# Mapping processes in the Emergency Department using the Functional Resonance Analysis Method (FRAM).


## Abstract

Emergency Departments are dynamic, complex and demanding environments. Introducing changes that lead to improvements in EDs can be challenging owing to the high staff turnover and mix, high patient volume with different needs and being the front door to the hospital for the sickest patients. Quality improvement is a methodology applied routinely in emergency departments to instigate change to improve several outcomes such as waiting times, time to definitive treatment and patient safety. Introducing the changes needed to transform the system in this way is seldom straightforward with the risk of 'not seeing the forest for the trees' when attempting to change the system. In this article, we demonstrate how the Functional Resonance Analysis Method (FRAM) can be used to capture the experiences and perceptions of frontline staff to identify the key functions in the system (the Trees), to understand the interactions and dependencies between them to make up the Emergency Department ecosystem (the forest) and to support quality improvement planning, identifying priorities and patient safety risks.

## INTRODUCTION

Quality improvement requires a systematic approach to evaluating and solving problems in patient care processes in an attempt to make changes that could improve patient outcomes (1). A foundational step of any quality improvement project is to identify problems that can be addressed; however the process of identifying problems is varied with many options such as audit or reflection on individual case outcomes and experiences (1). In busy healthcare workplaces, when identifying where and how improvements in quality are needed and possible, the first step is often to understand how the system operates and how structure and processes within the system interact with each other (2). Deciding on improvement work based purely on isolated experiences risks underappreciating wider factors contributing to that problem whilst also missing implications of making changes to current work processes.

This paper will describe a tool for visualizing and understanding complex systems called the Functional Resonance Analysis Method (FRAM) which can guide improvement work. In the paper, we start by considering how emergency departments are complex sociotechnical systems; secondly, we explore linear versus non-linear mapping tools for understanding systems; thirdly we will introduce the concept of Functional Resonance Analysis Method; and finally discuss the lessons learnt from a case study applying FRAM in an ED and consider implications for future use.

### Emergency Departments are complex sociotechnical systems

Emergency departments (ED) are complex sociotechnical systems (3). The term ‘sociotechnical’ (4) is used to indicate outcomes are achieved through interactions between human, social, organizational, and technical factors. The ED is highly complex because many interrelated constraints influence functioning, such as unpredictable patient demand, changeable staffing levels, and the ability to communicate across hierarchies within and between professional groups and clinical specialties. When attempting to understand these complex systems, it is easy to fall into the trap of not seeing the forest for the trees. Too much focus on one aspect (human, social or technical) of the system results in losing sight of the importance of the system as a whole or the implications one tree has upon another when change is made.

As a complex sociotechnical system, clinical and other important outcomes in the ED are ‘emergent’ system properties, i.e., that outcomes, wanted or unwanted, arise from the multiple interactions between many processes taking place in the ED simultaneously as opposed to simple linear cause-and-effect relationships (5). Modelling the key functions and their interactions in a complex sociotechnical system, and learning to improve them, is therefore very challenging (6).

The field of Human Factors promotes learning about and optimizing sociotechnical systems design through (7):

- Systems Thinking: examining interactions between individual parts (e.g., clinicians, patients, physical and social environments, etc.) and their impact on the overall system’s behavior (e.g., wanted or unwanted outcomes) rather than focusing on the behavior of a single part (e.g., the decisions and actions of a nurse); and,
- Human-Centered Design: placing product and/or system users at the heart of the design process, involving them at every stage to ensure capabilities, needs and preferences are addressed.

Understanding a complex sociotechnical system can be facilitated by approximate modeling of the interacting ED system elements and processes to better understand how the socio- and technical elements of the system design affects and impacts the ED's effectiveness.

**Tools for mapping complex sociotechnical systems: Linear versus nonlinear tools**

Tools which help in mapping system complexity, such as SEIPS (8) are helpful to understand the range and nature of the different factors, particularly human, that are involved. But to proceed further we need to “map” some sort of structure to understand the workings of the interacting processes. For example, ‘process mapping’ (Table 1) can help create a visual display of these vital, connected steps within a process and often follow a linear trajectory to complete end-to-end mapping of the process. Process mapping and other similar methods, such as swim lane mapping, have been extensively applied in the healthcare setting to drive quality improvement (9,10).

