ERGONOMICS AND RESILIENCE ENGINEERING IN MODELLING COMPLEX SYSTEMS: VARIABILITY MANAGEMENT FOR RECONCILING WORK-AS-IMAGINED AND WORK-AS-DONE

Rodrigo Arcuri Marques Pereira

Tese de Doutorado apresentada ao Programa de Pós-graduação em Engenharia de Produção, COPPE, da Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Doutor em Engenharia de Produção.

Orientadores: Mario Cesar Rodríguez Vidal
Paulo Victor Rodrigues de Carvalho

Rio de Janeiro
Dezembro de 2020

ERGONOMICS AND RESILIENCE ENGINEERING IN MODELLING COMPLEX SYSTEMS: VARIABILITY MANAGEMENT FOR RECONCILING WORK-AS-IMAGINED AND WORK-AS-DONE

Rodrigo Arcuri Marques Pereira

TESE SUBMETIDA AO CORPO DOCENTE DO INSTITUTO ALBERTO LUIZ COIMBRA DE PÓS-GRADUAÇÃO E PESQUISA DE ENGENHARIA DA UNIVERSIDADE FEDERAL DO RIO DE JANEIRO COMO PARTE DOS REQUISITOS NECESSÁRIOS PARA A OBTENÇÃO DO GRAU DE DOUTOR EM CIÊNCIAS EM ENGENHARIA DE PRODUÇÃO.

Orientadores: Mario Cesar Rodríguez Vidal
Paulo Victor Rodrigues de Carvalho

Aprovada por: Prof. Mario Cesar Rodríguez Vidal
Prof. Paulo Victor Rodrigues de Carvalho
Prof. Carlos Alberto Nunes Cosenza
Prof. Alessandro Jatobá
Profª. Catherine Marie Burns
Prof. Erik Hollnagel

Rio de Janeiro
DEZEMBRO DE 2020

Arcuri, Rodrigo Marques Pereira

Ergonomics and Resilience Engineering in modelling complex systems: variability management for reconciling work-as-imagined and work-as-done/Rodrigo Arcuri Marques Pereira. - Rio de Janeiro: UFRJ/COPPE, 2020.

XXI, 207 p.: il.; 29,7 cm.

Orientadores: Mario Cesar Rodríguez Vidal
Paulo Victor Rodrigues de Carvalho

Tese (doutorado) – UFRJ/ COPPE/ Programa de Engenharia de Produção, 2020.

Referências Bibliográficas: p. 193-207.

1. Ergonomic Work Analysis. 2. FRAM. 3. System Safety. 4. Safety-II. 5. Resilient Performance. I. Vidal, Mario Cesar Rodríguez *et al*. II. Universidade Federal do Rio de Janeiro, COPPE, Programa de Engenharia de Produção. III. Título.

Dedicatória

Dedico esta tese à minha mãe, Regina Célia Arcuri, e à minha avó, Nayde Salek Arcuri, que atravessaram comigo os períodos mais duros e difíceis da produção deste trabalho, e cujos valores, amor e sabedoria foram como um farol durante minha caminhada.

Agradecimentos

A Deus, à minha mãe, Regina Célia Arcuri, à minha avó, Nayde Salek Arcuri, ao meu avô (*in memoriam*), Rogério Arcuri, aos meus dois grandes orientadores, Prof. Mario Cesar Vidal e Prof. Paulo Victor de Carvalho, à minha supervisora durante o período na Universidade de Waterloo, Profa. Catherine Burns, aos meus colegas de laboratório, de grupo e de rede de pesquisa, aos meus grandes amigos e a todos que me estiveram do meu lado e me apoiaram durante a realização deste trabalho.

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them".

Sir William H. Bragg

"All models are wrong. Some are useful".

George E. P. Box

Resumo da Tese apresentada à COPPE/UFRJ como parte dos requisitos necessários para a obtenção do grau de Doutor em Ciências (D.Sc.)

ERGONOMIA E ENGENHARIA DE RESILIÊNCIA NA MODELAGEM DE SISTEMAS COMPLEXOS: RECONCILIANDO O TRABALHO-COMO-IMAGINADO E O TRABALHO-COMO-REALIZADO

Rodrigo Arcuri Marques Pereira

Dezembro / 2020

Orientadores: Mario Cesar Rodríguez Vidal
Paulo Victor Rodrigues de Carvalho

Programa: Engenharia de Produção

Esta tese enfoca o problema da gestão da variabilidade em sistemas sociotécnicos complexos. Particularmente, ela explora como o design organizacional e tecnológico pode oferecer suporte a diferentes domínios quanto a lidar com a complexidade por meio da gestão da variabilidade. Para endereçar este problema, nós propomos uma metodologia – Modelagem Ergonômica Dinâmica – que une ferramentas e métodos da Ergonomia e Engenharia de Resiliência para guiar o design do sistema visando à gestão da variabilidade.

O valor da metodologia é avaliado por meio de sua aplicação a múltiplos domínios complexos sob cinco propósitos específicos distintos: A – mapear o impacto das condições do ambiente de um sistema no cumprimento de políticas públicas; B – entender as implicações de uma reestruturação organizacional para a resiliência e fragilidade; C – identificar requisitos de software para aprimorar a performance resiliente; D – fortalecer práticas de segurança que se originam do conhecimento dos operadores; e E – prever o comportamento e um sistema em uma situação de crise. Cada um dos estudos faz aportes ao *framework* da Engenharia de Resiliência e produz contribuições para a gestão da variabilidade no domínio em questão, tanto orientando o realinhamento entre demandas do sistema e as capacidades planejadas quanto suportando ajustes no *sharp-end*.

Abstract of Thesis presented to COPPE/UFRJ as a partial fulfillment of the requirements for the degree of Doctor of Science (D.Sc.)

ERGONOMICS AND RESILIENCE ENGINEERING IN MODELLING COMPLEX SYSTEMS: VARIABILITY MANAGEMENT FOR RECONCILING WORK-AS-IMAGINED AND WORK-AS-DONE

Rodrigo Arcuri Marques Pereira

December / 2020

Advisors: Mario Cesar Rodríguez Vidal
Paulo Victor Rodrigues de Carvalho

Department: Production Engineering

This thesis addresses the problem of managing variability in complex sociotechnical systems. Particularly, it explores how organizational and technological design can offer support to several domains in coping with complexity by means of variability management. To tackle this problem, we propose a methodology – Ergonomic Dynamic Modelling – that bridges tools and methods from Ergonomics and Resilience Engineering to guide system design in managing variability.

We examine the value of this methodology by applying it across multiple complex domains under five specific and distinct purposes: A - charting the impact of system's environment conditions in accomplishing public policies; B - understanding implications of organizational restructuring to resilience and brittleness; C – disclosing software requirements for improving resilient performance; D – strengthening safety practices stemming from workers' knowledge; and E – predicting system behavior under a crisis situation. Each study builds on the Resilience Engineering framework and produces contributions for managing variability in the addressed domain, both by helping designers to realign planned capacity and system demands and by supporting dynamic adaptations at the sharp-end.

Sumário

Lista de Figuras

Lista de Tabelas

Lista de Abreviaturas e Siglas

CTA – Cognitive Task Analysis

CHW – Community Health Worker

CWA – Cognitive Work Analysis

EHR – Electronic Health Record

EMR – Electronic Medical Record

EWA – Ergonomic Work Analysis

FHS – Family Health care Strategy

FHT – Family Health care Teams

FRAM – Functional Resonance Analysis Method

MTM – Medication Therapy Management

PHC – Primary Health Care

PHF – Primary Health care Facility

PMS – Pharmacy Management System

PNAB – Política Nacional de Atenção Básica (Brazilian Primary Health Care National Policy)

SUS – Sistema Único de Saúde (Brazilian National Healthcare System)

WAI – Work-as-imagined

WAD – Work-as-done

1 Introduction

Work-as-imagined (WAI) always projects work-as-done (WAD) in some sense, as workers need guidelines to perform their work. However, one must take into account that such projections are active rather than passive (HOLLNAGEL, 2014). Procedures and policies – produced at the blunt end of systems - cannot cope with everything that occurs in a complex workplace, and sometimes bring unnecessary constraints for work activities – produced at the sharp end of systems.

