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Research Article

A functional perspective for Intensive Care Unit modelling

Natália Ransolin[a,b*], Priscila Wachs[c], Wagner Pietrobelli Bueno[d]

[a]Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil

[b]Australian Institute of Health Innovation, Macquarie University, Sydney, New South Wales, Australia

[c]Programa de Pós-Graduação em Negócios, Escola de Negócios, Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre, RS, Brasil

[d]Centro Universitário Ritter dos Reis, Porto Alegre, RS, Brasil

*nransolin@gmail.com

Abstract

Paper aims: This study demonstrates the complexity of the patient flow from admission to discharge of an adult Intensive Care Unit (ICU) through the application of the Functional Resonance Analysis Method (FRAM).

Originality: This paper shows the daily functioning of the patient flow, shedding light on the high levels of interdependence and variabilities in Complex Sociotechnical Systems.

Research method: The research was developed according to the four steps for FRAM analysis. Sources of evidence involved empirical data collection in a leading teaching public hospital in Brazil.

Main findings: There were identified 34 functions performed mainly by caregivers and support staff. Five instantiations were described to illustrate the functional resonance scenarios caused by the variability propagation across the functions.

Implications for theory and practice: Limitations of this study and suggestions for future research are pointed out. The resulting model is a basis for context understanding for ongoing and following studies.

Keywords

Complexity. Healthcare. Services. Resilience. FRAM.

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1. Introduction

Healthcare services, such as the Intensive Care Unit (ICU), present a wide range of organizational, technical, and social aspects: routines and procedures; equipment, materials, and drugs; multidisciplinary teams, patients, and families (Vicente, 1999; Righi & Saurin, 2015). These several elements, highly interdependent, interacting in an uncertain way also characterize healthcare systems as Complex Sociotechnical Systems (CSS) (Clegg, 2000; Braithwaite et al., 2018). Considering the above, the ICU presents the four CSS attributes: (i) a large number of elements in dynamic interactions; (ii) a wide diversity of elements; (iii) unexpected variability; and (iv) resilience (Righi & Saurin, 2015).

Resilience, through the Resilience Engineering (RE) lens, is the ability of the CSS to adjust its performance before, during or after changes or disturbances (Hollnagel et al., 2013). Resilience is essential for the system to operate in expected and unexpected situations (Woods, 2006), such as CSS. RE recognizes that daily unpredictability gives rise to the duality between work-as-done (WAD) and work-as-imagined (WAI), and the work system organization should manage to bridge the gap by considering the experience of frontline teams (Saurin et al., 2013). This implies that there is a gap between the WAI (i.e., as protocols, standard operating procedures) and the everyday work (WAD), in order to respond with the expected performance, even in challenging situations (Dekker, 2003, 2006). It is not possible to completely approximate WAD and WAI due to CSS characteristics: the combination among different elements that interact dynamically creates unforeseen variability, resulting in a non-linear cause-effect relation (Carvalho et al., 2018).

In order to understand and develop the complexity and resilience of a system, it is important to know and understand the WAD by the teams. Knowing that: (i) resilience is not an attribute that the system has, but it is performed by the system; (ii) and CSS are characterized by the functions they perform, instead of how they are structured (Hollnagel et al., 2014).; (iii) the sign of this unintentional interaction of the normal variability of a CSS is known as Functional Resonance (Hollnagel, 2012).

In this sense, a model, method, or tool that allows understanding and representing the system's complexity is important (Mabry et al., 2008; Carey et al., 2015). The Functional Resonance Analysis Method (FRAM) is a method that enables the modelling of a CSS based on the RE precepts. FRAM is a systematic approach to creating a description or representation of how an activity or sequence of actions usually occurs to understand how the variability in the work affects a system (Patriarca et al., 2020). Additionally, there is a lack of a detailed model of the transition process of critically ill patients (Rennke et al., 2013). Thus, considering the above, this study aims to demonstrate the complexity of the patient flow from admission to discharge in an adult Intensive Care Unit (ICU) through the FRAM modelling.

2. Theoretical review

Research on system performance has investigated possible failures and accidents by modelling linear relationships between different elements, neglecting the inherent variability in CSS's everyday work that can lead to undesired outcomes (Salehi et al., 2021b). In turn, FRAM refutes linear CSS analyses based on Newtonian logic that typically reduces uncertainties (Dekker, 2011). Thus, FRAM modelling aims to unveil the complexity of the system's interdependencies hidden in other methods that do not investigate the interactions between CSS elements. FRAM is a method for functional modelling, being an appropriate approach to visualize and provide a deeper understanding about the system's functionality, considering the non-linear and dynamic relationships between different elements (Hounsgaard, 2016; Salehi et al., 2021a). FRAM's resulting model can evaluate interactions of users' daily activities in the environments, adapting to the dynamic nature of healthcare scenarios (Alm & Woltjer, 2010). Adopting a Human Factors approach and using the FRAM model allows for a better understanding of how work is done within the system and why variability exists in a complex healthcare environment (Pickup et al., 2018). Therefore, FRAM has been used for modelling WAD in healthcare, contributing to the redesign of work systems that support resilience and improve patient safety (Clay-Williams et al., 2015).