**Table 1 - Examples of commonly used process and system mapping tools**

| Tool | Brief description | Pros | Cons |
|---|---|---|---|
| Fault tree analysis (11) | A graphical tool using Boolean logic to establish a relationship between a particular system failure and all its contributing causes | Highlights critical components linked to system failure<br><br>Helps to prioritize action items to solve the problem<br><br>Large record of successful usage | Only examines one top failure event at a time<br><br>Difficult to capture time related and other delay factors<br><br>Not good for complex system analysis as it will have too many gates and events |
| Swim lane mapping (12) (Supplement 1) | Type of process map that indicates the department or party responsible for activities in an end-to-end business process | Overview of delays and overload issues to reduce utilization of resources<br><br>Used to segregate process steps that contain similar characteristics<br><br>Gives quantitative estimates of system reliabilities | Focus is on *who* is doing the work rather than *what* is actually being done<br><br>Difficult to use when multiple parties are responsible for a part of the process |
| Process mapping (9) | A tool to visually explain the workflow | A higher or detailed level understanding of how processes are connected<br><br>Establishes common understanding among employees on how process works<br><br>Helps to define the scope or boundary of a process during problem solving | Basic process map does not include time stamp, who is accountable for process step, how information exchange happens between process steps<br><br>Basic process map has limited ability to capture social interactions between participants in the healthcare setting, which is critical as diverse employees brings in varied motivations and specific knowledge of the process under analysis |

However, there are still some limitations of mapping for guiding service improvements, as discussed in Table 1, which can be addressed using more sophisticated visual techniques for capturing different types of variations in the complex healthcare systems, which is often non-linear and complex. The complex sociotechnical system is influenced by various organizational, technical, and social parts, which can interact simultaneously, affecting system outcomes. For example, the relationship between the time pressure to review a patient against a background of workload pressures and staff shortages in the ED, while interacting with other professionals from different specialties, who themselves have competing priorities. If the system design and related interactions are asynchronous or unfavorable, then it can cause patient harm.

Hollnagel (6) developed the Functional Resonance Analysis Method (FRAM) to overcome the challenges of using strictly predetermined, sequential, linear mapping approaches to make sense of complex, dynamic and non-linear systems, where outcomes emerge dependent on specific conditions (not predetermined). Due to the dynamic, complex and adaptive nature of many healthcare systems, modelling them accurately is extremely challenging and so FRAM and other similar methods only provide an approximation of the system condition and design (6).

Most of the initial applications of FRAM have been employed in conducting retrospective analyses of accidents in the logistics, aviation, marine and railway sectors (14,15,16,17). The first application of FRAM in healthcare analyzed an accident that resulted from retained surgical materials inside a patient's abdomen (18).

The term 'Functional Resonance' emphasizes that any disturbances and variabilities in the operation of a function (tasks and activities involved in care delivery) can propagate, interact with and hence, affect nonlinearly, all the other interrelated functions in the system. This means that such interactions and their effects can occur out of the expected, linear sequence of steps through which the process was predesigned to progress. Such sequences of interactions can seem to "emerge" unexpectedly. Thus, the system interactions and structure can change dynamically between steps in the process (called instantiations in FRAM). This allows the analyst to identify these often unexpected, non-sequential, non-linear effects on the performance of other functions in the system as 'resonances'.

### Creating a FRAM

To create a FRAM model the analyst first must develop an understanding of what actually is happening in the system and how the results are achieved in practice. Procedures, guidelines, and standards are useful to understand what is intended, but direct observations and in particular drawing on firsthand clinician's experiences are vital. Having achieved a common understanding of what's happening, the first step of a FRAM analysis is then to identify all the functions that are involved, each of which is represented as a simple hexagon. The formalized functional "aspects" (Table 2) are then used to establish the connections between them, e.g., 'to provide sedation/analgesia' is a function (Table 2).

