Analysing the Resilience of Hospitals' Surge Procedures Using the Functional Resonance Analysis Method

Farhad Mahmoudi, Sherif Mohamed and Fahim Tonmoy

Abstract Hospitals are a critical element of the healthcare system and their continuous function is highly important to the wellbeing of communities. In accordance with the criticality of their functional performance during disruptive events, several modelling and analysis approaches have been developed to investigate the extent of various aspects of hospitals' vulnerability and resilience. However, these approaches fall short in addressing either the degree of absorption, adaptation and, in some cases, degradation of the hospital as a system before its fundamental breakdown or fail to differentiate their performance in normal conditions versus surge circumstances and protocols. In this paper, these issues were addressed via deployment of the Functional Resonance Analysis Method (FRAM) and a macro analysis of the interactions among hospital system functions under surge conditions. The use of FRAM as the modelling technique helps to address the extent of system adaptability to changes and explore the hidden impact of different functions on overall system performance. The modelling involved identification of surge functions and fulfilment of conditions for the functions generating the outcomes. The study identifies the limitations existing in hospital surge procedures and highlights the difference between work-as-imagined and work-as-done regarding hospital surge procedures.

Keywords FRAM · Hospital functional performance · Resilience

1 Introduction

Hospital facilities, in the centre of the healthcare network, play a critical role in delivering healthcare services and enhancing society. Addressing their socio-economic

F. Mahmoudi · S. Mohamed (✉) · F. Tonmoy
School of Engineering and Built Environment, Griffith University, Gold Coast, QLD, Australia
e-mail: s.mohamed@griffith.edu.au

F. Mahmoudi
e-mail: farhad.mahmoudi@griffithuni.edu.au

F. Tonmoy
e-mail: f.tonmoy@griffith.edu.au

K. Panuwatwanich and C. Ko (eds.), *The 10th International Conference on Engineering, Project, and Production Management*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-15-1910-9_10

role requires these facilities to focus on enhancing the effectiveness and efficiency of the services they deliver. The main step in improving hospital functional performance (HFP) is identification of work-as-done (WAD) compared with work-as-imagined (WAI). In addressing these issues, various authors have studied hospital/healthcare processes from various angles and focusing on different services. Most papers will start with an introduction and end with conclusions. The conclusions section must be followed by references.

- Implementation of guidelines (Clay-Williams et al. 2015; Saurin et al. 2017).
- Identification of the factors contributing to the gap between WAI and WAD (Laugaland et al. 2014; Saurin and Werle 2017; Wachs and Saurin 2018; Damen et al. 2018).
- Understanding of how complexities affect healthcare processes (Raben et al. 2017; Raben et al. 2018; Ross et al. 2018).
- Enhancement of patient safety (Alm and Woltjer 2010).

The above publications examine hospitals' functional resilience from a resilience engineering perspective by addressing HFP from various dimensions in delivering different services. However, the issue of dealing with disruptive events requires a different approach, as hospitals perform under different sets of procedures and guidelines when a surge in number of patients is expected. Hence, the current paper aims to address HFP in the face of a surge of patients. The paper fulfils this objective by analysing HFP from a systemic perspective, by considering organisational, technical and external dimensions. For this purpose, a model is developed to cover a series of functions required to facilitate the flow of patients, from their registration at the Emergency Department until their discharge, using the functional resonance analysis method (FRAM). The remainder of this paper presents the chosen methodology, the findings of the application of FRAM and a discussion, before concluding with a summary.

2 Methodology

The FRAM, first introduced by Hollnagel (2004), identifies and measures performance variability. The FRAM is a qualitative analysis technique for identifying non-linear dependencies between sub-systems, and functional performance variability, considering complexity and socio-technical factors (Woltjer and Hollnagel 2008). These factors suggest that the socio-technical system's performance is complex and possesses emergence, which assumes performance variability is an inherent factor necessary for coping with changes within and outside the system (Furniss et al. 2016). The outcome of combinations of performance variability can be observed as the occurrence of emergent accidents in the absence of any major technological failure (Macchi 2010). Hence, via the application of FRAM, the emergent risks can be addressed, and the extent of their impacts can be reduced, mitigated or eliminated (Macchi 2010). The method is based on four pillars (Hollnagel 2004):