The first detailed description of FRAM basic principles is from Hollnagel & Goteman (2004). Hollnagel (2012) presents them as:

1. Principle of the equivalence of success and failures: the understanding that the causes that lead to success can also lead to failures;
2. Principle of approximate adjustments: people and organizations are constantly adjusting their performance in order to cope with the existing conditions;
3. Principle of emergence: understanding that not all events have an identifiable and specific cause;
4. Principle of Functional Resonance: used to describe and explain interactions and non-linear results.

According to Hollnagel (2012), the FRAM model can be used for specific types of analysis, either to understand how something went wrong, to risk analysis, to verify the feasibility of solutions or interventions, or to understand how some activities take place (i.e., WAD). Adjustments and evaluations of conditions that may impact the performance of activities in the system can be made, including the feasibility analysis of proposed solutions or interventions (Hollnagel et al., 2014). In addition, it aims to identify ways to monitor the development of the Functional Resonance, reduce or increase the potential variability of each function, which can lead to desired or undesired consequences. Thus, FRAM can be used to see how combinations of prerequisites and/or multiple resources can interfere with system design (Hollnagel & Goteman, 2004).

Since its conception (Hollnagel, 2012), FRAM has been used in several studies and areas, such as in aviation, urban transport, construction, and software development. Chart 1 shows some recent studies in healthcare, their aim, and also the FRAM´s contribution.

Chart 1. Bibliographic summary of FRAM studies in healthcare.

Paper	Aim of the study or study contribution	FRAM´s contribution
Sujan et al. (2022)	"to demonstrate how FRAM can be used to explore the adaptations and priority decisions ("trade-offs") clinical staff make in order to manage acute post-operative deterioration in emergency surgery patient"	modeled the response to a deteriorating patient after a surgery. Recommendations to improve organizational resilience were made.
Arcuri et al. (2022)	"analyses of the pandemic's effects in the access of riverine communities to the prehospital emergency healthcare system in the Brazilian Upper Amazon River region"	modeled the mobile emergency care system at the studied area, which provided data about possible variations and disruptions in atypical situations.
van Dijk et al. (2022)	"to gain more understanding (MR) of the low compliance of healthcare professionals with medication reconciliation standards by comparing national guidelines and hospital protocols for MR during discharge and in daily clinical practice"	to visualize MR during discharge, comparing work-as-imagined (FRAM modeled based on documents) and work-as-done (interviews about daily routine).
Slater et al. (2022)	to provide a macro system description of the COVID-19 pandemic response in the United Kingdom	"to describe the way in which the overall national pandemic response and management functions were deployed in the current UK COVID-19 response".
Salehi et al. (2021b)	method article, focused on presenting dynamic FRAM-based tool.	to support specialists and practitioners of complex operations to make decisions in complicated situations.
Furniss et al. (2020)	"to explore sources of performance variability in intravenous infusion administration in intensive care unit"	to identify and analyze the variability in intravenous medication and how to manage the trade-offs and create safety.
Kaya et al. (2019)	to understand performance variability and how variability influences the system in terms of both success and failure. The study focused on the drug administration process in a neonatal intensive care units.	argues that FRAM can support the four potential analyses: responde, monitor, anticipate and learn.
McNab et al. (2018)	"to explore and better understand how acutely ill patients who may have sepsis are currently identified and managed"	FRAM model was used in a workshop to discuss intervention improvement on a systems approach.
Wachs & Saurin (2018)	research questions: "how can procedures and the development of RSs be jointly analysed? What are the interactions between RSs and procedures?"	the study was conducted through the preparation and administration of intravenous medications in an emergency department. The FRAM was the fifth step of the proposed framework, focusing on the everyday work modelling.

3. Material and methods

3.1. Study context

The study was developed in an adult ICU of a teaching public hospital in Southern Brazil. The ICU patients are critical, which means they have "[...] comprised of one or more of the main physiological systems, with loss of self-regulation, requiring continuous assistance" (Brasil, 2010, p.3). Therefore, all ICU patients have high levels of criticality and require effective use of resources (bed, equipment, supplies, medicines, qualified professionals).

The studied ICU has 34 beds and is located on the top floor of a 13-floor building. About 200 employees work in that unit, from 15 different professional categories. There are 40 intensive care physicians (23 years of experience in intensive care on average), 32 nurses (18 years), and 115 nurse technicians (19 years). Nursing professionals work in six partially overlapping shifts, and the intensive care physicians work mainly at 12-hour shifts. Patients are admitted from the emergency department, the surgical and clinical wards, and other hospitals.

It is worth noting that this study is part of: a master's dissertation aimed to develop a framework for the integrated modelling of the built environment and functional requirements in order to support the analysis of resilient performance (Ransolin et al., 2020); a research project addressing the need for new methods for operations management in this healthcare institution, which was analysed and approved by the hospital ethical committee (CAEE number 79424617.0.0000.5327).

3.2. Research steps

The methodological approach was adopted according to the FRAM modelling proposed by Hollnagel (2012). Thus, the research development in this study is presented based on the four steps for conducting a FRAM analysis (Figure 1). The FRAM Model Visualizer software was used for the visual representation (http://functionalresonance.com/FMV/index.html).