Moreover, it is difficult for those in the blunt end of a complex system to grasp how much distance exists between WAI and WAD. This happens either because existing data at the sharp end are: (a) filtered through several organizational layers and (b) delayed to those at the blunt end (HOLLNAGEL, 2014). In this way, WAI and WAD are essential dimensions of work organization that must be as reconciled as possible, once gaps or misalignments between WAI and WAD might affect the system's ability to function within its boundaries (ANDERSON; ROSS; JAYE, 2017; BRAITHWAITE; WEARS; HOLLNAGEL, 2017, p. 20; CARVALHO, 2011). The distance between WAI and WAD is a consequence to the ever-present underspecified nature of work conditions (HOLLNAGEL, 2012, cap. 3).

In complex domains, such as nuclear power plants operation, aviation, offshore oil industry, and the ones studied in this thesis – primary health care, medication therapy management, artisanal coastal fishing and on-site emergency care - the value of knowing what (and how) things are being done is crucial for the success and safety of the activities. In these cases, monitoring and understanding the gap between prescription and practice (RIGHI; SAURIN, 2015), and reflecting on discrepancies between work as it is imagined and work as performed is important for design purposes as a way to tackle their brittle aspects (BRAITHWAITE; WEARS; HOLLNAGEL, 2017; DE CARVALHO et al., 2016). Therefore, workers create effectiveness by filling the gaps and building bridges. Gaps are a generic source of adaptive capacity, and by studying them we can learn what current system design might be missing, leading us to target which parts to build so the system is more effective and safer in the future (WOODS, 2006).

One way to move forward from understanding this differences and its consequences is to work towards Closer alignment between WAI and WAD, which can potentially reduce the requirement for adaptations *in situ* (ANDERSON; ROSS; JAYE, 2017). The idea behind this approach is to lead to better planned, coordinated and controlled adaptations which in turn may reduce adverse outcomes by creating a more stable environrment. A second approach to manage variability nad the gape between WAI and WAD lies in improving adaptations themselves (ANDERSON; ROSS; JAYE, 2017; NEMETH et al., 2011), which can be done by strengthening successful adaptations and dampening those that are risky or unsuccessful.

This PhD thesis addresses the problem of managing variability in complex sociotechnical systems. Particularly, it explores how organizational and technological design can offer support to safety-critical domains in coping with complexity by means of variability management. For this purpose, we apply a research approach combining Ergonomics and Resilience Engineering through a research design comprising a data collection phase using ethnographic methods and data coding, modelling and analysis using tools from the Resilience Engineering framework, including, Systems-Theoretic Accident Model and Processes (STAMP), the Functional Resonance Analysis Method (FRAM) and the resilience abilities. This general research approach was applied across different safety-critical domains, producing contributions on practical and methodological levels to five complex systems: (A) patient visits within primary care; (B) referral prioritization to specialized care; (C) medication therapy management; (D) artisanal sea fishing; and (E) mobile emergency care.

1.1 Research Problem and Research Questions

In this section, the research problem addressed in this thesis is described in terms of its topic, question and significance. The latter is divided in conceptual and practical significance as suggested by Booth, Colomb and Williams (2008).

The research problem is stated below:

- **Research topic**: variability management in complex systems;
- **Research question (major)**: How can we manage variability to reconcile work-as-imagined (WAI) and work-as-done (WAD) in complex systems?

This research problem configuration entails the **objective** of this thesis as its conceptual and practical significance. The **conceptual significance** of this thesis regards the description of the different ways in which variability affects the system outcomes and safety in complex domains, and how we can best cope with it. The **practical significance** of this thesis lies in informing organizational and/or technological design for complex systems, and particularly for the domains of primary care (comprising patient visits and decentralized referral prioritization to specialized care), medication therapy management, artisanal fishing and on-site (mobile) emergency care.

As to facilitate the tractability of the presented research problem, its research question was divided into three sub questions, as follows:

- **RQ1 - Research sub question 1**: How are system outcomes and safety impacted by variability in complex systems?
- **RQ2 - Research sub question 2**: How can we manage variability to reconcile WAI and WAD in complex systems through supporting dynamic adaptations at the sharp end?
- **RQ3 - Research sub question 3**: How can we manage variability to reconcile WAI and WAD in complex systems through realigning planned capacity and demand?

1.2 Objectives

In light of the presented research problem, the main objective of this thesis was to bridge Ergonomics and Resilience Engineering into a methodology that can inform technological and organizational design to manage variability in complex systems. Some specific objectives were also posed and addressed to illustrate how such methodology could be applied to specific puposes within the larger realm of managing variability in complex systems. Namely:

A. Chart system environment's impacts over public policy goals;
B. Understand implications of organizational restructuring to resilience and brittleness;
C. Disclose IT requirements for improving resilient performance;
D. Strengthen safety practices stemming from workers' knowledge;
E. Predict system behaviour under a crisis situation.

1.3 Motivation

In complex sociotechnical systems as PHC and artisanal fishing, variability is not only the reason why things can go wrong, but also the reason why things go right most of the time (HOLLNAGEL, 2014). Therefore, is necessary to study how work is really done at the sharp end, understanding and managing the intrinsic variability, rather than simply trying to reduce or dampen it (PATRIARCA et al., 2018).

In Brazil, Canada and other countries, there have been increasing efforts in order to consolidate primary health care as the major strategy to coordinating and providing comprehensive, equitable and high quality care. Therefore, processes that stem from PHC are usually the first contact that patients have with the health care systems. In the Brazilian case, the Family Health Care Strategy was initially about expanding access to care, but later on its responsibility has increased significantly, as it became a central and structural strategy in the Brazilian health care framework and its complexity grows as it includes more specialized services (GIOVANELLA et al., 2009), as the role of coordinator of care and gatekeeper for specialized care (ALMEIDA et al., 2013), by means of a decentralized referral prioritization system in the city of Rio de Janeiro.

One permanent challenge for public referral prioritization is that resources are limited and demand often greatly exceeds their supply, making it impossible to provide all individuals with effective care in optimal time. This is especially true in developing countries such as Brazil, where this contrast often reach levels where gatekeeping involves literally “life or death” decision-making. Despite this scenario, studies concerning coordination of care are scarce (VARGAS et al., 2016). The existing literature warns of limited coordination between PHC and specialized care in Latin America due to deficiencies in information exchange (HARRIS et al., 2007; VÁZQUEZ et al., 2017).

The need to reconcile WAI and WAD is also clear for the Patient Visit subsystem, in which the CHWs play a central role. In order to be successful at identifying health risks and monitoring health conditions of families living in the clinics` territories, CHWs need to adopt anticipatory maneuvers to deal with situations such as shootouts between the police and gangs of drug dealers, insalubrious conditions that pervade streets inside the communities, obstruction of access by landslides and sewage leaking, among others.

Literature indicates that some of these instantiations that emerge from territory conditions of patient visits – and which are not under control by CHWs – impact patient care (MATHESON et al., 2016), risking the accomplishment of the specific PNAB goals assigned to these professionals.

A number of factors has been appointed by the literature as contributors to safety issues for the domain of MTM, and particularly the dispensing process, including (WEIR; NEWHAM; BENNIE, 2020): (i) the internal environment of the pharmacy setting, (ii) the usability and design of pharmacy technology, (iii) the dispensing task itself, (iv) organisational factors, (v) external influences, and (vi) patient-related contributors. The health information technology systems in Canada provides a perfect test bed for researchers to study the impacts of health service systems in terms of the policies in data exchange between physicians and pharmacists (CHIN et al., 2018), as disclosed in section 1.4.3.

Artisanal fisheries constitute an important source of employment, income and food to millions of people from coastal communities worldwide, as well as a fundamental cultural and traditional identity factor at a regional level (GARCÍA-DE-LA-FUENTE; FERNÁNDEZ-VÁZQUEZ; RAMOS-CARVAJAL, 2016). However, artisanal coastal fishing presents highly risky and unpredictable situations and features: the use of poor work tools, difficult inhabitability, physical overload and high energy consumption, risk of accidents and incidents, improper handling of fish, interference from urban and tourism growth, which increases the situa tion of insecurity and requires adequate and continuous replanning (JAESCHKE; SALDANHA, 2012; SALDANHA et al., 2012).

