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Modelling Hospital Functional Performance Under Surge Conditions—The Application of FRAM and RAM

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Abstract. Nonlinear models for understanding complex socio-technical processes have not been fully adopted in the examination of hospitals' functional performance when managing the effects of disruptive events. In the literature, researchers have focused on the various dimensions of hospital functional performance (HFP) using different methods. However, they have not sufficiently addressed the inherent behaviours of systems that diminish the efficiency and effectiveness of HFP when operating under different protocols. The current paper aims to identify the pathway through which functional variabilities may propagate throughout the system when dealing with medical surge. To achieve this objective, the application of the functional resonance analysis method (FRAM) is integrated with the application of the resilience analysis matrix (RAM) to analyse HFP. The results identify 23 couplings in 153 interactions between 29 functions that have the potential to affect overall HFP. The approach of this research has revealed how managing the variability of certain interactions can enhance the efficiency and effectiveness of HFP in dealing with disruptive events.

Keywords: hospital functional performance, resilience, functional resonance analysis method.

1 Introduction

The continuity of hospital functional performance (HFP) is a significant public health concern in every society. Further, given that hospitals are one of the frontline services that deal with disruptive events, the resilience of HFP and maintaining the delivery of their primary services during disruptive events is a priority. As a complex socio-technical system, a hospital's performance can be affected by fluctuations of different types of individual functions (e.g. mechanical, human, organisational, technological) that are essential for its continuous operation. A combination of performance variabilities can accumulate over time and lead to system failure (i.e. accidents). The outcome of a combination performance variabilities can be observed as the occurrence of accidents in the absence of any major technological failure [1]. Therefore, it is critical to understand how functional performance variability can affect overall HFP.

The general purpose of the functional resonance analysis method (FRAM) is to assess every system's work-as-done (WAD) rather than its work-as-imagined (WAI).

In FRAM, the complexity and social factors involve the interfaces between adaptable human agents and technology, coupling and dependence effects, nonlinear dependencies between subsystems, and functional performance variability [2]. FRAM can be used as a technique of system-accident investigation and as a risk-assessment method to inform and design activities for large distributed systems. The literature has shown the application of FRAM in the healthcare sector to be useful, and this method has been used to examine the hidden dynamics that can affect the delivery of services. The following lists the principal points of focus of this literature:

- identifying and managing emerging risks and opportunities [3-9]
- enhancing healthcare personnel, and staff performance capability under different conditions [10]
- allocating different types of resources to enhance the system's thresholds and enlarge its buffering capacity [11]
- implementing guidelines in the healthcare organisation [5,12]; and
- enhancing the efficiency of everyday processes [13].

Despite the above attempts, the available research seems to have been reluctant to highlight the criticality of certain functions to the overall workflow of a hospital, and how a stress or disruption to these functions can affect their performance. The lack of clarity about critical couplings between functions often results from the complexity of the FRAM representation. However, understanding these couplings and the importance of individual functions can help hospital management to understand which functions within the hospital's workflow are critical for continuous operation even under surge conditions. Hollnagel [14] suggest the following steps for developing a FRAM model:

1. definition of the purpose of the analysis (identifying whether the purpose of the modelling is to perform an accident investigation or a risk/safety assessment)
2. identification of system's functions (identifying the activities that must be performed to produce a certain output)
3. description of function (identifying six aspects a function needs to produce its outcome described in terms of input, output, time, precondition, resource, control)
4. identification of potential variability of functions (evaluating the possibility of a function's output varying in isolation from the rest of the system)
5. analysis of aggregated variability (analysing how the system reacts when dealing with functional variability under certain instantiations to produce a certain output).

To address the inherent limitation of FRAM (i.e. the complexity of its representation), Lundberg and Woltjer [15] developed a tool based on the resilience analysis matrix (RAM) to support the traditional FRAM approach. RAM is proposed to aid the evaluation of a system in relation to safety and resilience. The following lists the general idea behind RAM [4]:

- revealing hidden patterns and functional interdependencies
- providing an analytical overview of the complex system under examination
- uncovering instantiations and differences between WAD and WAI
- illustrating emergent properties of the system's resilience.