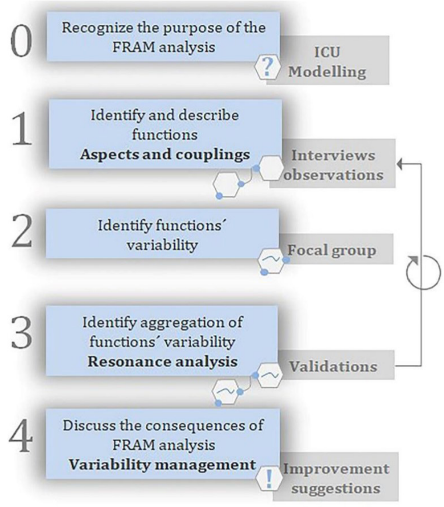

Figure 1. Research steps based on FRAM modelling (adapted from Hollnagel, 2012).

0) **Recognize the purpose of the FRAM analysis:** analyse risks, analyse adverse events, verify the feasibility of solutions or interventions, understand activity or service in its context.

1) **Identify and describe functions:** functions are the necessary activities to perform a process executed by an agent (technical, human, or organization). The function is usually represented by a hexagon. Each edge is one of the six possible aspects of a function: input (which activates the function and/or is used for output; it is the link with the upstream functions), output (the result of the function; it is the link with the downstream functions), control (supervises or regulates the function), precondition (conditions that must be met before the function can be executed), time (temporal aspects that affect the execution of the function) and resources (necessary or consumed by the function when activated). For a FRAM model to be complete, the aspects of the functions must have a relationship with another function (Hollnagel et al., 2014). Figure 2 shows an example of the function <terminal cleaning (patient bay)> and its aspects.

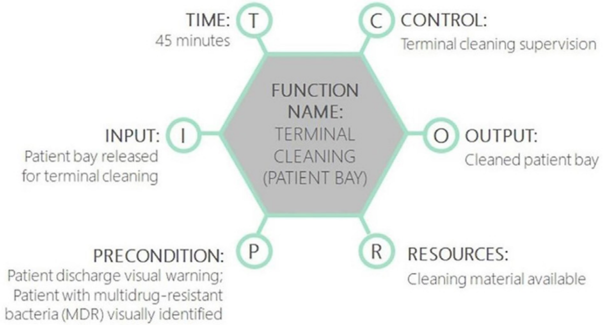

Figure 2. Example of a function and its aspects.

2) **Identify functions' variability:** the output of the functions can vary either in precision (acceptable, unacceptable, imprecise) or/and in time (too early, on time, late, or did not happen) (Hollnagel, 2012). Furthermore, the criticality of functions' outputs variability can be assigned similarly to an approach proposed by Riccardo et al. (2018): score 0 for function's outputs with no variability, score 1 with variability is in terms of either precision or time, and score two if there is variability in both precision and time.

3) **Identify aggregation of functions' variability:** coupling between functions, whereas the output of a function can have an effect on one of the five aspects of another function.

4) **Discuss the consequences of FRAM analysis:** highlights among the FRAM results, according to the study purpose.

3.3. Data collection

This qualitative study has the following data collection instruments: observations, document analysis, individual interviews, and focal groups. The data collection occurred from January 2018 to June 2019.

The observations were characterized as non-participants and totalized 67 hours, performed at different times of the day and during days of the week, in order to take into account the variability of the actual work, and included monitoring of meetings, rounds, shift changes, and patient care. In addition, researchers used a diary to record both observed facts and insights from observations. These observations contributed to the researchers' acclimatization, the understanding of workflows, the identification of functions and their variability (WAD), and the means to make sense of information from other data sources.

The documents contributed to the understanding of work-as-imagined, system performance, infection control indicators, which provided insight into the variability of some functions (e.g., handwashing). Other documents analysed were: standard operational procedures; regulations such as RDC7 and RDC50 (Brasil, 2010), related to the functioning and the built environment of ICUs in Brazil.

A total of 16 semi-structured interviews were carried out (15,5 hours) in the first moment. Different workers and areas were included in the interviews: 4 allied health professionals (pharmacist, physiotherapist, speech therapist, nutritionist); 3 physicians, one of them was the ICU medical chief; 3 nurses, including the ICU nursing chief and a former nursing chief; 1 administrative staff; 1 nurse technician; 1 cleaning staff; 2 family members and 1 patient. In addition, all the participants received and signed a copy of the Informed Consent.

The interviews were based on a five-question script encompassing: a description of the activities carried out by the interviewee; interactions with other professionals and activities; difficulties for carrying out their activities; variabilities in their activities; and suggestions for improvements. Those questions were adapted for interviewing patients to gather their perspectives on patient flow, functions, and system variabilities.

Another data collection instrument adopted was a focal group. 19 ICU workers participated and were distributed into five groups. Each group received a set of functions, and they discussed whether the functions' preconditions were met or not, and identified the functions' variabilities. This meeting lasted 1 hour.

The last data collection instrument adopted was a "refinement interview." During these interviews, each function was presented and discussed, including its aspects and possible variabilities. The refinement interviews were individual, and five interviewees (nurse, nurse technician, physician, risk manager, and physiotherapist) participated. Those interviews allowed a deeper understanding of the functions, variabilities, and functional resonances. This step lasted a total of 12,5 hours. The end of data collection was defined by the criterion of theoretical saturation (Eisenhardt, 1989), i.e., it was completed when no new information and result patterns emerged.

3.4. Data analysis

Data analysis occurred through data triangulation, considering all data sources previously presented (Crandall et al., 2006). First, the researchers read the documents, transcripts of interviews, and the field diary, extracting from this information related to the previously defined categories of analysis (Chart 2). Then, the extracted excerpts were included in a spreadsheet, grouped, and consolidated according to the analysis categories involved in the FRAM construction.