In remote ultra-peripheral regions such as the inner parts of the Amazon, mobile emergency care through water ambulances is the only gateway for riverine communities to the health care system (FERREIRA et al., 2020). Nevertheless, this work system presents numerous challenges for intervention teams (water ambulance crews) and dispatch teams at the Dispatch Central. Radio and cell phone coverage is low, hampering communication between the two teams and, consequentially, delivery of emergency care. Also, distance traveled with the water ambulance (and sometimes on foot, after reaching closest docking point for community) is long and may go over 6 hours for the Içá river (major Amazon River tributary in the Upper Amazon River region). Combined, these two obstacles can make for risky and challenging decision-making from the crew.

1.4 Research Settings

In this section we briefly outline the research settings and vital contextual information for the five studies presented in this thesis.

1.4.1 Patient Visits or House Calls

The Alma Ata Declaration (WORLD HEALTH ORGANIZATION & UNICEF, 1978) states that Primary Health Care (PHC) is the first level of a continuous care process, and initiates by congregating people, families and the health system. The countries that oriented their health systems by PHC accomplished better results on health promotion (STARFIELD; SHI, 2002). PHC follows throughout the world some essential principles: care on first contact, longitudinally care, integrity and coordination of care.

The Family Health care Strategy (FHS) has historically been the major strategy in Brazil concerning PHC, and in this context the Política Nacional de Atenção Básica (Brazilian Primary Health Care National Policy – PNAB) (MINISTRY OF HEALTH OF BRAZIL, 2012) lists responsibilities and tasks of PHC professionals in order to provide adequate health care to people.

As primary health care is characterized by a set of individual and collective actions focused on keeping people healthy – rather than focused on healing - the Family Health Care Strategy is an important instance of the Brazilian health care system. The FHS develops through educational and assistance actions for promotion of health and prevention of diseases, performed by family health care teams, in patient's residences or primary health care facilities (clinics that host the FHS). Primary Health care Facilities (PHF) usually host between 3 and 8 teams, and each team is composed at least by a family doctor, a nurse, a nurse technician, and between 6 to 12 community health workers (CHW). However, many Family Health care Teams (FHT) also comprise a dentist, a dentist auxiliary and a dental hygiene technician.

Community health workers play an important role in primary health care as responsible for linking communities and health services, mapping the territory, collecting data on socio-economic conditions of population, especially when communities are poorly developed, dangerous, unhealthy, or affected by urban violence. One of the key attributions for CHWs in Brazil, as established by the PNAB, is conducting patient triage along with nurses and nurse technicians. This process is mainly oriented through the Manchester Triage Protocol (MACKWAY-JONES; MARSDEN; WINDLE, 2014) as a basis of risk assessment to the spontaneous demand. However, in Brazil (and particularly in poorly developed territories within the clinic's coverage) FHTs must also take into account social vulnerability criteria which greatly impact decision making o who will have priority in care (JATOBÁ et al., 2016). Therefore, decisions are often made in the face of different expectations of patients` future outcomes (ENDSLEY; WRIGHT, 2008).

This facet of CHWs' work in Brazil is even more visible in patient visits (also known as house calls), a process that encompasses the majority of CHWs' attributions and takes most of their weekly schedule (about 75%). To effectively perform patient visits in poor territories, CHWs must gain expertise in community skills - a specific set of abilities conceptualized and thoroughly investigated by Bellas (2017). The planning for patient visit requires several decisions made in collaboration with the rest of the healthcare team. To visit their patients, community health workers must verify whether there are any results of examinations to deliver, whether there are patients to carry from home to the clinic, and whether there are any specific demands.

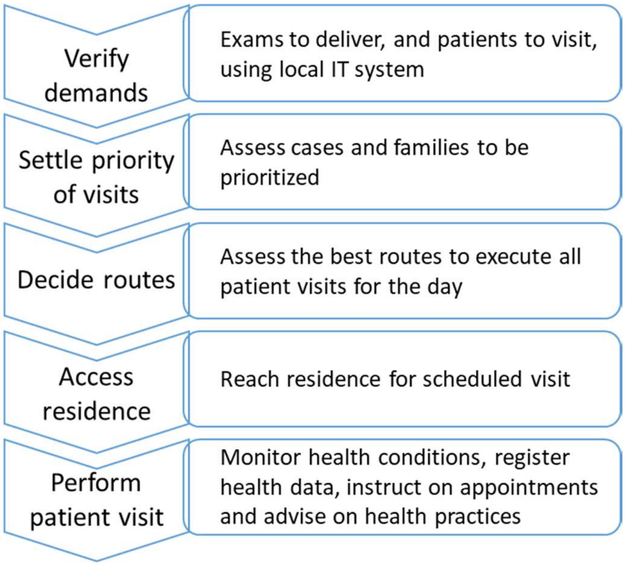


Figure 1-1 – Main steps at patient visits by community health workers

When needed, psychological counselling from workers is essential to strengthen the bonds between the primary healthcare teams and the territory's population, as well as facilitate the ongoing and future patient visits. In cases when the worker concludes that the patient should seek help from a psychiatrist or a psychologist, he instructs the patient on the necessary steps to schedule an appointment at the clinic.

1.4.2 Referral Prioritization to Specializied Health Care

Adequate prioritization of patient referrals at a macro level is strategic to public health systems. Investigation on advantages and drawbacks of different referral prioritization models is a recurrent theme around the world, including North America, Europe and Brazil (ASKILDSEN; HOLMÅS; KAARBOE, 2011; MACCORMICK; COLLECUTT; PARRY, 2003; MARINHO DA SILVA; SANTOS; BORENSTEIN, 2010; SABIK; LIE, 2008; SALTMAN; RICO; BOERMA, 2006). A number of disciplines from Production Engineering have been studying the domain in recent years (GAGNON; SÁNCHEZ; PONS, 2006; HALL et al., 2013; RAJEEV CHADHA; AMITA SINGH; JAY KALRA, 2012).

Referral prioritization in the Brazilian National Health Care System (SUS) comprises three large systems: referral prioritization to ambulatory care; referral prioritization for hospital stays; and referral prioritization for emergency care. These are fundamentally different systems in terms of their designed processes, patient flow intensity and support technologies.

The referral prioritization system for ambulatory care aims to assign the limited vacancies from specialized care to patient cases most in need coming from primary care. Specifically, it prioritizes vacancies for specialized procedures such as consultations with medical specialists, elective surgeries and lab tests. Information flows within this system are illustrated in Figure 1-2. This referral prioritization system contrasts with the other two by the more intense patient flows; by the volume of medical resources deployed; and for the fact that its IT routines are conducted single-handedly inside one large web-based health information system named SISREG, currently running at version 3.

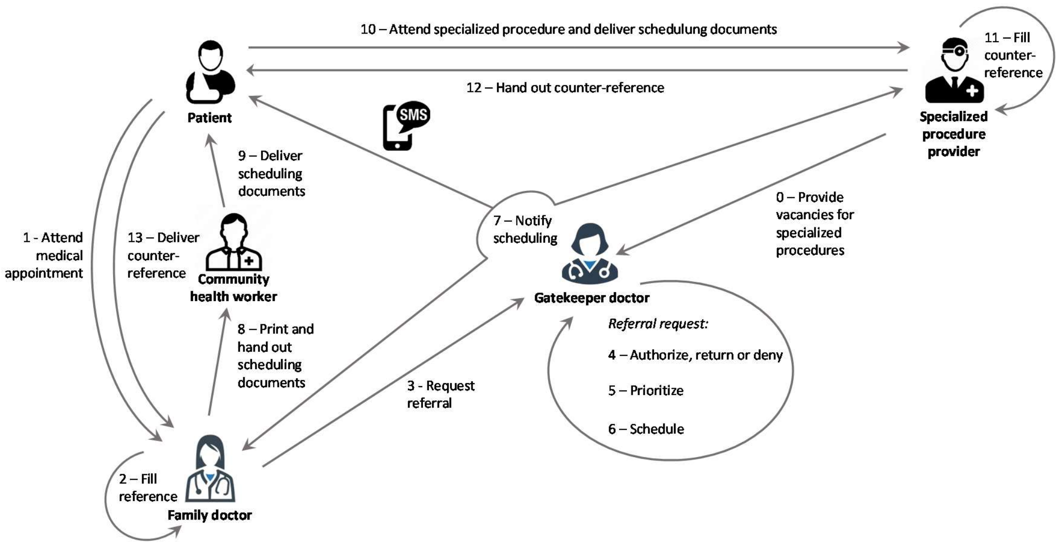


Figure 1-2 – Main steps and information flows in decentralized referral prioritization

Each state and municipality has the prerogative of organizing each of these three referral prioritization systems in the most appropriate way according to local particularities. This autonomy is maintained as long as they follow the general guidelines established by the National Referral Prioritization Policy (MINISTÉRIO DA SAÚDE, 2008) and the Brazilian Family Health Care Strategy (MINISTÉRIO DA SAÚDE, 2006), the major strategy for primary health care in Brazil.