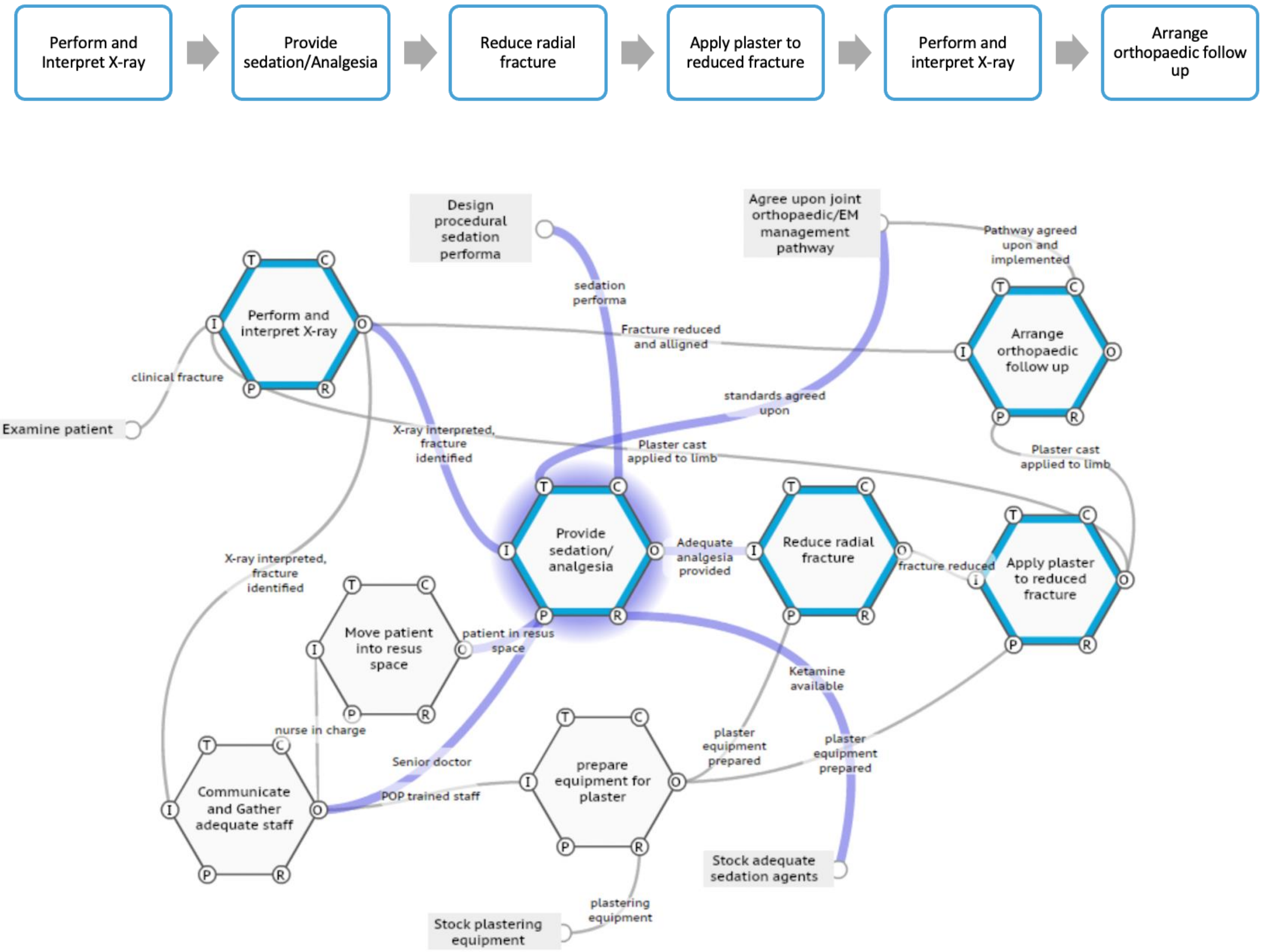
**Table 2 – Aspects for the function 'provide sedation/analgesia'**

| Aspect | Description of aspect | Example |
|---|---|---|
| Input (I) | Something that triggers the start of the function | Identification of fracture requiring reduction |
| Output (O) | The result or product of the function | Adequate analgesia/sedation provided |
| Precondition (P) | Factors that must be present prior to the function starting, but do not trigger the start of it | Resus space available for procedure |
| Control (C) | Anything that will control or monitor the function | Procedural sedation performer |
| Time (T) | Time constraints or targets that influence the function | Targets on time to analgesia |
| Resource (R) | Needed for or consumed by the function | Sedation agent e.g., ketamine |

This subsequent FRAM "model" of the system involved allows visualization of the non-linear nature of emergency medicine, which is often overlooked when using traditional linear mapping tools (19). At most, linear approaches will include information linked to input, output, time, and resources. Utilizing the systematic nature of the six aspects in FRAM allows for the identification of multiple overlooked interdependencies and visualize their connections. This can be important when analyzing past events, the system's current state, and designing future change.

For example, in Figure 1, the difference can be noted between describing the management of a distal radius fracture using a linear (above) versus a non-linear method such as FRAM (below).

**Figure 1 - Visual comparison between simple linear process versus non-linear FRAM model**




In Figure 1, the ‘provide sedation/analgesia’ function has connections with seven other functions. If one were to evaluate why a particular fracture reduction went wrong, it is possible to work back down the linear process map until a problem is identified. This could be, in this example, that the patient did not receive adequate sedation which resulted in a poor reduction. It is easy and common to blame the clinician responsible.

However, inadequate sedation could be due to any one of the numerous connections between the different functions. For instance, if all resuscitation bays were occupied, the patient may not have had adequate monitoring and therefore could have received less potent sedation. Alternatively, a senior clinician trained in sedation may not have been present or contactable, and as a result, a less potent analgesic or sedative could also have been selected.

Identifying a focus for QI work can often be based upon isolated experiences and does not take a systems approach to understanding the complex problem. We therefore demonstrate in the following case study how FRAM was utilized to aid evaluation and identify priorities for improvement work within a large university teaching hospital emergency department.