Chart 2. Data collection instruments vs. data analysis.

Analysis Categories	Description	Data Collection Instruments				
		Observation	Document Analysis	General Interview	Focal Group	Refinement Interview
Functions	Necessary activities for patient care in ICU.	X	X	X		X
Agents	Who/what performs the function (Human, Technology or Organization).	X	X	X		X
Aspects	Input, Output, Control, Precondition, Time, Resource. Each function has, at least, one input and one output.	X	X	X	X	X
Variabilities	The output of each function is precise and finishes on time. If not, it has variability.	X		X	X	X
Improvement Opportunities	Improvement opportunities to reduce the variability of the function or to support the worker (team) to cope with the variability.	X		X	X	X

4. Results and discussion

4.1. ICU modelling through FRAM

The purpose of the FRAM modelling was to understand the CSS under analysis, focusing on the patient flow inside the ICU, starting at patient admission until their discharge. Thus, the FRAM model gave a broad perspective on all the functions related to patient care in an adult ICU.

When mapping a dynamic reality, the functions of the FRAM model were not numbered, as they did not follow a rigid sequential order but were cyclical at each patient admission and discharge. As a result, the model (Figure 3) has a series of functions that feedback throughout the development of the process. This iteration between functions is called looping, where the output of one function is the input to another function that somehow feeds the first through one of the six aspects of the FRAM model functions. Chart 3 presents all identified functions and their descriptions, outputs, identified potential variability, and criticality classification.

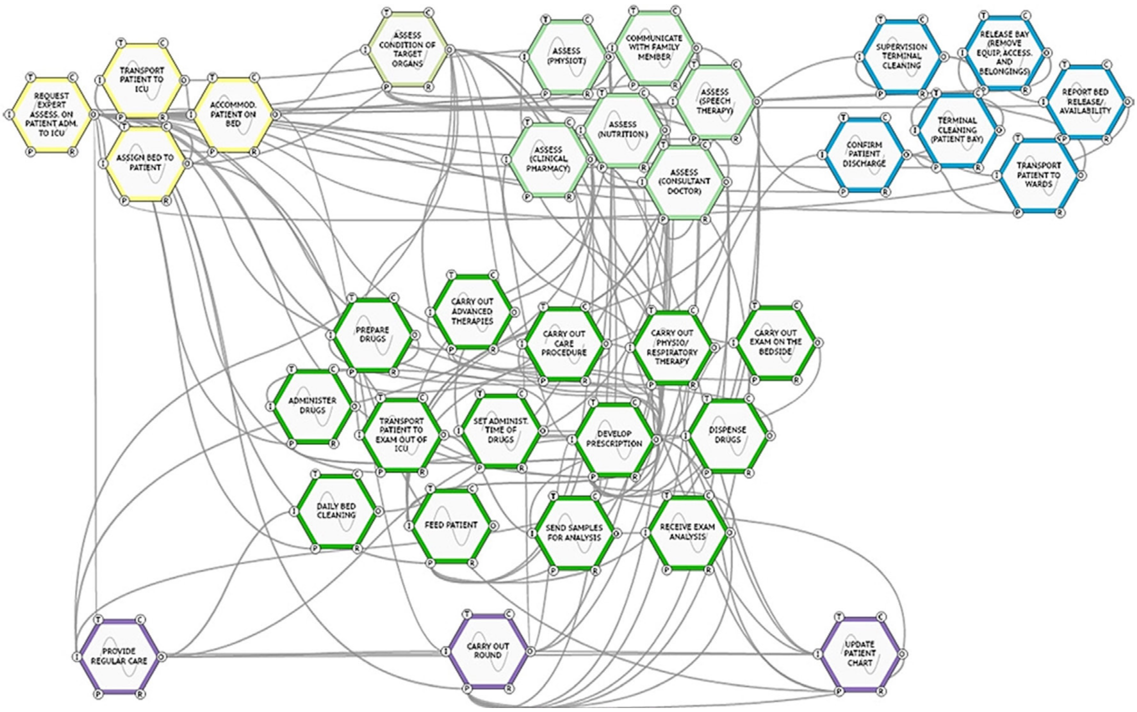

Figure 3. FRAM model of the studied ICU.

Overall, there are 34 functions from patient admission to discharge from the ICU, which were divided into four large groups in this process: care handover (admission) - yellow color; patient assessment - green color; care assistance - lilac color; care handover (discharge) - blue color. All functions have potential output variability concerning time and/or precision, as shown in Chart 3. Considering the criticality of the function, 14 functions were classified as the most critical (score 2).

Patients are admitted to the ICU in four main ways: from the operating room after surgical procedures when the patient's condition is more unstable; from the emergency department; from hospitalization after the worsening of their condition; through the local health system (i.e., external demand). To admit a patient to the ICU, the unit of origin must request a criticality assessment from the hospital's Rapid Response Team (RRT), responsible for managing the institution's critical beds. If approved, the bed is administratively allocated to the patient, and the transport of the patient from the unit of origin to the ICU is released, under the supervision of the responsible team at that moment.

In possession of the patient's clinical information contained in the electronic medical record and verbally transmitted during the care handover between the caregivers from the unit of origin, the RRT, and the ICU, and after the patient's bed accommodation, the medical, nursing, physiotherapy and nutrition in the ICU proceed

Chart 3. Functions, descriptions, outputs, potential variability, and criticality classification.