- The principle of equivalence of success and failure: failure is the product of shortcomings in the system's adaptability for coping with change in operational conditions, which is a consequence of complexity. In other words, success can be defined as the ability to anticipate the changing shape of risk before exposure, while failure is a permanent or temporary absence of that ability.
- The principle of approximate adjustments: because of the dynamics of random changes in operational conditions, the capability of finding effective ways of overcoming problems is crucial. Hence, the coincident and combination of inadequate adjustments create overall instability, which can become the reason for malfunctions or failures.
- The principle of emergence: under normal operational conditions, variability of performance is unlikely to have a major impact on the overall system's functional performance. Yet, variability of multiple functions might combine in unconventional ways, leading to major consequences and impacts that are nonlinear in nature. Hence, the intractability and adaptability of socio-technical systems in response to conditions and demands make it impossible to describe all couplings in the system and anticipate more than the most regular events.
- The principle of functional resonance: the FRAM suggests resonance principles replace traditional cause–effect relationships. Interdependencies make it possible for impacts to spread around the system, rather than in traditional cause–effect links, as described by the Small World Phenomenon (Travers and Milgram 1977).

Based on these principles, FRAM focuses on the functions needed to generate system outcomes, their potential variability, the way they may resonate and how to manage functional performance variability (Hollnagel 2004, 2012). Using FRAM provides understanding on functional variability and appropriate actions to reduce the likelihood of such variability. Hollnagel (2004, 2012) outlined the steps to analyse a system using FRAM:

- Step 0: recognise the purpose of the FRAM analysis. FRAM can be used for accident investigation and safety assessment purposes; however, the details needed for each purpose differs from other purposes.
- Step 1: identify and describe the functions. A function is a normal activity performed in a socio-technical system to achieve a specific objective. Each function can be related to other functions via six aspects, as described below:

    (1) Input: what is processed and transformed by the function or what is needed for the function to start?
    (2) Output: what is transformed or produced via performing the function?
    (3) Precondition: what needs to exist before a function is carried out?
    (4) Resources: what needs to be consumed to produce the output?
    (5) Time: what temporal constraints affect the function?
    (6) Control: what is needed to control and monitor the function?

- Step 2: determine the potential for variability. Identification of how individual function outputs may vary even when not affected by input variation.

- Step 3: define functional resonance. This step deals with the potential impacts of upstream functions on downstream functions (DFs).
- Step 4: manage performance variability. Identification of existing risks and opportunities and management of performance variability.

In the current paper, FRAM was applied to a public hospital in Queensland, Australia. The selection of subject matter experts was based on certain criteria such as knowledge and experience with the subject matter. Particularly, the interviewed experts were selected based on their expertise in Emergency, disaster and business continuity management practices and/or having expertise in patient flow management. The application of the FRAM started by brainstorming, reviewing and analysing documents, through which the general flow of patients and resources were identified. We followed the guidelines published by the US Department of Homeland Security (2007) and the series of publications, policies and guidelines issued by the NSW Ministry of Health to draw a preliminary model. The primary FRAM model was then assessed for flow of the critical functions, and their relative aspects were finalised in an interview with disaster management experts. Next, the primary model was presented to disaster and emergency experts in the chosen hospital, to conduct a case study to identify missing links and functions performed. In the final step, the experts identified each function's output variability as well as the impact of variability in upstream functions on outputs.

3 Results

In the current paper, the focus of the FRAM is on the hospital system variability when operating under a surge caused by a disruptive event. Although the general purpose of applying FRAM is accident analysis or risk assessment, the aim of the current analysis is to assess the interaction among various dimensions of HFP involving patient flow, hospital surge procedures, availability of utilities and redundancies, and external stakeholders. The focus of this paper does not involve human factors resulting in unwanted events; instead, it identifies the impact of current policies and practices on HFP from a socio-technical perspective.

Overall, 29 functions were identified for FRAM analysis. In the second step, 171 couplings were identified among function aspects (an example is presented in Fig. 1). Based on the identified functions and their aspects, a visual representation of the hospital's patient flow model is visualised via the use of FMV software (FRAM Model Visualiser) (see Fig. 1). In Fig. 2, hexagon colours represent various types of functions: green = patient flow; red = hospital surge procedures; yellow = system maintenance, availability of utilities and redundancies; purple = organisational readiness; and phosphoric green and burgundy = functions performed by external stakeholders.