These high-level national public health policies enable the coordination of care concerning referral prioritization for both amulatory care and hospital stays to be performed by primary health care, more specifically by the FHTs, which are composed by multi professional expertise including doctors, nurses, dentists, nurse technicians and CHWs. However, due to low coverage of the cities' populations by the primary care structure as designed by the Family Health Care Strategy (FHS) - and also due to disagreements between local government institutions, hospitals and other players - this framework is still only partially functional in most municipalities of the country.

The city of Rio de Janeiro presented this same scenario until 2009, when reforms in the health care sector were initiated, managing to elevate the FHS coverage from 7% in that year to 70% in 2016 (SORANZ et al., 2016, p. 200). In 2012 the referral prioritization systems for ambulatory care and hospital were both restructured to operate mainly from primary health care, thus assigning at least one physician in each PHF as a gatekeeper doctor.

Differently from many complex subsystems of the health care domain - as emergency rooms and patient visits by family health care teams (FHTs) – decision-making by gatekeepers is not designed to be made in a collaborative environment. Instead, it is assumed to be conducted by gatekeeper doctors (i.e. the physicians responsible for allowing or denying medical procedures requests from doctors working in FHTs) alone based solely on information displayed by a support health information system. The nature of these decisions lies in three main sequential steps regarding medical procedures requests submitted by doctors from PHFs:

1. Validate or alter previously set risk assessment for each of the requests;
2. Authorize requests, deny them or send them back and ask for more details to support the need for a specialized procedure;
3. Scheduling of the most critical requests - based on risk factors and waiting time - to the limited vacancies available in hospitals, specialized clinics and diagnosis centers.

1.4.3 Medication Therapy Management

Pharmacists and physicians use different pieces of information to provide patient care. Physicians record diagnostic information, including physical evaluations and tests, while pharmacists keep detailed records of medications provided. Most of community pharmacists do not have access to the reason a medication was prescribed, the diagnostic test, or laboratory results, and assess appropriateness and dispensed medications using the limited information contained on a prescription or patient recall (MERCER et al., 2018). Medication therapy management in Canada includes medication dispensing, medication review, follow-up and other processes, performed by several actors, the main ones being prescribers (who can be physicians or nurse practitioners), clinical pharmacists (a specific role in which pharmacists act as consultants from within medical clinics) and dispensing pharmacists, who work at community pharmacies. The main process (medication dispensing) is briefly outlined in Figure 1-1.

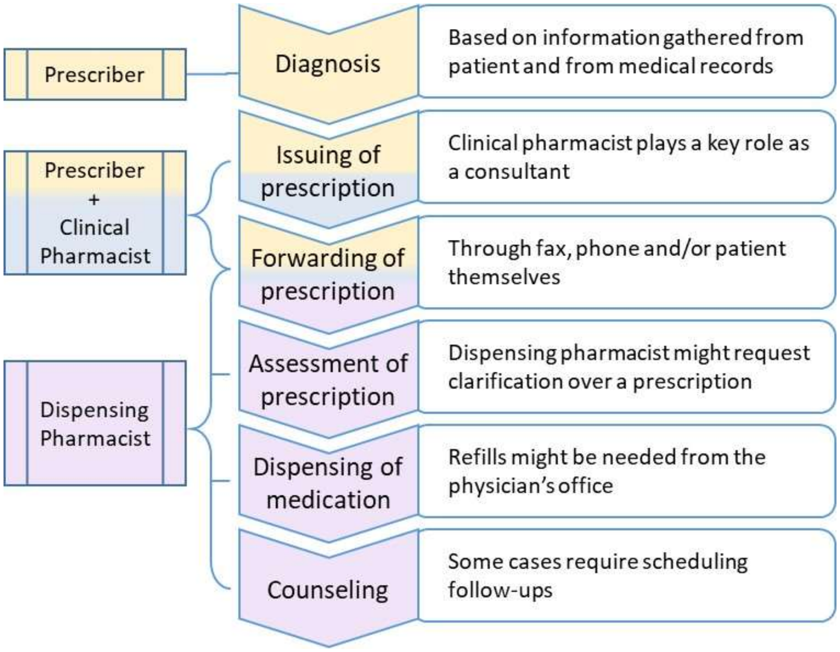


Figure 1-3 – Main steps for medication dispensing, the major process conducted within medication therapy management

Communication between pharmacists and physicians is heavily dependent on the fax machine. Unlike a phone, faxed documents provide a written record of an encounter. However, fax machines are not connected with pharmacist and physician information systems, reducing the efficiency of their use (MERCER et al., 2018). In Canada, prescribers' work is supported to some degree by information technology, mainly through office-based electronic medical records (EMRs) and regional or provincial electronic health records (EHRs). These health records contain hospital data (e.g., discharge summaries), laboratory data, diagnostic imaging, and sometimes dispensing information (CHIN et al., 2018). Pharmacists use a pharmacy management system (PMSs), and some may have access to the information in the EHR to support medication reviews, and the identification of adverse drug interactions. A schematic view of information flows for medication therapy management is shown in Figure 1-4.

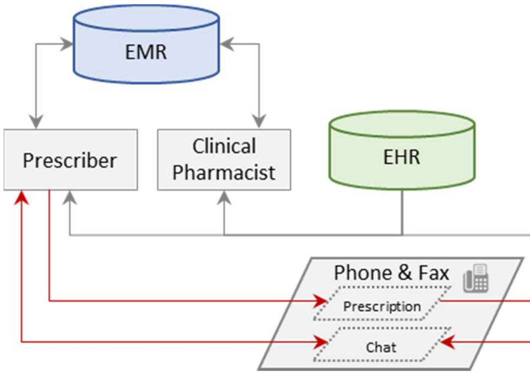


Figure 1-4 – IT systems and information flows for medication therapy management in Southwestern Ontario, Canada (prevalent case). Red arrows represent direct communication

In clinical settings, medication-related decisions are often passed verbally among patients, doctors, nurses, and pharmacists, and the message can become distorted (MERCER et al., 2018). Too often, however, critical information is not shared, even when an electronic health record (EHR) is used, and the decision to prescribe or not prescribe, to take or not take a medication, is made with missing or distorted information (HALL et al., 2016). In most health care settings, pharmacists and physicians often do not communicate well because they largely work independently and in parallel with each other, rather than collaboratively (AUSTIN; GREGORY; MARTIN, 2007, 2007).

1.4.4 Artisanal coastal fishing

Artisanal fishing performed with rafts is one traditional and peculiar characteristic of Brazilian northeast, and is marked by unpredictability, risk, accidents and incidents, precarious conditions of work and hygiene and low financial return (SALDANHA et al., 2012). In the state of Rio Grande do Norte, Brazil, that activity is held by several costal communities with the finality of subsistence and commercialization.

Artisan fishing is the one which occurs through manual work performed by the raftsmen, using small vessels in the capture and in small scale (JAESCHKE; SALDANHA, 2012). The raft is a secular vessel used in artisan fishing and named according to its dimensions. The small-sized ones are called botes or catraias, measuring around 3.5 meters; the medium-sized ones are knowns as paquetes, 4 to 5 meters length; the jangada de alto is the model that reaches 8 meters length (JAESCHKE; SALDANHA, 2012).