GROUP	FUNCTIONS	DESCRIPTION	OUTPUTS	VARIABILITY		
				T	P	C
CARE HANDOVER (ADMISSION)	REQUEST EXPERT ASSESSMENT ON PATIENT ADMISSION TO ICU	An ICU bed is requested by activating the RRT (Rapid Response Team) to assess whether the patient is considered critical to be admitted in the ICU, using pre-defined criteria.	RRT ACTIVATED; PATIENT SIGNALIZED (IF MULTIDRUG-RES. BACTERIA)	X		1
	ASSIGN BED TO PATIENT	The RRT receives the bed request, and if the patient meets the recommended criteria for ICU admission, the bed is allocated according to prioritization. The secretary proceeds with the electronic health recording of the patient's admission to the ICU.	PATIENT BED ALLOCATED; CARE HANDOVER PERFORMED; ELECTRONIC HEALTH RECORD COMPLETED	X		1
	TRANSPORT PATIENT TO ICU	Transport of the patient from the unit of origin to the ICU, under the supervision of the responsible team at the moment.	PATIENT'S ARRIVAL IN THE ICU	X	X	2
	ACCOMMODATE PATIENT ON BED	In the ICU, accommodation of the patient in the allocated bed.	PATIENT ACCOMMODATED ON THE BED	X	X	2
PATIENT ASSESSMENT (1st)	ASSESS CONDITION OF TARGET ORGANS	The first patient assessment is carried out mainly by professionals from the medical, nursing, physiotherapy, and nutrition teams. In the ICU, the patient's needs are related to the dysfunctions of one or more target organs: heart, lung, kidney, their combinations, and the advanced therapies offered to them: hemodynamics, ventilatory support, hemodialysis, etc. Most of the time, the patient arrives with little or no condition to communicate (sleepy, intubated), and the ICU team receives information from the RRT, verbally, during the care handover, and from the patient's medical health record.	TARGET ORGANS DYSFUNCTION EVALUATION PERFORMED; CONSULTING REQUESTED; EXAMINATION REQUESTED; ADVANCED THERAPY(S) REQUESTED	X	X	2
PATIENT ASSESSMENT (2nd)	COMMUNICATE WITH FAMILY MEMBER	Team communication with the patient's relatives and/or companions upon admission and throughout their stay. It covers the behavior guidelines in an ICU and on specific patient care. It also aims to investigate the clinical aspects of patient diagnosis.	COMMUNICATION WITH FAMILY MEMBERS PERFORMED		X	1
	ASSESS (SPEECH THERAPY)	When requested by the medical team, an assessment is performed by the speech therapist.	DIAGNOSIS BY THE SPECIALIST PERFORMED	X	X	2
	ASSESS (NUTRITIONIST)	When requested by the medical team, an evaluation is performed by the nutritionist.	DIAGNOSIS BY THE SPECIALIST PERFORMED; PATIENT ORIENTED ON EATING OR FASTING	X	X	2
	ASSESS (PHYSIOTHERAPY)	When requested by the medical team, an evaluation is performed by the physiotherapist.	DIAGNOSIS BY THE SPECIALIST PERFORMED	X	X	2
	ASSESS (CONSULTANT DOCTOR)	When requested by the medical team, an evaluation is performed by the consultant doctor.	DIAGNOSIS BY THE SPECIALIST PERFORMED		X	1
	ASSESS (CLINICAL PHARMACY)	Evaluation of the medical prescription by the clinical pharmacist when drugs are reviewed concerning the patient's conditions.	MEDICAL PRESCRIPTION REVISED	X	X	2
PATIENT ASSESSMENT AND CARE	CARRY OUT CARE PROCEDURE	Care procedures typically performed in the patient's bay, such as catheter insertion, etc.	CARE PROCEDURE UNDERTAKEN	X	X	2
	CARRY OUT ADVANCED THERAPIES	After assessing the dysfunctions of the patient's target organs and/or reassessments over the length of the patient's stay in the ICU, life support is offered through advanced therapies, such as Hemodialysis, Extracorporeal Membrane Oxygenation (ECMO), Mechanical ventilation, among others.	ADVANCED THERAPIES PERFORMED	X	X	2
	CARRY OUT PHYSIO/ RESPIRATORY THERAPY	If prescribed, perform motor and/or chest physiotherapy.	PHYSIOTHERAPY PERFORMED	X	X	2
	DEVELOP PRESCRIPTION	Medical prescription: registration of patient clinical decision-making in the electronic health record. Nursing prescription: patient care, after assessment of their needs.	PRESCRIPTION DEVELOPED; CONSULTING REQUESTED; PATIENT ORIENTED ON EATING OR FASTING;EXAMINATION REQUESTED;ADVANCED THERAPIES REQUESTED		X	1
	SET ADMINISTRATIVE TIME OF DRUGS	Determine time slots for drug administration, according to the medical prescription.	TIME SETTED FOR DRUG ADMINISTRATION	X		1

Chart 3. Continued...

