen G (2022) 'A probabilistic framework for risk management and emergency decision-making of marine oil spill accidents', *Process Safety and Environmental Protection,* 162:932–943. https://doi.org/10.1016/j.psep.2022.04.048

Xu N, Lovreglio R, Kuligowski ED, Cova TJ, Nilsson D and Zhao X (2023) 'Predicting and Assessing Wildfire Evacuation Decision-Making Using Machine Learning: Findings from the 2019 Kincade Fire', *Fire Technology* 59:793–825. https://doi.org/10.1007/s10694-023-01363-1

Yang Z, Chen Z, Lee K, Owens E, Boufadel M, An C and Taylor E (2021) 'Decision support tools for oil spill response (OSR-DSTs): Approaches, challenges, and future research perspectives', *Marine Pollution Bulletin,* 167:112313. https://doi.org/10.1016/j.marpolbul.2021.112313

Zarghami S and Dumrak J (2021) 'Implications of artificial intelligence for bushfire management', *Australian Journal of Emergency Management,* 36(1):84–91. https://doi.org/10.47389/36.1.84

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