Based on the application of RAM, Patriarca et al. [16] developed a supporting tool, called 'myFRAM'. The integration of these two approaches provides the opportunity to track the potential pathways through which functional variability can either be dampened or amplified. Patriarca et al. [17] used the integration of RAM and FRAM to examine the couplings among the functions. Such integration makes it possible to focus on the impact of certain system couplings and functions on each other [15,17] rather than dealing with FRAM visual presentation. Therefore, the aim of the current research is to identify the functions that are critical for maintaining HFP when dealing with abnormal conditions in which a hospital might be performing under the activation of its surge procedures, rather than performing business as usual. This aim is achieved by modelling the process of patient flow (from registration to discharge) within an emergency department (ED).

2 Methodology

This research took certain steps to collect the data necessary for developing the FRAM model to represent HFP in the process of patient flow from registration to discharge in the ED. The data collection began by reviewing and analysing documents. The analysis outcome was the identification of the functions that represent the general flow of patients, flow of data and resources, and the essential functions for transition to, and operation under surge protocols. The primary identified functions and their relative aspects were then finalised in an interview with disaster-management experts to merge and simplify the primary model. The primary model was then presented to disaster and emergency experts to conduct the case study. The experts were asked to identify missing links and functions that were believed critical for the system's successful operation. Finally, the normal and expected variability of each function's output in relation to its precision and timing were evaluated by the experts. Through employing RAM, the potential effect of variabilities in the upstream functions on their downstream functions were identified and analysed.

3 Results

Developed from the document analysis and rounds of interviews with the experts in disaster and emergency management, 29 functions (presented in Table 1) were selected for developing the FRAM model. Further, Fig. 1. presents a typical FRAM function and its couplings. The aspects of these functions interact via 171 couplings. As stated, the purpose of identifying these functions is to investigate how HFP can be affected if a surge protocol is triggered. Therefore, the FRAM model involves key functions in the general pathway of hospital patient flow (from registration to discharge) and their supporting activities, policies and utilities (e.g. power supplies, water supply), as well as the performance of the hospital's external alliances. It is important to note that the identified functions can be broken down into smaller functions. However, this breakdown was considered to be outside the scope of this research. After identifying the functions, the potential sources of variability of each function were identified through assessment of the deviation of each output's (WAD) from its expected output (WAI).

Table 1. List of FRAM Functions

#	Function	#	Function	#	Function
1	Triage, Assessment and Streaming	11	Number of Available Beds	21	Reassessing and Prioritising Surge Patient Flow
2	Early Treatment and Fast Track	12	Maintaining Water Supply	22	Direct Medical Surge Tactical Operations (Leadership)
3	Acute Care	13	Maintaining Medical Gas Supply	23	Procedures to Execute the Surge Plans
4	Inpatient Ward Admission	14	Maintaining Hospital Spatial Capacity	24	Activating Medical Surge Capacity
5	Discharge	15	Availability of Emergency Plans	25	Implementing Surge Staffing Procedures
6	Bed Management	16	Performing Emergency Trainings and Drills	26	Assessing, Tracking and Deploying Extra Assets and Resources
7	Accessing Patients' Clinical History	17	Establishing Disaster Cooperation Mechanism	27	Emergency Triage and Pre-hospital Treatment
8	Performing Maintenance	18	Reporting from External Agents	28	Emergency Operation Centre Management
9	Maintaining Information/ Communication System	19	Assessing the Nature and Scope of the Event	29	Medical Supplies Management, Distribution and Logistics
10	Maintaining Power Supply	20	Sharing Information, Assessing and Updating		

Reassessing and prioritising 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*	
	Downstream Couplings	*Triage, Assessing and Streaming (C9), Early Treatment (C25), Acute Care (C43), Inpatient Ward Admission (C62), Discharge (C73), Direct Medical Surge Tactical Operations (Leadership)(C137), Activating Medical Surge Capacity (C149)*	

Fig. 1. Example of a Function and its Connections to UFs

In contrast to the analysis of FRAM's traditional representation, the FRAM model was analysed using the application of RAM. The integration of RAM and FRAM helped to highlight the relationships among the couplings of functions rather than simply identifying the functional interactions [15]. Thus, the study was able to identify the relationships among the functions through which functional resonance can cascade. After identifying these relationships, by using myFRAM, a 171*171 RAM matrix was generated based on the couplings of functions, and the potential variability of each coupling was identified in relation to the timing of generating the output and the quality of the output.