## Case study from Wales, UK

### Context

The ED (locally referred to as the Emergency Unit) at the University Hospital of Wales is a major trauma center located in the capital city of Wales in the U.K. It sees approximately 530 patients per day with one third arriving via ambulance, another third requiring immediate treatment for life- or limb-threatening condition and a final third who can wait to be assessed in the ED waiting room. This case study focuses on the latter group and describes how FRAM aided the service evaluation process with the primary objective of visualizing where and how the system could be optimized to improve the work processes in the ambulatory stream of the ED which locally had the greatest demand of all areas in the department.

### Creation of a FRAM model

A FRAM model (Supplement 2) was created using the approach outlined by Hollnagel (6), which includes:

(i) **Data collection to identify and describe the important system functions**: this involves characterizing each function using the six basic characteristics (called aspects), and together the functions constitute a FRAM model.

(ii) **Build the FRAM model using the FRAM model visualizer (FMV) software (20):** creating the FRAM model enables examination of specific "instantiations" (how the functions couple together and produce outcomes under certain conditions or within a defined timeframe) observed during the process. The model is usually checked and validated with those involved in the delivery of the process. FRAM modeling can also be done using spreadsheet software instead of the free to use FMV.

(iii) **Analyze the implications of the observed functions and any potential variability**: this requires consideration of possible and actual variability in one or more instantiations of the model and considering the implications for those working with/in receipt of the process.

(iv) **Develop recommendations on how to manage variability:** finally, recommendations are made considering what is known about the instantiations to remove and/or manage the observed variability. Sometimes attenuating variability that can lead to undesirable results or enhancing variability that can lead to desired results.

**Data collection**

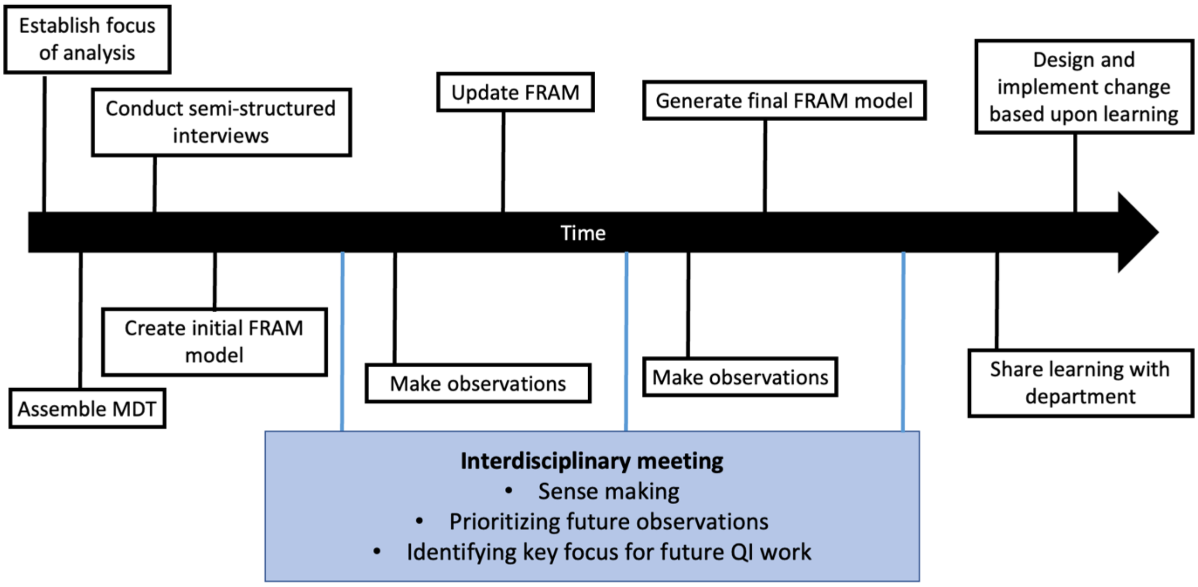
Initial data collection was carried out using semi-structured interviews with ED staff. During the interviews, functions were identified and then the six aspects (Table 1) of each function, including its variability, were explored with participants. An initial FRAM model was created from eight initial interviews conducted by a medical student over two weeks in November 2020. Additional in-house observations (30 hours in total) and further informal interviews were conducted by a non-clinician. Data collectors were not blinded to objectives; however, the non-clinical observer had no prior experience of observation in a healthcare context nor extensive prior knowledge of the system. Documented observations were used to refine and update the FRAM model. Data collection ended once no new functions or aspects were identified. All data collection was carried out by a medical student and a non-clinical business student. Verbal consent was obtained from all staff involved with interviews and observations; they were informed of how data would be utilized as part of the service evaluation process. No identifiable data was collected.

A total of 36 functions and their aspects were identified and inputted into the FMV (20). The FMV graphically represented connections between each function based upon the six aspects entered by the user. The FMV software allowed for functions to be marked as being variable or not variable. The degree of the variability was described qualitatively as free text in the FMV. The model's validity was enhanced by cross-checking with a senior emergency medicine (EM) physician.