GROUP	FUNCTIONS	DESCRIPTION	OUTPUTS	VARIABILITY		
				T	P	C
PATIENT ASSESSMENT AND CARE	DISPENSE DRUGS	In possession of the drug's schedule, request it at the Satellite Pharmacy and distribute them on each patient's bed.	DRUGS DISPENSED	X		1
	PREPARE DRUGS	At the nursing station, preparation of the drug to be administered to the patient.	DRUG PREPARED	X		1
	ADMINISTER DRUGS	Administering the drug prepared to the patient.	MEDICATED PATIENT	X		1
	FEED PATIENT	Offer the diet to the patient, according to recommendations such as food consistency and drug interactions.	PATIENT FED		X	1
	TRANSPORT PATIENT TO EXAM OUT OF ICU	Transport the patient for examinations in the Hospital's Radiology unit. In this case, the Radiology team accompanies the transport.	EXAMINATION PERFORMED	X	X	2
	CARRY OUT EXAM ON THE BEDSIDE	X-ray tests or blood collection for laboratory tests on the patient in bed.	EXAMINATION PERFORMED	X		1
	SEND SAMPLES FOR ANALYSIS	Sending the exams for laboratory analysis.	SAMPLE SENT	X	X	2
	RECEIVE EXAM ANALYSIS	Receipt of clinical reports by the laboratory or imaging by Radiology.	CLINICAL REPORT RECEIVED	X		1
	DAILY BED CLEANING	Daily cleaning of physical spaces in all ICU rooms, including the patient's bay.	PATIENT BAY SANITIZED		X	1
CARE ASSISTANCE	PROVIDE REGULAR CARE	Constant care assistance, monitoring, (re) assessing, and intervention on the patient, promoting greater quality in the care offered, 24/ day, during their stay in the ICU. This function exerts a control aspect in other functions related to direct patient care.	PATIENT ASSISTED;PATIENT ASSESSMENT PERFORMED	X		1
	CARRY OUT ROUND	A multidisciplinary round is held around the patient, when the daily plan is defined, based on the exchange of information between professionals and, often, with the patient/family member.	DAILY PLAN PREPARED;PATIENT PRE-DISCHARGE CONDITION IDENTIFIED		X	1
	UPDATE PATIENT CHART	Registering in the electronic health record all care decisions and interventions made on the patient and their response to treatments.	PATIENT CHART UPDATED	X	X	2
CARE HANDOVER (DISCHARGE)	CONFIRM PATIENT DISCHARGE	After the Pre-discharge notice (i.e., the patient can be discharged within 24 hours), the responsible physician confirms discharge.	PATIENT DISCHARGE OF ICU CONFIRMED;PATIENT DISCHARGE PLATE VISIBLE	X		1
	TRANSPORT PATIENT TO WARDS	After confirmation of ICU discharge and availability of the bed in the hospital ward, the patient is transported to the new bed.	PATIENT TRANSPORTED TO HOSPITAL WARD		X	1
	RELEASE BAY (REMOVE EQUIP, ACCESS. AND BELONGINGS)	After the patient leaves the ICU, they remove equipment and accessories used by the patient in the bay to clean and deliver their belongings.	PATIENT BAY RELEASED FOR TERMINAL CLEANING		X	1
	TERMINAL CLEANING (PATIENT BAY)	Cleaning the bay (bed, furniture, curtains, floor, ceiling, etc.) upon patient discharge and leaving. At the end of cleaning and supervision, the bay must be in its default configuration to receive a new patient.	PATIENT'S BAY CLEANED	X	X	2
	SUPERVISION TERMINAL CLEANING	After terminal cleaning, the supervision team checks, according to protocols and bioluminescence test, whether the environment is properly clean.	CLEANING SUPERVISION PERFORMED	X		1
	REPORT BED RELEASE/ AVAILABILITY	Once the supervision accepts the terminal cleaning, the secretary is informed that the patient bed is free for future demands. The secretary inserts this information into the hospital system.	PATIENT BED RELEASED		X	1

with the first assessment of the patient, whose main objective is to identify the dysfunctions of one or more target organs. Most of the time, the patient arrives with little or no condition to communicate because they are under sedation, sleepy, or intubated, with great importance given to the flow of information between the external and the ICU teams. Therefore, this first assessment aims to provide immediate care for the clinical condition causing the patient's admission to the ICU.

In the second moment of patient assessment, continuously throughout the ICU stay, the teams seek to communicate with the patient's family and caregivers, to convey necessary guidance on appropriate behavior in the ICU, and especially to seek more clinical information about the patient, as well as to assist in decision-making.

Critically ill patients are often unresponsive and unable to contribute to the team. Consequently, families serve as a valuable resource for patient's care, as the team gets to know the patient better through the family (Wong et al., 2015).

Furthermore, in this second moment, the assessments provided by different professionals in patient care occur to support the clinical diagnosis, as requested by the responsible physician: speech therapy, nutrition, respiratoy and physical therapy, medical specialty, and clinical pharmacy. In addition, regular ICU medical staff members treat patients using state-of-the-art techniques and can consult specialists in different medical, surgical, or diagnostic disciplines whenever necessary (Faculty of Intensive Care Medicine, 2015). These professionals make up the so-called "multi-professional team". Communication with family members and multidisciplinary assessment take place throughout the patient's stay in the ICU.

Assessments and the treatment itself occur throughout the patient's stay in the ICU (Malhotra et al., 2007). The procedure, the first activity to be offered for the patient's treatment, can occur soon after the initial assessment provided by the team or after the preparation of the prescription. The prescription is divided into medical and nursing prescription, containing the plan of care to provide the necessary treatment and is written after the assessment. The prescription guides the clinical conduct to be performed on the patient every 24 hours. Most procedures are performed in the patient's box, such as catheter insertion, puncture, and diagnostic or therapeutic procedures, depending on the intended purpose.