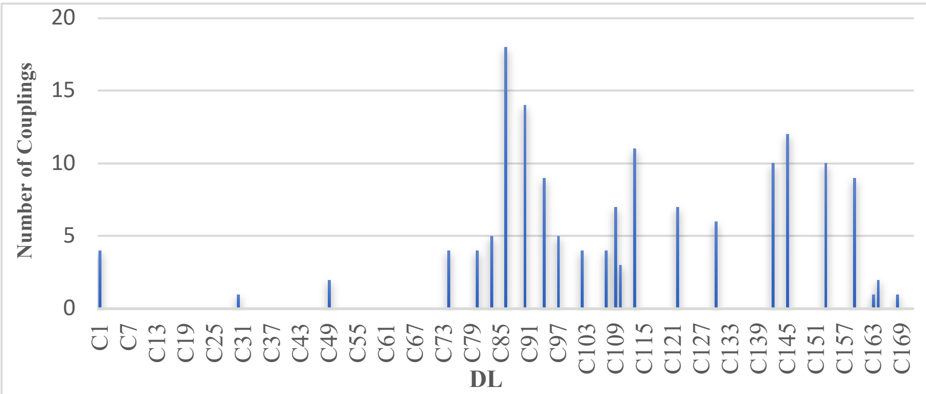

Fig. 2. Representation of DL generated by RAM

Based on the generated RAM, the number of critical couplings generated by each upstream function is identified. The functions of Maintaining Power Supply and Maintaining Information/Communication System have the highest number of outputs and therefore the greatest effect on the overall HFP. The following functions have the next-greatest effect on the overall HFP: Number of Available Beds; Procedures to Execute Surge Plans; Activating Medical Surge Capacity; Implementing Surge Staffing Procedures; Availability of Emergency Plans; Sharing Information, Assessing and Updating; Assessing, Tracking and Deploying Extra Assets and Resources. Fig. 2 presents the downstream link (DL) index (i.e. the index that considers number of DLs). The higher the value of the DL, the higher the potential of the system being affected by variability in the generated output. C86=18 (Performing Maintenance and Maintaining Information/Communication System) have the highest DL value; followed by C90=14 (Performing Maintenance and Maintaining Power Supply); C113=11 (Notification from Internal and External Stakeholders); C142,145,153=10 (Activating Procedures to Execute Surge Plans through Leadership, and Executing Surge Plans) and C94,159=9 (Available Beds Notification and Executing Surge Plans). Based on the generated matrix of couplings, the critical flow of tasks in the hospital is identified, as visually represented in Fig. 3. It is important to note that the model presented in Fig. 3 is only a representation of the potential sources of variability in the HFP via the application of RAM. The highlighted functions represent certain couplings among functions that functional variability may cascade through them.