**Analysis of the FRAM model**

An iterative approach of recurrent observations, multiple FRAM model versions and weekly multidisciplinary team meetings were conducted (Figure 2).

**Figure 2 – Overview of iterative approach to data collection and analysis**




Attending the interdisciplinary meetings were in-residence ED student researchers, the senior EM physician, two non-EM physicians and additional advice was sought from two non-clinicians with interests in system design and engineering. These meetings were conducted for three key reasons. Firstly, to minimize bias of interpretation from staff accounts and to help validate the observations through peer-review by the senior EM physician. Secondly, to establish foci for further data collection to fill any identified gaps in the FRAM model. Finally, we aimed to identify relevant learning that could be fed back to clinical leaders (Supplement 3), which supported us to validate our interpretations with stakeholders and discover which functions should be a focus for future QI work.

## Outputs from the FRAM analysis

### Enabling in-depth insight about functioning

Utilizing the FRAM methodology allowed our team to understand how specific areas of the ED function. Creating the FRAM model required the team to understand the variability of functions taking place while defining all the connections and interdependencies between these functions. The FRAM model visually brought these two pieces of information to discuss how different variabilities in key functions could influence other functions in the system and potentially lead to desired and undesirable outcomes.

### Identifying variability and its implications

The ‘triage’ function was identified as highly variable due to differences in the scope of work carried out at triage. Whilst all triage staff used a standardized triage tool (21) to differentiate acuity of presentation, some triaging staff members would work beyond this and use clinical judgement to refer patients to other services or discharge patients’ home. We noted this outcome was outside the work expected for the triage function but can improve patient flow and reduce overcrowding.

Our team used the FRAM model to consider the different implications of this variability on other functions upstream and downstream of the triage function (Figure 3).

**Figure 3 – FRAM model abstract highlighting connections between triage and other functions**

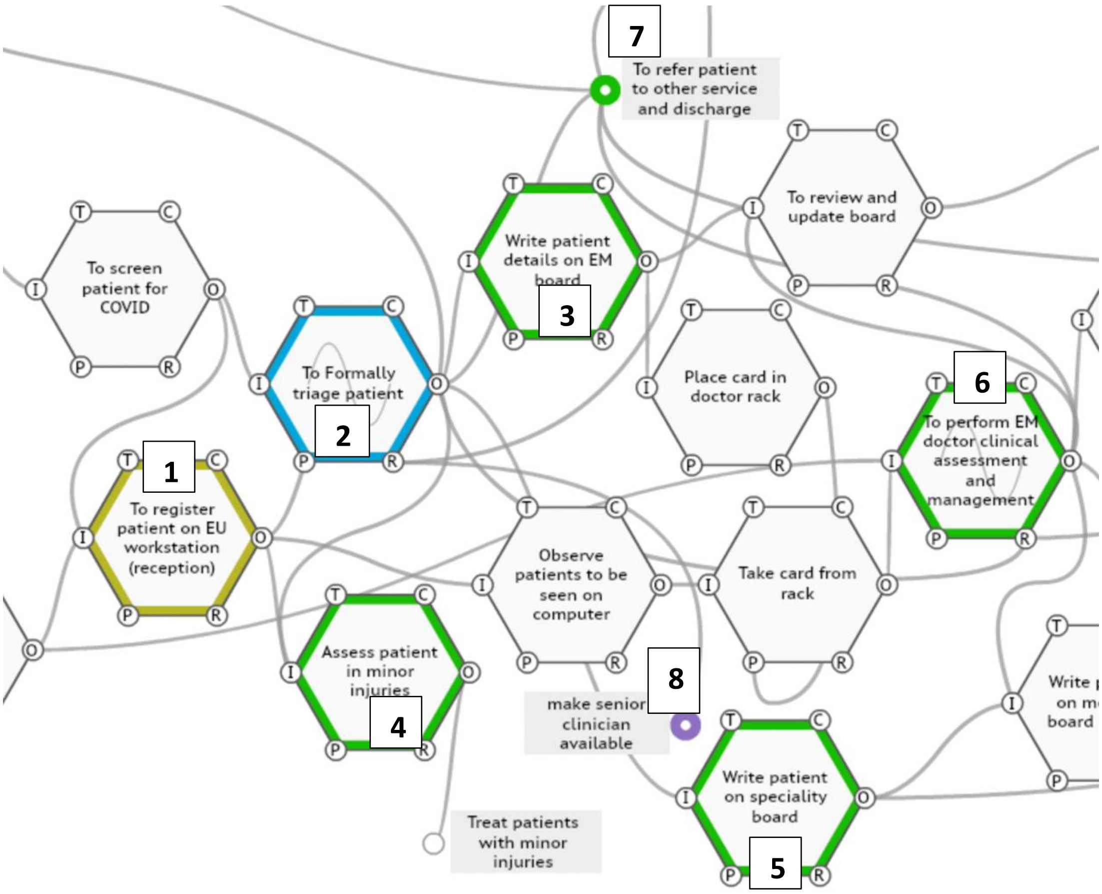



Figure 3: A zoomed-in FRAM model of the ED. Functions are represented by hexagons, with each point denoting a specific aspect of the function, namely; (I) Input, (O) Output, (T) Time, (C) Control, (P) Precondition, (R) Resource. This figure highlights the non-linear connections between the different functions. Blue hexagon = function of focus, Green hexagon = outputs of focus function, Yellow hexagon = precondition for focus function and Purple = resource for focus function.
EU = Emergency Unit. EM = Emergency Medicine