The artisanal fishing with rafts in Ponta Negra beach in Natal, Rio Grande do Norte state, is developed by about forty male fishermen. Most of the fishermen lives at

Vila de Ponta Negra, an area localized approximately 850 meters from the anchoring of the rafts. Some of them have license to fish lobster and receive a minimum wage during the time of closure (december to may), used for the acquisition of food, and investments as necessary equipment and utensils for the fishing and the rafts (SALDANHA et al., 2012). Although they perform a number of different fishing kinds of expeditions, the main one is the fish capture expedition, illustrated in Figure 1-5.

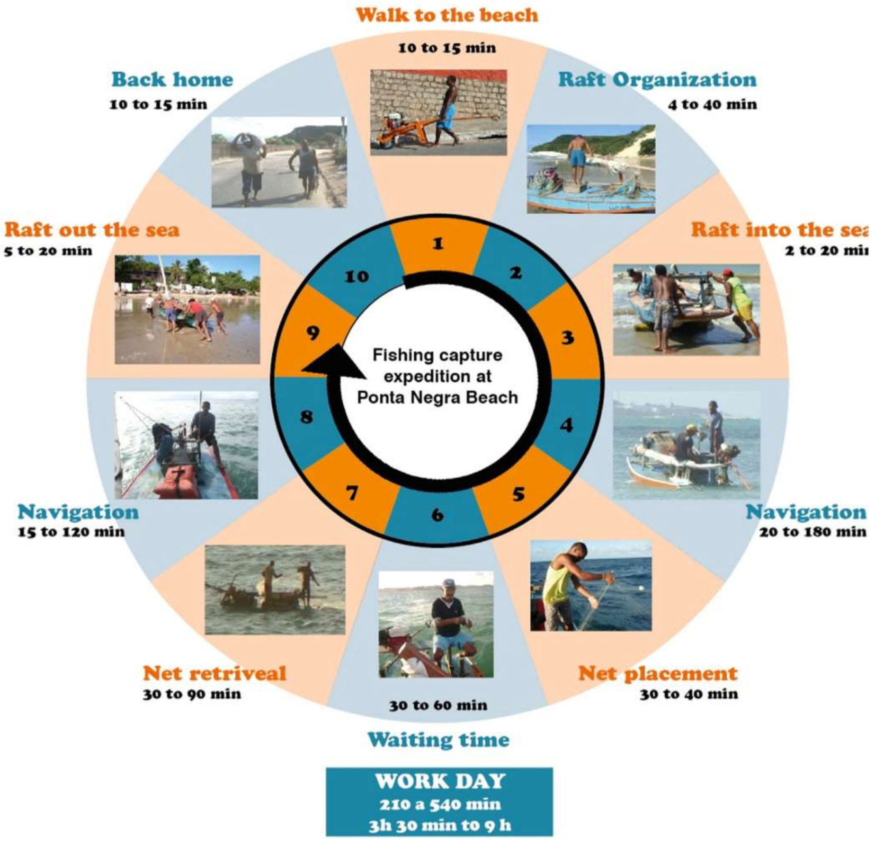


Figure 1-5 – Main steps in fish capture expedition

(JAESCHKE; SALDANHA, 2012)

According to Celestino et al. (2012), the artisanal coastal fishing activity demands mental overload, because the fishermen need to have the domain of marine territory and the natural elements that compose it, so that the arrival at the fishing spot is successful . It bears also high physical load, by virtue of performing the activity itself, such as loading and unloading the raft from the sea and collect and disposal of the networks (CELESTINO et al., 2012).

1.4.5 *Mobile emergency care for riverine communities*

In Brazil, the Mobile Emergency Medical Service (SAMU) is a healthcare service that delivers prehospital emergency care to incidents when necessary. SAMU is part of the Brazilian Unified Healthcare System (SUS) and covers about 83% of the country's population (about 170 million people) (FRASÃO, 2018).

Launched in 2003 by the Federal Government as part of the National Emergency Care Policy (Machado et al., 2011), SAMU provides emergency medical care in residences, worksites, and public locations. The service is available for dispatch through a standard single-access phone number (192), which is toll-free. The call is answered by a regional dispatch, which determines the appropriate medical resources required by the patient, and mobilizes the ambulance crew closest to the occurrence. The water ambulance crew are stationed throughout strategically-located decentralized bases. Meanwhile, the Dispatch communicates with local health care facilities and keeps track of beds and services' availability.

SAMU services in riverside and coastal areas are carried out through water ambulances. The major process carried out by SAMU in riverside and coastal areas is the rescue service, labeled in this thesis as "Process A" and shown in Figure 1-6.

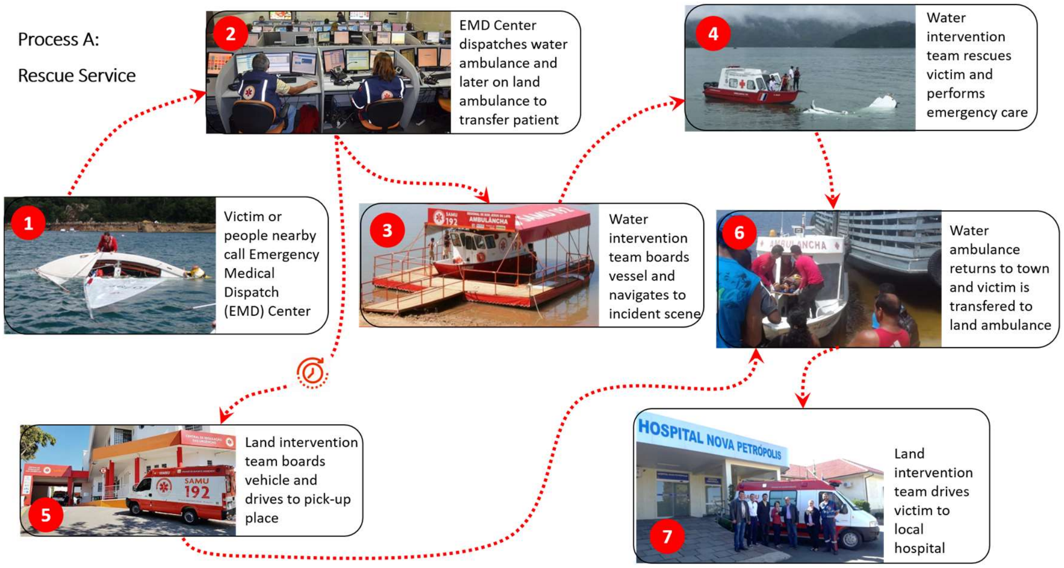


Figure 1-6 – Main steps for rescue service, the major process in riverine mobile emergency care

Water ambulances, commonly called "ambulanchas," a neologism from the merging of the words "ambulance" and "speedboats" (in Portuguese, "ambulância" and “lanchas”). Compared to land routes, waterway environments present certain particularities, such as the inconsistency in navigability conditions and the route to be traversed, which is often lengthy and deserted. These features increase the complexity of providing a high-quality and safe emergency care service.

From all Brazilian regions where SAMU operates water ambulance services, the largest and most dependable on it is the Upper Amazon River region, where an Emergency Dispatch Center coordinates the mobile emergency care response to five on-call SAMU water intervention teams (as well as land teams) stationed along the Amazon River cities (FERREIRA et al., 2020).

The upper Amazon River region, a part of the Brazilian state of Amazonas, encompasses 240,000 inhabitants. The region surrounds a stretch of about 900 km of the Amazon River (along with some of its tributaries). Due to the local conditions - underdeveloped local infrastructure, sparse population density and local geography consisting of forested and floodable plains - the primary access to cities in Upper Amazon River region is through the waterways of its rivers. The hydrography of the area consists of rivers, streams, and boreholes, which enable the flow of people and cargo between urban centers and inland communities.

Unlike other regions of Brazil and the world, where water ambulances are complements to land and air emergency care (CALISKAN; ALTINTAS, 2019), in this region that is the only service available to most emergency care provided to the local rural and indigenous population (FERREIRA et al., 2020).