In the next step, the experts were asked to clarify the extent of expected variability in each function's output. These variabilities were identified regarding the timing and

Re-assessment and prioritisation of surge patient flow	**Description**	*Review triaging of all in-patients and transfer/discharge patients with lower priority*	
	Aspects	**Description of the Aspect**	**UF Function's Name**
	Input	*Expected number of casualties exceeds the hospital capacity*	*Assess the Nature and Scope of the Event*
	Precondition	*Execution of the surge plans*	*Procedures to execute the Surge Plans*
		Having agreements for medical facilities and equipment	*Establish Disaster Cooperation Mechanism*
	Resource	*Availability of the Information/Communication System*	*Maintaining Information/Communication System*
		Supplying Power	*Maintaining Power Supply*
	Control	*Calculated number of Available Beds*	*Number of Available Beds*
		Transition from pre-event bed utilization to access surge capabilities and Adding surge beds.	*Activate Medical Surge Capacity*
		Available Surge Plans	*Availability of Emergency Plans*
	Output	*Prioritisation of available beds*	

Fig. 1 Example of a function and its connections to UFs

Fig. 2 The complete FRAM for HFP under surge conditions

precision of the outputs that functions produce. As indicated by experts, the patient flow function output has the possibility of being produced later than expected. Specifically, when dealing with surge conditions, delays can reduce the efficiency of HFP. Further, it was identified that cooperation mechanisms and communication among the hospital and its external stakeholders do not appear to be efficient when dealing with disruptive events. Figure 3 demonstrates the assigned values for functional variability and their criticality scale by the experts as well as the number of DFs that their variability can be transferred to. These values (Green = No impact, Yellow = Moderate impact, Red = High impact) were identified based on the collective impact of functions outputs regarding to their timing and precision. Based on the collective

#	Function	Number of DFs	Timing	Precision	Criticality
1	Triage, Assessment and Streaming	4	On Time	Acceptable	
2	Early Treatment and Fast Track	1	On Time	Precise	
3	Acute Care	2	Too late	Precise	
4	Inpatient Ward Admission	2	Too late	Acceptable	
5	Discharge	0	Too late	Acceptable	
6	Bed Management	4	On Time	Acceptable	
7	Access to Patients Clinical History	4	On Time	Precise	
8	Performing Maintenance	5	On Time	Precise	
9	Maintaining Information/Communication System	18	On Time	Precise	
10	Maintaining Power Supply	14	On Time	Precise	
11	Number of Available Beds	9	On Time	Precise	
12	Maintaining Water Supply	5	On Time	Precise	
13	Maintaining Medical Gas Supply	4	On Time	Precise	
14	Maintaining Hospital Spatial Capacity	4	On Time	Precise	
15	Availability of Emergency Plans	11	On Time	Precise	
16	Performing Emergency Trainings and Drills	7	Too late	Acceptable	
17	Establish Disaster Cooperation Mechanism	5	Too late	Acceptable	
18	Report from External Agents	2	On Time	Acceptable	
19	Assess the Nature and Scope of the Event	3	On Time	Acceptable	
20	Sharing information, assessment and update	11	On Time	Precise	
21	Re-assessment and prioritisation of surge patient flow	7	On Time	Acceptable	
22	Direct Medical Surge Tactical Operations (Leadership)	6	On Time	Acceptable	
23	Procedures to execute the Surge Plans	10	On Time	Acceptable	
24	Activate Medical Surge Capacity	12	On Time	Acceptable	
25	Implement Surge Staffing Procedures	10	On Time	Acceptable	
26	Assessment, tracking, and deployment of extra assets, and resources	9	Too late	Acceptable	
27	Emergency Triage and Pre-Hospital Treatment	1	On Time	Acceptable	
28	Emergency Operation Centre Management	2	On Time	Acceptable	
29	Medical Supplies Management and Distribution and Logistics	1	Too late	Acceptable	