In possession of the prescription, the following activities can be carried out: scheduling the drug; dispense drug; prepare medicine; administer drug; feed the patient. Also, after the prescription for exams is requested, the patient can be transported for exams in the radiology unit, as well as exams performed at the patient's bedside. The examination reports, carried out by the laboratory or by radiology, are sent via an electronic system.

The concurrent cleaning activity of the bed occurs daily while the patient is occupying the bed (Faculty of Intensive Care Medicine, 2015) and involves the cleaning of furniture and space of the box. There is a group specialized in cleaning: familiarized with the ICU environment and the Hospital Infection Control Commission (HICC) protocols.

Some other activities are developed throughout the patient's length of staying in the ICU: providing constant care, an activity performed by the nursing technician, who at the rate of one for each patient or at most two, is constantly observing and providing direct patient care; carrying out a round, a time for exchanging information about the patient's clinical condition and for learning. This daily interdisciplinary ICU clinical round is the moment when the whole team of healthcare workers meets at the bedside and reviews the status of every patient. The ICU clinical round takes about 20 minutes per patient and provides input for medical orders and exams. Preferably, the round should be carried out in the patient's presence, if possible, in the presence of a family member or companion. All ICU health professionals involved in direct patient care participate in these rounds (Faculty of Intensive Care Medicine, 2015). Patient evolution is the activity of recording in the system's electronic medical record all decisions and interventions made on the patient and the treatment response performed by the care team.

The transition from care to the discharge of the patient from the ICU starts with the confirmation of discharge from the ICU, after the medical team has confirmed that the patient is able to be transferred to a less intensive care unit. Confirmation of discharge should be performed with caution, as the rate of unplanned readmission to the ICU within 48 hours of discharge, after admission, should be minimal (Faculty of Intensive Care Medicine, 2015). As soon as the bed that meets the patient's needs is available at the hospital's destination unit, the responsible ICU team will transport the patient.

After the patient leaves the bed, the nursing technician releases the bed to the cleaning team, removing the patient's equipment and accessories for cleaning and sterilization and delivering the belongings to the patient's family. The cleaning team is activated to perform the terminal cleaning of the bed. The entire area (bed, furniture, curtains, floor, ceiling) undergoes cleaning with chemical products and a specific protocol developed by the hospital's HICC. After the terminal cleaning activity, the supervision team checks it, according to the CCIH protocols and bioluminescence test. At the end of the cleaning and supervision, the bed area is ready to receive a new patient. The ICU secretary is informed and enters this information (bed availability) into the system.

The resulting FRAM model provides a common ground for the research project studies under development in the same institution. The broad perspective adopted in this study (i.e., the patient flow from admission to discharge in an adult ICU) may support investigations focusing on one or more of the four large groups of functions. Moreover, the high level of granularity in the description of the FRAM functions provides detailed information on the transition of critically ill patients, which is a gap mentioned by past studies (Rennke et al., 2013).

4.2. FRAM instantiation

The step "identify functions' variability" identified potential variability in all functions. Five instantiations were described, representing the aggregation of functions' variability (resonance of the variability) in the closest downstream functions (Chart 4). The five instantiations described were chosen based on the criticality of the functions (Chart 3). Such analysis is essential to reflect on and plan actions to promote the system's resilience, keeping it safe and efficient.

Chart 4. Instantiations.

Functions ressonation	Instantiations
Transport patient to ICU > accommodate patient on bed > assess conditions of target organs	Transporting the patient to the ICU is a highly unstable event due to the patient's health conditions and limited inventory along the way. In addition, waiting for the elevator and possible complications in the patient's condition may affect the patient's accommodation in bed, interfering with the diagnosis of the first assessment.
Communicate with family member> carry out round patient > assess (speech therapy) /assess (nutritionist) / assess (physiotherapy) /assess (clinical pharmacy) > update patient chart >develop prescription	The patient information contained in the clinical record often lacks the history brought by the family, which may be absent in clinical decision-making situations. In addition, multidisciplinary rounds should ideally bring together family members and at least one representative of the multidisciplinary team, which is often not feasible. Added to this is the potential delay in the consultancy evolution by the multidisciplinary team in the system due to the limited supply of computers. Finally, communication via the system is insufficient, requiring professionals to rework to ensure that the medical team has accessed the prescribed guidelines.
	Frequent miscommunications accumulate until the diagnosis and prescription of patient care.
Develop prescription > carry out exam on the bedside > transport patient to exam out of ICU> provide regular care	The lack of management in the distribution of the schedule for requesting and scheduling exams to patients overloads the routine of nursing technicians in the ICU and Radiology. They must accompany the patient throughout the course and examination. Also, transporting the patient for examination is an event of high instability due to the patient's health conditions and limited inventory along the way. In Radiology, the patient must be switched to a metal-free stretcher to access the CT room. These factors delay the care of other patients or leave them unattended in the ICU.
Set administrative time of drugs > dispense drugs > prepare drugs > administer drugs	The lack of a shift in time to schedule drugs to patients hampers the prescription schedule, requiring a routine for all employees. This situation overloads both the pharmacy space and nursing stations as well as the respective teams. In addition, the nursing technician must review the prescription items with the drug. Drug preparation and admission is a high percentage of technician time, and such bottlenecks and delays in drug dispensing and preparation can spill over into patient administration.
Confirm patient discharge > release bay > terminal cleaning (patient bay) > supervision terminal cleaning > report bed release/availability > assign bed to patient	Information is presented below.