1.5 Structure of the Thesis

This thesis is organized in seven sections. Section 2 presents essential background on the conceptual framework used in the thesis, and their link with the domains studied is established. Section 3 frames the methodology used in the research design of the thesis’ studies. Section 5 lists the results as well as the research effort for each study carried out. A Discussion on the major findings is developed in Section 5, ehile Sections 6 and 7 show the Conclusions and References for the thesis.

2 Theoretical Foundations

2.1 Complex Socio-technical Systems

According to Hollnagel and Woods (2005a), every work system is sociotechnical, since they always comprise people and their devices, although it is necessary to distinguish between systems where the technology has the central role, and systems in which people are responsible for determining what is done and how work occurs. In particular, a system can be viewed and studied as sociotechnical when its technological elements and organizational structure are dependent on each other and on its social elements (EUERBY; BURNS, 2010).

Relatively few interacting agents within a socio-technical system are sufficient to give rise to complexity (EUERBY; BURNS, 2010), and thus sociotechnical systems are often subject to complexity properties such as distributed character of information and representations and limited functional decomposability (PAVARD; DUGDALE, 2006). Any attempt to break down such systems to understand them will forfeit important hidden interactive dynamics, providing “an incomplete picture at best” (BRAITHWAITE et al., 2013). A complex system is an iterative system which possesses one or several non-linear regulation rings (BERTALANFFY, 1984; PAVARD; DUGDALE, 2002).

According to Vicente (1999), in complex sociotechnical systems people need to work in teams in order to obtain a satisfactory functional performance. This social dimension implies a need for a clear communication as well as coordination of activities. Vicente, Pavard and Dugdale also add up the risk dimension to complex socio-technical systems, once unpredictable outcomes that emerge from the system can bring disastrous consequences for both the workers and large groups of stakeholders. Effective management of the variability amidst the system processes - described as early as in Vidal (1985) - is thus an invaluable asset to cope with domain complexity (RASMUSSEN; LIND, 1981) and maintain system resilience (HOLLNAGEL, 2012).

Pavard and Dugdale (2006) define four properties of complex systems:

- **Non-determinism:** even when system elements are fairly well-known, it is impossible to anticipate system behaviour in a precise way;

- **Limited functional decomposability**: it is difficult or impossible to study system properties through an analytical approach;
- **Distributed nature of information and representation**: some functions within the complex system cannot be positioned. Information is embedded in different locations and under the power of multiple agents;
- **Emmergence and self-organization**: when situations are unpredictable, new information emerge also in unpredictable fashion. Information transmission between agents depends on environmental factors and on the cognition of each individual agent.

Emergent outcomes in complex systems have been described as non-linear, in terms of a lack of proportionality between precedents and consequents. One way that has been put forward to explain this is that emergence stems from unexpected and unintended combinations of performance variability where the governing principle is resonance rather than causality (HOLLNAGEL, 2012). The idea of resonance means that all the performance adjustments may be of small or even unoticed magnitude, even though the outcome may be so large that is noticeable - and sometimes harmful or dangerous (HOLLNAGEL, 2014). This also makes the case that unwanted outcomes cannot be ensured by constraining variability, but only by managing it (monitoring and damping).

Some properties in complex systems are emergent, in the sense they arise from the interactions among the components – such is the case for Safety (LEVESON, 2017). Therefore, the property of "safety" only makes sense when all the interactions among the system components are considered together (LEVESON, 2017).

The interplay between dependent components is an essential aspect in understanding human work in complex systems. Although difficult to observe, the analysis of the behaviour of the system relies on the description of events, relationships, control actions, and adaptations within the system (HOLLNAGEL; WOODS, 2005a).

2.1.1 Complexity and the addressed domains

Primary health care, medication therapy management, mobile emergency care and artisanal fishing score much of the aforementioned elements of complexity. Health care systems can be classified as complex socio-technical systems since they display characteristics such as large problem space and a high degree of hazards, coupling, uncertainty and disturbances (ST-MAURICE; BURNS, 2015; VICENTE, 1999). Braithaite et al. (2013) lists several elements present in the health care domain that characterize its systems as complex ones. According to the authors, the following aspects can be stressed about health care systems:

- Open, large, and broadly effective systems;
- Emergent behaviour and continuous adaptation over time;
- Its different components can be simultaneously fragile or robust, stable or changeable, differentially coupled, relatively risky or risk-averse;
- Features can vary by time, setting or sub-system.

Artisanal fishing is not traditionally studied as a complex system. However, it displays characteristics of complexity such as unexpected variability and resilience, according to the classification made by Righi and Saurin (2015) and hazards,, disturbances, and uncertain data, according to the classification framework proposed by (2006). The ever-changing characteristics of the maritime environment, the need of constant interactions, their potential to produce resilient performance, and their influence on the safety of workers indicate the need for a holistic, socio-technical approach based on system and resilience engineering to understand the health and safety issues of workers involved in fishing (UTNE, 2006), according to the Safety-II perspective.

2.2 Resilience Engineering and Safety-II

Complex socio-technical systems pose unique challenges for system safety. In fact, the accident of Three Mile Island and others that followed led the famous thesis by Perrow (1984) that total prevention of accidents was impossible since socio- technical systems had become so complex that accidents should be considered as normal events. Therefore, unanticipated interactions of multiple and small failures were bound to lead to unwanted outcomes, accidents, and disasters (PERROW, 1984). These ideas contributed to the modern view of safety.

Safety is commonly defined as the absence of unacceptable risks (HURST; WILLIAMS; MARSHALL, 1998). The United States Defense Department Standard for System Safety (MIL-STD-882) has defined safety since the late sixties as “freedom from conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment”. In her seminal paper defining the

Systems-Theoretic Accident Model and Processes – STAMP (LEVESON, 2004), Leveson argues that the complexification of systems led to our capability of designing them surpassing our capability of fully understanding them. Leveson (2011) considers safety to be a control-based problem. From this view, the purpose of safety oriented activities is to eliminate hazard states and therefore, to control events or courses of action that could lead to unsafe circumstances and potential accidents.

However, Leveson (2011) also argues that system design should ensure that variability in performance is safe and conflicts between productivity, achieving system goals, and safety are eliminated or minimized. Therefore, system design should be such that when performance of operators, hardware, software, managers, etc. varies outside safe boundaries, safety is still maintained (LEVESON, 2011).

Resilience Engineering emerged from Cognitive Systems Engineering (BISANTZ; BURNS; FAIRBANKS, 2014; HOLLNAGEL; WOODS, 1983, 2005b) in the beginning of last decade (HOLLNAGEL; WOODS; LEVESON, 2006), as a way to better understand safety and general functioning of complex-socio-technical systems when performing close to their boundaries. Resilience has been defined as "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances so that it can sustain required operations, even after a major mishap or in the presence of continuous stress" (HOLLNAGEL; WOODS; LEVESON, 2006; NEMETH et al., 2008). Resilience has been considered an emergent property of systems, providing the means for organizations to target resource investments by integrating safety and productivity concerns (NEMETH et al., 2008), and some if its contributions to the understanding, design and management of complex socio-technical systems are listed in Patriarca et al. (PATRIARCA et al., 2018).

Resilience Engineering states that events more often are due to an unfortunate combination of a number of conditions, than to the failure of a single function or component (HOLLNAGEL; WOODS; LEVESON, 2006). The system thus must be designed to allow humans to be flexible and resilient and to handle unexpected events (LEVESON, 2011).

A recent view on safety, labeled as Safety-II (HOLLNAGEL, 2014, 2018), is complimentary complementary to the traditional view (labelled as Safety-I), and poses system safety as a variability-based problem, and states that performance variability is the underlying reason for both acceptable and unacceptable outcomes. Safety-II was conceptualized from applying the Resilience Engineering perspectiveto complex systesms in understanding and managing safety.

Resilience engineering argues that the Safety-I perspective is insufficient to treat the problem of system safety, and states that both acceptable and unacceptable outcomes are originated from the same underlying reasons (HOLLNAGEL, 2011). Therefore, we cannot understand how unacceptable outcomes happen unless we first understand how acceptable outcomes happen. Therefure, failures are viewed as the flip side of successes.