Fig. 3 Assigned values for functional variability and their criticality scale

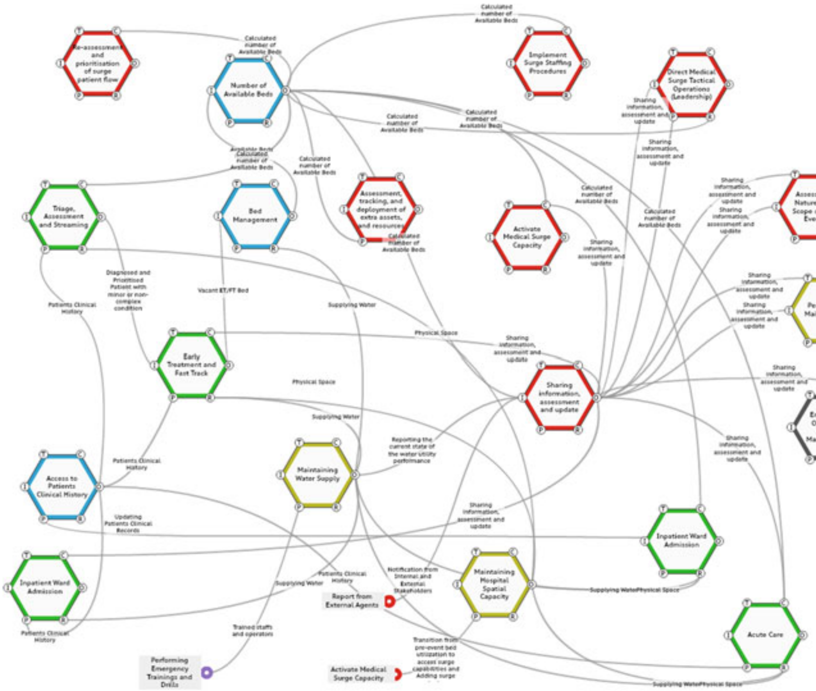

Fig. 4 Map of propagation of functional variabilities

impact of functional variabilities, it is evident that while selected functions were producing outputs with at least acceptable precision, the timing of generating outputs were the factor determining the criticality of functional variabilities.

Finally, by considering the values assigned in Fig. 2 and interactions among the UFs and DFs, Fig. 4 narrows the number of identified interactions to 83 links and demonstrates those interactions through which UF variabilities can resonate and affect the entire system. Therefore, functional variabilities can spread and amplify via these couplings. On the flip side, Fig. 4 presents those couplings that can dampen functional variabilities. It is worth mentioning that in both Figs. 4 and 5, not all interdependencies among functions are presented, and couplings that exert no influence on the DFs are not presented.

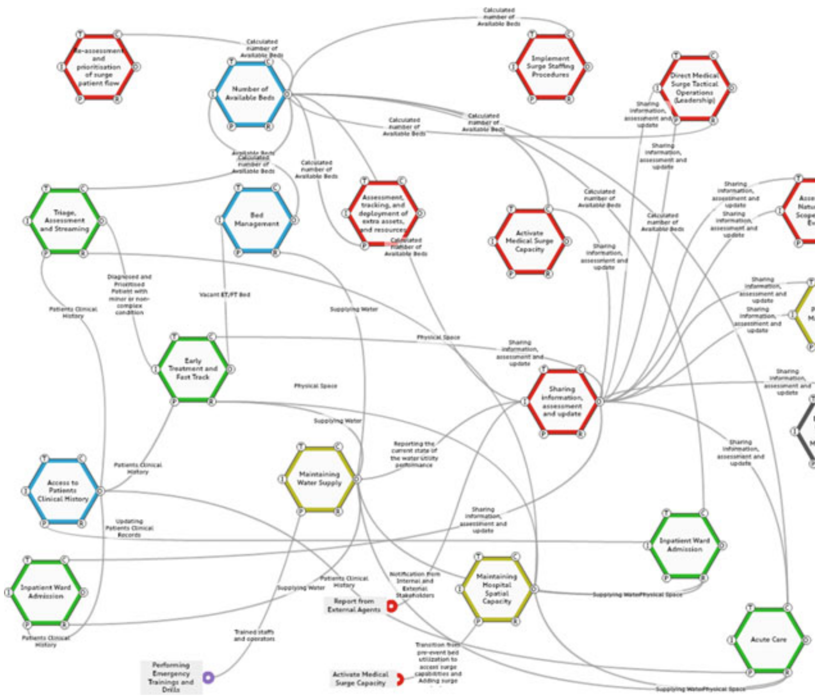

Fig. 5 Map of dampening of functional variabilities

4 Discussion

This paper aimed to understand HFP under surge protocols. This goal was achieved through the identification of functions performed, possible functional variability generated via performing those tasks, and the cascading effect of those variabilities through the system via couplings among functions. The results of the project provide a fresh perspective on how different dimensions of HFP can interact at a system level.