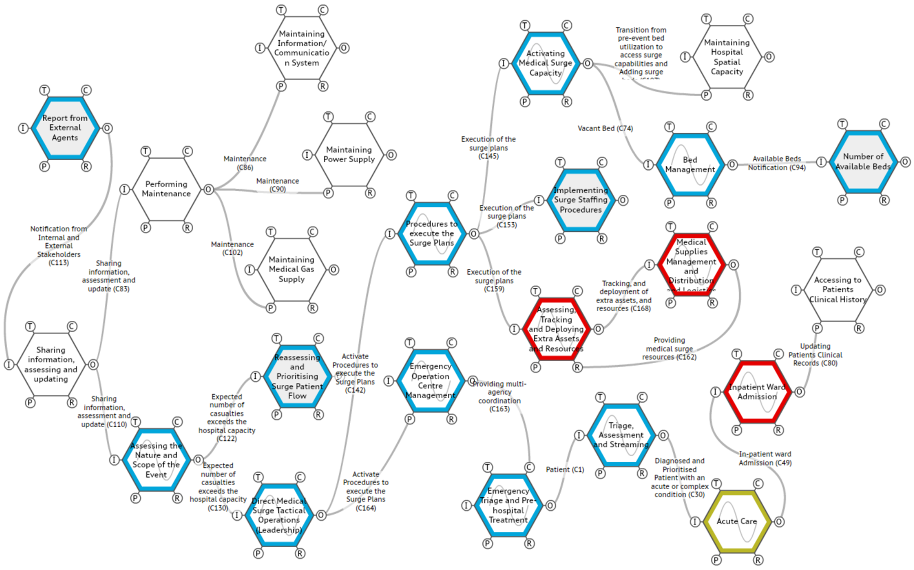

Fig. 3. Critical pathway of the hospital task flow under a surge condition

4 Discussion

The approach to examining HFP used in this study can highlight the areas on which decision makers must focus to enhance the effectiveness and efficiency of their protocols, polices, guidelines and practices, as well as of their resource allocation. This paper considers hospital's patient flow as a series of foreground functions getting supported by various types of background functions (technical, organizational, external). As shown in Fig. 2, the integration of two approaches of RAM and FRAM, highlighted which couplings have the greatest effect on the HFP resilience and those couplings potential effect on the performance of their downstream functions. Thus, using RAM can support FRAM by providing a better understanding the effect of each coupling on the entire system.

The other contribution of this study is the identification of the pathway through which functional variability can spread through specific couplings. The findings suggest that in HFP, information sharing throughout the system, performing technical maintenance, the availability of efficient procedures for implementing a surge plan, and directing surge tactical operations play a critical role when managing function variability. These findings are in line with a previous publication by the same authors [18], using a different modelling technique, which highlights the direct and indirect effects of leadership and procedures for executing surge plans on hospital surge capacity and cooperation. Further, these finding also shed light on the importance of the contextual factors that are involved in the implementation of particular efforts [7]. In addition, the findings highlight the importance of increasing the buffering capacity of functions that may generate variability due to lack a of resources and enhancing the ability for self-organisation of these functions (e.g. adding vacant beds, providing extra assets and resources) [11]. The use of RAM and its representation provided a new perspective on HFP and surge procedures. This perspective can help decision and policy makers to identify possible risks that propagate function variability and the existing buffers that can decrease generated variability in their upstream functions. Future studies should address the extent of the effect of the identified couplings on downstream functions and how they deal with the variability imposed by their upstream functions.

5 Conclusions

This paper examines HFP during events in which a hospital must perform under surge conditions. It also examines a socio-technical systems' behaviour when dealing with undesirable changes in the internal or external environment, and how those changes can affect their productivity and quality of services. Using FRAM as the method of modelling and analysis allowed identification of functions and parameters that can affect overall HFP. By focusing on a hospital system, the research identified the couplings that influence a hospital's primary services while operating under conditions that trigger surge protocols. Through description of the interactions among the different functions of the HFP and the potential effect of each function on overall performance, FRAM provided new insight into HFP. Further, the integration of the applications of FRAM and RAM provided a method that enabled the complex representation of traditional FRAM to be simplified. This approach can be used to highlight different pathways via which hospital functions generate outputs. The use of RAM translated FRAM's visual representation into a matrix that enabled the simplification and identification of functional interdependencies, and the visualisation of the resilience of HFP. This study shed lights on the functions that can impose risk of generating emergent outcomes, and on the system's buffering capacity. Through identifying the functions that can reduce emergent, decision makers and disaster-management teams can identify the thresholds and buffering capacities embedded into the hospital's system. The perspective offered in this paper can help disaster-management teams to effectively target different tasks that can generate emergent via their performance variabilities and enhance the buffering capacity of a system. Future research plans to examine the effect of different couplings on downstream functions to assess the hidden interactions among functions via scenario analysis.

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