From a Safety-II perspective, the purpose of safety management in complex systems is to optimize work performance, avoiding possible predicaments (HOLLNAGEL, 2014). Therefore, safety should be improved through constant performance adjustments made by operators to meet changing demands and deal with disturbances and surprises (SUJAN; HUANG; BRAITHWAITE, 2017).

Recent studies that applied the Safety-II approach in investigating healthcare systems and patient safety found that, as happens in much less regulated sectors (SALDANHA et al., 2020), safety in healthcare processes is also constructed as needed. Safety management is not only the product of rules and procedures, but it also develops mainly due to adjustments for overcoming constraints in time and resources in everyday clinical work (KROEZE; WIMMER, 2019; MERANDI et al., 2018; SCHUTIJSER, 2019).

As Safety-II sheds new light in methods and techniques traditionally used to assess and manage safety, Hollnagel (2014) states that Safety-II will also require methods on its own, to manage performance variability rather than just constraining it. Among these, the one that seems to be getting most attention from the Resilience Engineering community (and increasingly among communities of practice) in the past few years has been the Functional Resonance Analysis Method (FRAM) (HOLLNAGEL, 2012; PATRIARCA et al., 2020).

3 Methodology Summary

The previous section established a conceptual framework for the studies carried out within this PhD thesis and show how the studied domains display dimensions of complexity. In domains such as the ones studied in this thesis, which are characterized by the dimensions of complexity as discussed in Section 2, we believe a methodology encompassing Ergonomic Work Analysis (EWA) and the Functional Resonance Analysis Method (FRAM) – along with *ad hoc* use of other supporting concepts and techniques such as the Resilience Cornerstones, Cognitive Task Analysis (CTA) and the Systems-Theoretic Accident Model and Processes (STAMP) – provides a solid background to investigate variability management and understanding WAD as an active projection of WAI along the several aspects that pervade work in these domains, including distributed cognition, human-computer interfaces, communication tools and safety measures.

3.1 Ergonomic Work Analysis

EWA is a formative work analysis approach, which has origins in the works of Ombredane and Faverge (1955) and expanded through the works of Wisner (1995a, 1995b), Vidal (MÁSCULO; VIDAL, 2011, cap. 12) and many others. The full methodology comprises the phases of framing, global analysis, operation modelling and validation (JATOBÁ et al., 2016). Solutions are co-designed with workers in a participatory view, taking into account the differences between work-as-prescribed and work-as-done, as well as effective variability management in complex sociotechnical systems.

EWA has a broad spectrum of work situation modelling, considering physical, cognitive and organization dimensions and the links between them, especially the impacts of organizational and technological aspects in the physical and cognitive workload of operators. Data is usually collected through an ethnography study by observations, documentation analysis and semi-structured interviews, being conversational action one of the successfully applied techniques for this purpose (VIDAL; BONFATTI, 2003; VIDAL, 1994). The contributions of EWA to improving work settings extend across several domains, including artisanal coastal fishing (CELESTINO et al., 2012; JAESCHKE; SALDANHA, 2012; SALDANHA et al., 2012) and health care, which several applications in the latter being summarized by Carayon (CARAYON, 2016).

EWA has been applied to study variability, safety, and resilient performance in complex socio-technical systems such as nuclear power plants (CARVALHO, 2006; CARVALHO; BENCHEKROUN; GOMES, 2012), overhead power lines maintenance (ARCURI; VIDAL; MOREIRA, 2016a, 2016b), aviation (DE CARVALHO et al., 2016), health care (JATOBÁ et al., 2016) and artisanal coastal fishing (SALDANHA et al., 2017).

3.2 Functional Resonance Analysis Method (FRAM)

An approach based on variability is important because it allows us to understand not only variability as the reason why things go wrong, but also the reason why things go right most of the time (HOLLNAGEL, 2014). The Functional Resonance Analysis Method - FRAM (HOLLNAGEL, 2012) is a method specifically oriented to model complex sociotechnical systems by focusing analysis in the functions responsible for the system outcomes as well as the variability couplings between them. FRAM's biggest strenght is representing and analizing system's interdependencies, and it has established itself as the main method to model work systems following the Resilience Engineering approach.

Despite many times being used as a risk assessment method, it contrasts with other methods in this field (such as FMEA and Fault Tree Analysis) because its purpose is to produce a description of how the system functions. In a similar sense, when applied for accident analysis, a FRAM model will explain a particular accident as a specific instantaneous overlap (resonance) of diverse function variabilities, which are very much the same variabilities that during normal operation are responsible for adjusting performance in order to achieve system goals.

On the other hand, FRAM also differs from traditional process modelling notations (such as BPMN and EPC) because it models not only Input » Output relations between functions, but also non-linear couplings that shape how functional variability spreads downstream along the process. It is precisely these couplings that, in certain instances of the system functioning, create a dangerous resonance path that can lead to accidents.

The FRAM is compatible with the chosen research problem and methodology for its qualitative nature and emphasis on variability sources. This allows for the identification of the main aspects that affect operator performance within a system, and also the impact of a redesign of individual functions in that system (SAURIN; ROSSO; COLLIGAN, 2017)

FRAM has been used extensively on studying discrepancies between WAI and WAD as sources of disruptions in the system's performance, in diverse domains (PATRIARCA et al., 2020). These experiences include health care (CLAY-WILLIAMS; HOUNSGAARD; HOLLNAGEL, 2015; RABEN et al., 2017), energy and oil (CABRERA AGUILERA et al., 2016; FRANÇA et al., 2020), manufacturing (ALBERY; BORYS; TEPE, 2016; ZHENG; TIAN; ZHAO, 2016), aviation (CARVALHO, 2011), and maritime operations (PATRIARCA; BERGSTRÖM, 2017). FRAM has showed useful on discussions on adaptive behaviour and understanding why WAI may not match WAD.

3.3 Ergonomic Dynamic Modelling

In light of the discussed methodological framework, we propose here a methodology, called Ergonomic Dynamic Modelling, covering the broad steps of Ergonomic Work Analysis, including the Social Construction framework (MÁSCULO; VIDAL, 2011, cap. 12) for research design and data collection; and the FRAM as main tool for modelling and systematization of variability, as to produce recommendations on variability management for complex systems. This methodology is outlined in Figure 3-1 and applied to address the five specific objectives (A-E) of this thesis.

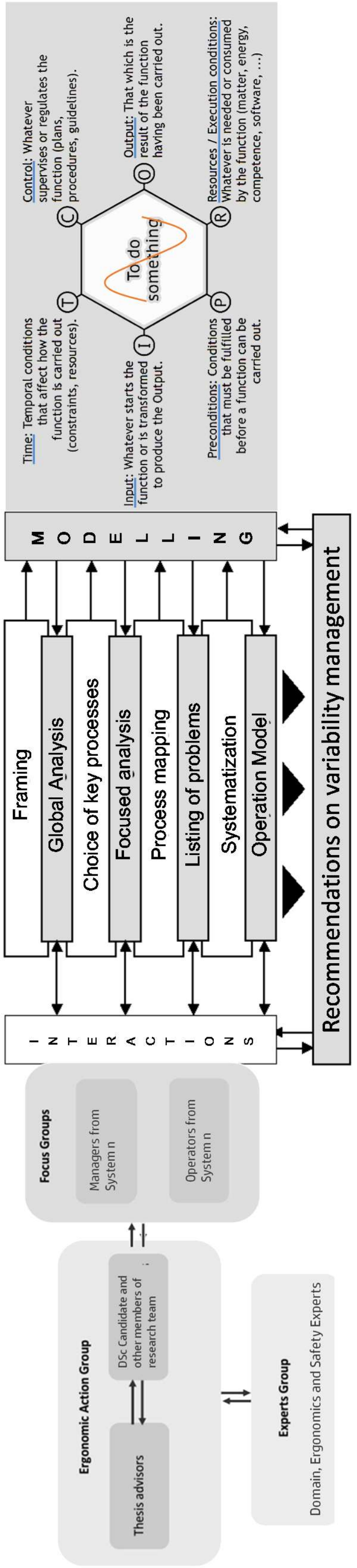


Figure 3-1 – Proposed methodology of Ergonomic Dynamic Modelling

4 Results

We wrote five research papers to address the research questions posed in this thesis. In the next subsections, we present the mentioned articles. Four of those papers have been published so far, thus we present citation info for them in the corresponding section's foreword. The fifth paper (Article E) is currently under submission process.