FRAM application to analyse the system, considering complexity theories and the socio-technical perspective, was proven to be helpful in achieving the objectives of the paper. The FRAM highlights the deviation between WAI and WAD in the context of HFP when dealing with surges. The findings of the study highlight the type of dynamic interactions among functions. The results indicate that propagating functional variabilities throughout the system can take a toll on the timing of the hospital's overall performance. Figure 3 shows those interactions that increase the possibility of transferring UF variabilities to their DFs. As explained by the FRAM principles, the overall system can adapt itself to noise passing through under normal conditions; however, in surge conditions and when the system is under the stress, the resonating impact of these variabilities can exert a noticeable impact on HFP.

Further, the findings of the current paper shed light on interactions among functions through which certain functional variabilities are dampened. Thus, Fig. 4 represents potential opportunities in the hospital system, by highlighting the system's potential and ability to deal with a portion of functional variability and functional resonance. Hence, FRAM has been proven to be an insightful technique to demonstrate the synergy among various dimensions of HFP and lay out areas of improvement by which the system can perform efficiently and enhance resilience.

The current study highlights the fact that technical functions often deliver outputs on time with the utmost precision regarding quality. However, with the in-built redundancies in hospital design, Fig. 4 identifies a low probability for variability being produced by the routine performance of such infrastructure. In contrast, it can be argued that availability of trained staff, vacant beds and resources are existing challenges. These challenges are amplified via lack of coordination mechanisms with internal and external stakeholders, leadership, and assessment, tracking and deployment of extra assets and resources. The cooperation among the leadership team, and the government, for facilitating and establishment of the communication capacity contributes to the effectiveness of Coordination of the Response Agents. It can be argued that by establishing cooperation and information sharing mechanisms among responding agents, as well as performing regular training and drills, the efficiency of inter-agency cooperation can be improved.

Further, it has been clarified that lack of efficiency and effectiveness of implementation of surge procedures and re-assessment and prioritisation of patient flow can create variability and amplify impacts on HFP. The lack of efficiency in reassessment and prioritisation of patient flow has been argued to prolong the length of stay in the hospital, even though the efficiency of ED throughput increases (Shimada et al. 2012). Morton et al. (2015) reviewed and highlighted the impact of the variability of this coupling as the potential increase in mortality rate (in severe cases), decrease in the ED and Acute Care wards throughput and consequently reducing the hospital surge capacity. In total, hospital's capability of providing available beds during surge, controls the allocation of resources throughout the process. These impacts can heavily affect the overall timing of performing tasks and, therefore, reduce the number of patients serviced.

In summary, this paper offers a unique insight into HFP for a hospital system dealing with adverse events and operating under a surge. The current modelling and analysis considered complexity theory and adopted a systemic approach to the hospital systems rather than a micro approach in which typical hospital functions are analysed at the organisation–human–technology interaction level. By approaching HFP at the system level, decision-/policy-makers may gain a realistic understanding of WAD and the potential inherit risks and opportunities existing in the system. Consequently, the findings support those of Clay-Williams et al. (2015), by demonstrating the potential of using FRAM to obtain insights into a hospital system for implementing, updating and revising the current guidelines, protocols and practices. Further, the system approach provides insights into interdepartmental interactions and the types of impacts these can impose on HFP. Therefore, the hospital will be able to decrease potential risks by either improving performance of certain functions or enhancing the buffering capacity of their DFs.

5 Conclusions

HFP during clinical surges is a complex issue, especially when aligned with an increase in healthcare demand due to disruptive events (natural and man-made). It requires involvement of different inter-organisational and external stakeholders to deliver critical healthcare services. This paper provides a comprehensive insight into this complex process using a FRAM analysis. The application of FRAM as an analysis technique clarified the deviation between WAI and WAD and highlighted the hidden obstacles and opportunities in hospital system performance.

The results of this paper identified certain couplings that have the potential to vary the output of their DFs and highlighted the DFs' potential to cope with certain types of variations in their receiving aspects. Based on these findings, it can be argued that success in the context of HFP should be defined in terms of the timing of performing each function. Therefore, decision-/policy-makers must focus on ways to make HFP practices during clinical surges more efficient and increase the buffering capacity of those functions that play a critical role in propagating functional variabilities throughout the system. Future studies need to identify the critical path among functions, via which functional variabilities can resonate, as well as investigate the impacts of technical, organisational and external influences on HFP.