Figure 4 presents the fifth instantiation studied. The function <terminal cleaning (patient bay)> is used as a starting point for the discussion, and the aspects of the functions illustrated are just the ones that have couplings with the other functions in the figure.

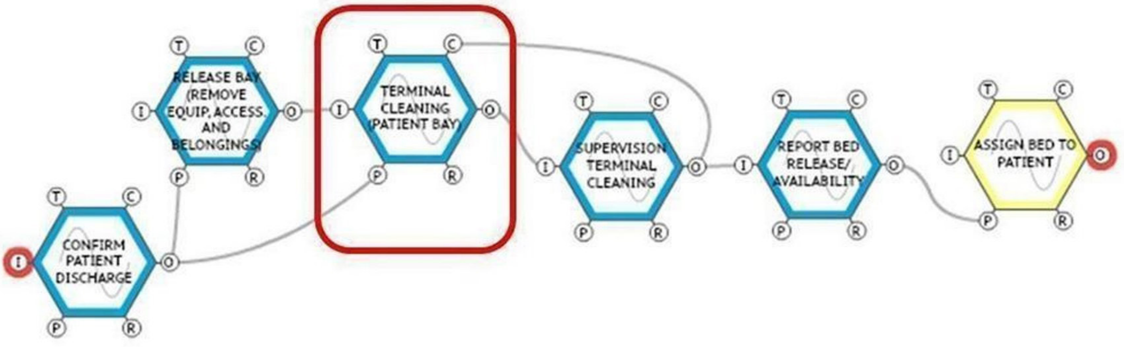

Figure 4. Terminal cleaning instantiation.

A delay (output variability regarding time) on <terminal cleaning (patient bay)> resonates on downstream functions, as does a delay on <assign bed to patient>. As presented above, a patient in need of ICU care is a critically ill patient, and the delay in assigning him a bed could impact the quality of care. A precondition for <terminal cleaning (patient bay)> and <release bay> is the visualization of the patient's discharge plate. The patient discharge confirmation plaque must be visible for bed release and patient transport to the hospital. Without this, the discharge confirmation is lost in the system, forcing the teams to search for information and increasing the time for releasing the ICU bed. As with terminal cleaning, high plaque plays an essential role in bed clearance. The team begins to prepare from the moment of viewing the discharge plate, which means that the bed will soon be released for the technicians to remove the equipment and belongings used by the patient, and later they will be able to sanitize the box. The cleaning of the box starts with the release of the bed. Another critical point that is evident with the use of FRAM is the existing looping between system functions. In this case, the output of <terminal cleaning (patient bay)> is the input for <supervision terminal cleaning>, which at the same time has as its output the control aspect of <terminal cleaning (patient bay)>. Once approved by supervision, <report bed release/availability> is a precondition for <assign bed to patient>.

The instantiation analysis shows the interaction between functions of the system and the repercussion of the functions' variability on the performance of other functions of the system. Reflecting on strategies that the organization can adopt for this particular case, the importance of effective visual management is highlighted. In the case of a CSS, this strategy aligns with the guideline "supporting the visibility of processes and outcomes" for management of CSS presented by Saurin et al. (2013).

The findings presented in this study reinforced the four CSS attributes (Righi & Saurin, 2015): FRAM model and instantiations highlight the significant number and diversity of elements dynamically interacting (i.e., 34 functions distributed in four interrelated groups) and the sources of inherent variability that require resilient performance of healthcare workers. To cope with undesired outcomes, workers play daily efforts to absorb challenging situations during the WAD (Dekker, 2006). Ultimately, workers' resilience to achieve the expected performance is also a non-linear reaction that increases the gap in relation to the WAI, which is not entirely addressable by consequence (Carvalho et al., 2018).

5. Conclusions

ICUs are CSS composed of several dynamical processes that uniquely perform and deliver high-level healthcare services. The interdependencies and variabilities of functions can be systematically explored through the lens of RE, which aligns with the complexity of healthcare services. Since FRAM provides a model for shedding light on the WAD, initiatives can be undertaken to be compatible with the way they are already working instead of constantly trying to fit in the WAI.

The aim of this research was considered to be addressed, since it was possible to model an adult ICU in Southern Brazil. Results showed a FRAM model embracing the major steps associated with patient flow from admission to discharge of that unit. Furthermore, FRAM instantiations illustrate the functional resonance scenarios, showing the variability propagations across the model.

Some limitations of this study are related to the operationalization of FRAM. Efforts are needed either for researchers to collect data and validate the model and for professionals to improve care processes based on regular FRAM analyses. Multidisciplinary interventions require a high number of professionals with different backgrounds, which often is a difficult task to conduct since their availability is scarce. Future studies could explore potential improvements in making it easier to construct and represent FRAM models. Some possible benefits are worker´s greater engagement, widening the analysis and process improvement opportunities. Also, a broader view of the ICU boundaries, focusing on its interactions with other hospital units, is a topic under study. Moreover, other fields such as manufacturing and oil and gas can benefit from FRAM modelling for design and improvements of systems or investigations.

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