The FRAM allowed our team to study the variabilities reported by staff. The triage function [function 2] influences numerous other functions [function 3,4,5,6,7]. The implications include providing the necessary inputs for a successful discharge [function 7] or acting as a resource for the full clinical assessment [function 6].

The FRAM shows that the ability of the triage function to provide the input required for discharge or referral to another service was often influenced by the availability of a senior clinician [function 8] to assist with clinical decision-making. Again, this is a deviation from strict triage, but can aid patient flow and is often referred to as ‘Rapid Assessment’.

A clear distinction between junior and senior staff-led triage/rapid assessment was observed, as well as differences between nurse- and doctor-led triage, and their outcomes. Initial decisions made at triage could influence the junior clinicians’ decision-making while conducting the full clinical assessments. A senior clinician’s presence [function 8] would result in different outputs from triage [function 2], such as improved guidance in clinical decision-making, increasing clinical efficiency and reducing unnecessary investigations.

The FRAM also allowed visualization of less-apparent pathways. The output of having senior clinicians available [function 8] acts as a resource for the triage function [function 2] to modify its outputs, subsequently acting as a resource for the full clinical assessment [function 6]. We observed that this relationship is not clear in linear, input-and-output relationships but concluded would be clinically significant in practice. This also demonstrates how variability in one function can spread to other functions. For example, if clinical demand for senior clinicians is high elsewhere in the department, then they cannot act as a resource for the triage process. This variation can result in altered triage outputs, which are also influenced by multiple other factors. This altered output will provide a resource for the full clinical assessment.

The non-linear connections shown in Figure 3 highlight how FRAM can aid teams in studying how variability in one function can influence the outputs of another and then subsequently on another - this is referred to as functional resonance. The significance of this resonance helped inform the business case for a new Rapid Assessment and Treatment Zone (RATZ) where a consultant emergency physician can offer senior-level decision making at the triage stage to support an increase in positive downstream effects.

**Visualizing Flow of Work**

The FRAM model allowed the ED team to visualize the flow of work. It permitted easy recognition of bottlenecks in the workflow that were unexpected before using FRAM. The specialty review function is when an in-hospital specialty team performs a clinical review of a patient referred to them by the ED team. Completing this function is often necessary before patients can move on and leave the ED. Our team identified the specialty review as having the potential of congesting workflow and delaying the completion of downstream functions (Figure 4 – yellow functions).