References

Alm H, Woltjer R (2010) Patient safety investigation through the lens of FRAM. Human factors: a system view of human, technology and organisation. Maastricht, The Netherlands: Shaker Publishing, pp 53–65

Clay-Williams R, Hounsgaard J, Hollnagel E (2015) Where the rubber meets the road: using FRAM to align work-as-imagined with work-as-done when implementing clinical guidelines. Implement Sci 10(1):125

Damen NL, de Vos MS, Moesker MJ, Braithwaite J, de Lind van Wijngaarden RAF, Kaplan J, Clay-Williams R (2018) Preoperative anticoagulation management in everyday clinical practice: an international comparative analysis of work-as-done using the functional resonance analysis method. J Patient Saf

Das P, Benneyan J, Powers L, Carmody M, Kerwin J, Singer S (2018) Engineering safer care coordination from hospital to home: lessons from the USA. Futur Hosp J 5(3):164–170

Furniss D, Curzon P, Blandford A (2016) Using FRAM beyond safety: a case study to explore how sociotechnical systems can flourish or stall. Theor Issue Ergon Sci 17(5–6):507–532

Hollnagel E (2004) Barriers and accident prevention. Routledge

Hollnagel E (2012) An application of the functional resonance analysis method (FRAM) to risk assessment of organisational change (No. SSM–2013–09). Swedish Radiation Safety Authority

Laugaland K, Aase K, Waring J (2014) Hospital discharge of the elderly-an observational case study of functions, variability and performance-shaping factors. BMC Health Serv Res 14(1):365

Macchi L (2010) A Resilience Engineering approach for the evaluation of performance variability: development and application of the functional resonance analysis method for air traffic management safety assessment. (Doctoral dissertation, École Nationale Supérieure des Mines de Paris)
Morton MJ, DeAugustinis ML, Velasquez CA, Singh S, Kelen GD (2015) Developments in surge research priorities: a systematic review of the literature following the academic emergency medicine consensus conference, 2007–2015. Acad Emerg Med 22(11):1235–1252
Pickup L, Atkinson S, Hollnagel E, Bowie P, Gray S, Rawlinson S, Forrester K (2017) Blood sampling-two sides to the story. Appl Ergon 59:234–242
Raben DC, Bogh SB, Viskum B, Mikkelsen KL, Hollnagel E (2017) Proposing leading indicators for blood sampling: application of a method based on the principles of resilient healthcare. Cogn Technol Work 19(4):809–817
Raben DC, Viskum B, Mikkelsen KL, Hounsgaard J, Bogh SB, Hollnagel E (2018) Application of a non-linear model to understand healthcare processes: using the functional resonance analysis method on a case study of the early detection of sepsis. Reliab Eng Syst Saf 177:1–11
Ross A, Sherriff A, Kidd J, Gnich W, Anderson J, Deas L, Macpherson L (2018) A systems approach using the functional resonance analysis method to support fluoride varnish application for children attending general dental practice. Appl Ergon 68:294–303
Saurin TA, Rosso CB, Colligan L (2017). Towards a resilient and lean health care. In: Resilient health care (Vol 3, No. 17). Routledge in association with GSE Research, pp 3–17
Saurin TA, Werle NJB (2017) A framework for the analysis of slack in socio-technical systems. Reliab Eng Syst Saf 167:439–451
Shimada M, Tanabe A, Gunshin M, Riffenburgh RH, Tanen DA (2012) Resource utilization in the emergency department of a tertiary care university-based hospital in Tokyo before and after the 2011 Great East Japan earthquake and tsunami. Prehospital Disaster Med 27(6):515–518
Travers J, Milgram S (1977) An experimental study of the small world problem. In: social networks. Academic Press, pp 179–197
US Department of Homeland Security (2007) Target capabilities list: a companion to the national preparedness guidelines
Woltjer R, Hollnagel E (2008) Functional modeling for risk assessment of automation in a changing air traffic management environment. In: Proceedings of the 4th international conference working on safety, vol 30
Wachs P, Saurin TA (2018) Modelling interactions between procedures and resilience skills. Appl Ergon 68:328–337