**Figure 4 – Function acting as bottleneck**

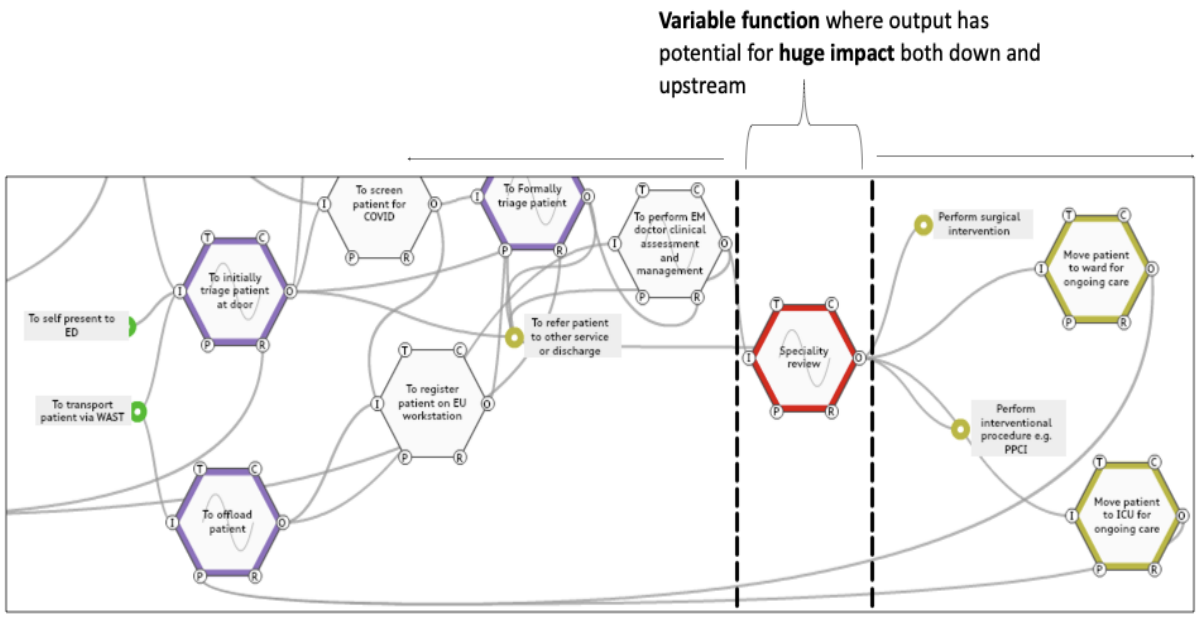



Figure 4: A zoomed-in FRAM model of the ED. Purple = functions identified as being variable, Green = starting points of FRAM, Yellow = functions influenced by output of speciality review function

The FRAM also allowed the ED team, inclusive of clinicians of all grades and managers, to understand the implications this bottleneck can have on the immediate upstream functions (i.e., impact on the timeliness and quality of patient care received), and how these functions can impact downstream operations (i.e., impact on other patients). When shown this observation, staff described the frequency of delays due to specialty review and the team then used the FRAM model to study the effects of this. Delays in completing this function result in delays in patients being moved out of the department e.g., to appropriate ward environments. The movement of patients from the department will then subsequently allow for the offload of patients from ambulances demonstrated by the outcome (O) of the moving patient to ward function acting as a precondition (P) for the offload patient from ambulance function. This demonstrates how FRAM was utilized to understand the variability present in one function first and then use the connections of this function with others to observe how the variability described can impact overall system functioning (resonance). The visual representation was also displayed in presentations to senior management of the hospital to facilitate change and led to successful investment in future quality improvement projects alongside in-hospital specialty teams. One of these projects has involved taking functions identified as bottlenecks (figure 4) and identifying existing routine data to quantify the variability quantitatively. Currently, from observing the specialty review function (Figure 4) in terms of time between referral and specialty review, collection of this data on different days and times is influencing discussions about staff resource management to help dampen unwanted variability in this system-wide dependent function.

**Lessons learnt from applying FRAM methodology in the ED**

A busy clinical team can utilize the FRAM with minimal training to model the complex workings of an ED by systematically describing each tree (e.g., triage, data transfer, specialty referrals) and understanding how interactions between these trees make the forest (ED). Subsequent analysis of the FRAM can then identify key foci (trees) for future improvement work and collate essential information required to guide this future work in the context of the wider forest.

**Convenience of FRAM for the practicing clinician**

Despite the FRAM models' complex appearance, the model was created by a full-time clinician who had undergone half-day training on FRAM principles and FMV software. This study demonstrates how EM clinicians can utilize FRAM without the need for the involvement of academics. Additionally, the FMV software is open access, making FRAM modelling feasible with no financial expense.

Data collection can take many forms and be adapted to suit the user. We conducted interviews and observations to identify the functions, aspects and descriptions of variability. There is no one defined way of collecting the data, provided it describes the *'work-as-is',* currently taking place. Focus groups, interviews, walk-through-talk-throughs and observations are all possible ways to obtain the data. This flexibility further increases the usability of this tool in a busy clinical.  Data for this case study was collected during an international pandemic and further highlights the flexibility of the tool to function during times of rapid system change.

**The potential of the non-clinical observer in understanding complex work**

As part of the data collection, a non-clinical observer helped bring fresh eyes to how data was transferred within the system. This provided observations that our clinical team member (who had worked in the department for three years) had overlooked. It was clear that this new more objective perspective permitted the identification and description of work functions that had become second nature to clinical staff. The process of information transfer within the department and with other teams in the hospital was deemed too convoluted (Figure 5). This is something that staff had accepted as standard practice and had been overlooked by the clinical observer.

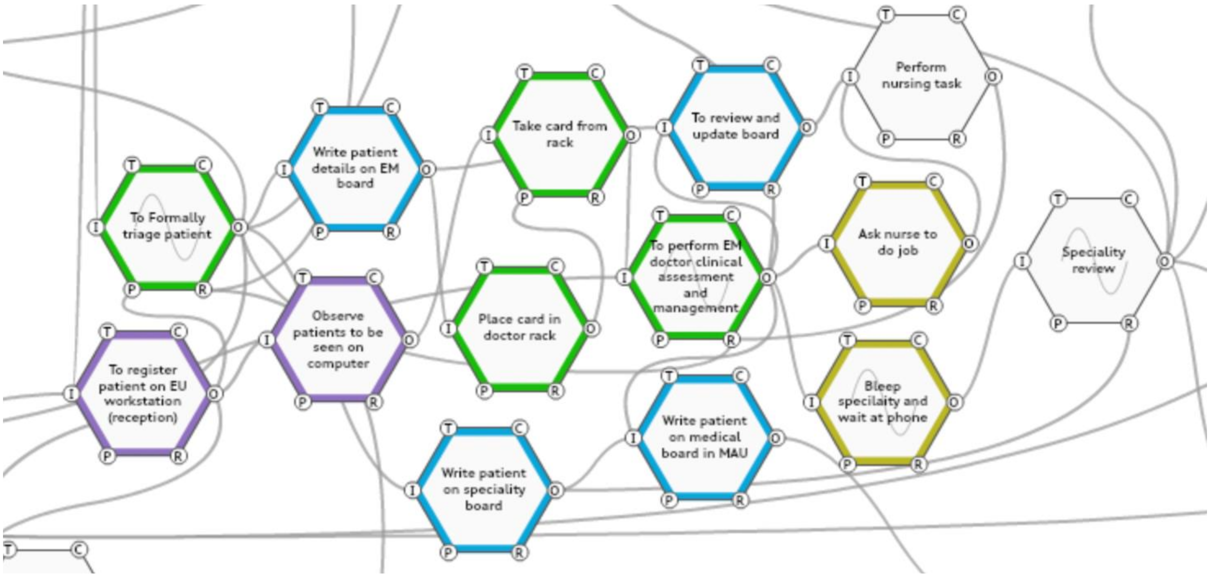



Figure 5 – FRAM abstract demonstrating the different forms of data transfer. Paper (Green), Computer (purple), Whiteboard (Blue).

The data transfer process was described as taking place on the computer, on whiteboards and on paper notes. There were different whiteboards for different specialties and information was passed between medical and nursing staff through verbal, paper-based and whiteboard-based communication. These inefficiencies identified through using FRAM went on to form the basis of a piece of work that utilized a pedometer worn by the triage nurse throughout a 12-hour shift to quantify this. On average, nurses were taking 10,000 to 12,000 steps during a shift (7-8 kilometers), simply to update multiple whiteboards.

The process of FRAM did not just identify system inefficiencies. It also allowed us to develop a deeper understanding of how staff used information, including where patients were located, what jobs needed completing and which doctor was responsible for each patient. Having this information visually displayed so that anyone could update was the aspect that staff found most valuable to their current practice.

Identifying staff-perceived essential information helped inform a new computer-based solution and the creation of virtual whiteboards. Importantly, having a model of how work is currently conducted from staff perspectives helped inform the development of a computer system designed to support workers instead of replicating the current system laden with workarounds.

**Role of FRAM in supporting the identification of Human Factors issues in healthcare**

The World Health Organization has made clear recommendations that it is vital to understand both organizational and human factors design issues for improving healthcare (2). We have described with a case study a method that can potentially contribute to achieving this recommendation despite the difficulties of adequately and comprehensively describing highly complex sociotechnical systems (3).

We have demonstrated that FRAM can be successfully integrated into an acute care context to model an existing complex sociotechnical ED system. It has aided discussing and analyzing where and how the system could be improved. On reflection, FRAM is a tool for describing work, and if used in isolation without discussion and stakeholder analysis, it would not have produced the outputs we achieved. The FRAM model provided a starting point for rich interdisciplinary discussions about how healthcare systems work and allowed for the simulation of variable functions and their upstream and downstream implications. In short, it provides a ‘window on the system’ by describing work-as-done (the reality of everyday clinical practice experienced by those at the ‘sharp-end’) rather than work-as-imagined (as is often enshrined in policy, evidence-based guidelines and in the minds of those managers and leaders far from sharp-end practice) (22).

This work has demonstrated the usefulness of a naïve observer in describing work that has become second nature to the regular staff that struggle “to see the forest for the trees”. This, combined with the ease of use of the FRAM, suggests that FRAM could be integrated into student-led and junior professional-led projects to ensure ED teams and leaders can receive frequent updates to understand current ED work.
Teams should consider how they can utilize naïve observers, such as students and those new to the ED team, for data collection. Furthermore, integration of a longitudinal process over time with FRAM at the core of departmental improvement means all work conducted to improve care can be done in the context of wider system understanding. At the very least, evidenced by our case study, our project has highlighted to the ED team the need to embrace methods that are better suited to understanding complex care environments, rather than applying methods based on simple cause-and-effect thinking (23,24).

## Conclusion

Our case study demonstrated the successful integration of FRAM in an ED to model the complex work taking place using a recognized systems approach. Analysis of this model has been used to make recommendations about priorities for quality improvement activity that considers wider system functioning and potential redesigns to better support the work and wellbeing of the ED team and enhance patient safety. Our approach and findings should be of interest to EDs and other hospital departments globally with a strong interest in exploring the synergies between human factors and quality improvement sciences.

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