4.1 Article A: Patient visits in poorly developed territories: a case study with community health workers

4.1.1 Foreword

In this paper we address how instances of problems from context or territory conditions for patient visitis within primary health care conducted at poor communities trigger different couplings between system functions and impact the accomplishment of a public health policy.

This chapter resulted in one scientific article, with the following citation information:

Jatobá, A., Bellas, H. C., Koster, I., Arcuri, R., Vidal, M. C. R., & de Carvalho, P. V. R. (2018). Patient visits in poorly developed territories: A case study with community health workers. *Cognition, Technology & Work*, *20*, 125–152. https://doi.org/10.1007/s10111-017-0455-x

4.1.2 Introduction

Primary care is the first level of a continuous process of health care, starting by bringing together, people, families, communities, and the healthcare system. Moreover, one must take primary care to people, as close as possible, making health assistance accessible and effective by preventing diseases, promoting health, while people become active participants in their own care (WORLD HEALTH ORGANIZATION & UNICEF, 1978).

The Family Healthcare Strategy is the major strategy for primary health care in Brazil; thus, the Brazilian Primary Healthcare Policy (MINISTRY OF HEALTH OF BRAZIL, 2012) lists responsibilities and tasks assigned to primary care professionals in order to provide adequate care to people. Although the functions, tasks, and responsibilities listed in the policy somehow reflect a portion of actual work, the work environment influences the behaviour of healthcare professionals, once their work relies on the conditions of the territory and of the people who live in it. Therefore, the primary care policy is not a complete representation of how workers actually perform, and stands more closely to pre-scriptions that came from how high-level system managers imagine work.

Work-as-imagined (WAI) always projects work-as-done (WAD) in some sense, as workers need guidelines to perform their work. However, one must take into account that such projections are active rather than passive (HOLLNAGEL, 2017); thus, procedures and policies cannot cope with everything that occurs in a complex workplace, and sometimes bring unnecessary constraints for work activities. In this way, WAI and WAD are essential dimensions of work organization that must be as reconciled as possible, once gaps or misalignments between WAI and WAD might affect the system's ability to function within its boundaries (ANDERSON; ROSS; JAYE, 2017; BRAITHWAITE; WEARS; HOLLNAGEL, 2017; CARVALHO, 2011).

Moreover, workers' behaviour has impacts systemic and individually, e.g. when the actual effects do not conform to expectations, due to external or internal variability, the worker adjusts his behaviour to the variation, at some physical and mental cost, such as fatigue and stress (NYSSEN; BÉRASTÉGUI, 2017; ROSA; HADDAD; DE CARVALHO, 2015).

Community health workers play an important role in primary health care as responsible for linking communities and health services, mapping the territory, collecting data on socio-economic conditions of population, especially when communities are poorly developed, dangerous, unhealthy, or affected by urban violence. Thus, it is hard to predict or expect how the work of community health workers will occur, given that different workers perform it, at different times, and in different places and conditions. Moreover, if the higher levels of the organization are not fully aware on what really happens, there are no possibilities for feedback, correction, or learning.

This paper models in detail patient visits in primary health care, highlighting the role of community health workers. It is part of a bigger research project on the Brazilian primary healthcare strategy. In a previous work, we carried out field studies to investigate patient triage in primary health care (JATOBÁ et al., 2016). In this research, also based on field studies, we followed community health workers' activities when performing patient visits of two primary healthcare clinics in Rio de Janeiro. Our analysis, supported by the FRAM (HOLLNAGEL, 2009, 2012), indicates how variability produces gaps between the instructions prescribed in the primary healthcare policy and the community health workers' actions, enabling wide reflections on how instructions, procedures, assignments can be designed to cope with the intrinsic variability of the setting.

Furthermore, our study aims at describing the day-to-day adaptations of community health workers performing patient visits, as this work analysis might help in reducing the distance between WAI and WAD (NYSSEN; BÉRASTÉGUI, 2017) and enable more accurate discussions on the functioning of the system.This paper has five sections. Section 4.1.5 presents the methods, and Section 4.1.12 shows the results. Section 4.1.15 shows a discussion, and Section 4.1.16 presents our conclusions.

4.1.3 Research Problem

The interplay between dependent components is an essential aspect in understanding human work in complex systems. Although difficult to observe, the analysis of the behaviour of the system relies on the description of events, relationships, control actions, and adaptations within the system (HOLLNAGEL; WOODS, 2005a).

Furthermore, human issues like fatigue, emotions, past experiences, and culture have many effects in the dynamics of complex systems like health care, with reflections on workers' rules and mental models. Working in deprived areas is particularly challenging for primary care workers, as some characteristics of the territory—which the healthcare worker cannot control or change—affect patient care (MATHESON et al., 2016).

In health care, WAD on the front line of patient care is always different from WAI by the ones who write policies and guidelines, which leads to misunderstanding of how patient care works and the standardization towards ineffective patient care

(BLANDFORD; FURNISS; VINCENT, 2014; CLAY-WILLIAMS; HOUNSGAARD; HOLLNAGEL, 2015).

Although policies, procedures, and guidelines should be realistic and correspond to WAD in some extent, the greater the complexity of the work environment, the greater the possibility of unexpected events, as well as the difficulty in understanding the system's operation. Thus, workers adapt and improvise, in order to fulfil the gaps in their understanding of work performance, and therefore strive to accomplish the expected results.

Understanding variability, identifying its sources, and exploring the discrepancies between WAI and WAD are useful for improving the system's overall functioning, since normal performance is not the one prescribed in rules and norms, but rather what occurs as result of adaptations according to the context of the work environment (CLAY-WILLIAMS; HOUNSGAARD; HOLLNAGEL, 2015; HOLLNAGEL, 2004).

Thus, the significance of our study relies on the description of how variability affects the performance of community health workers during patient visits, and understanding their strategies and adaptations to cope with the challenges that a complex work environment like primary health care presents.

4.1.4 Research settings

Primary health care addresses the community to provide preventive, curative, and rehabilitative health services and must consider the economic conditions and social values of the country and its communities. Although these conditions vary from country to country, primary care actions must include in general: nutrition, basic sanitation, maternal and childcare, immunization, control of endemic diseases, and education concerning prevailing health problems (WORLD HEALTH ORGANIZATION & UNICEF, 1978).

The subject of improving the quality of healthcare services has always been a huge challenge in Brazil, especially due to the country's large dimensions and its political and sanitary conditions. In this context, the Brazilian Primary Healthcare Policy and the Family Healthcare Strategy are important players, as they prioritize prevention actions and promotion of health, rather than emergency care.

The Brazilian Primary Healthcare Policy finds its basis on four principles: integrality, quality, equity, and social participation. In addition, the Family Healthcare Strategy arises as a strategy to reorganize primary care in Brazil, making primary care clinics the core of the care model, with multi-professional teams responsible for assisting a limited amount of families, in delimited geographical spaces (PAIM et al., 2011). Thus, the Family Healthcare Strategy becomes the major strategy for reducing health problems—specially—of vulnerable and deprived populations, as well as reducing costs with medium and high-complexity procedures.

Within a family health team, community health workers play the role of dialoguing with the communities' members, mapping, and identifying risks, along with environmental aspects of the territory. In addition, community health workers are responsible for carrying out promotion actions and assess the infrastructure of the territory in order to rise awareness in the government to the population's demands (FAUSTO et al., 2011; MACIAZEKI-GOMES et al., 2016; MACINKO et al., 2007).

Furthermore, the Brazilian Primary Healthcare Policy lists eight specific tasks—or assignments—for community health workers, as follows:

A. Maintain the registration of families according to strict geographical area;
B. Register the entire population of his area and keep patient records up to date;
C. Guide families to which concerns the use of available health services;
D. Perform scheduled and spontaneous activities;
E. Oversee families according to their risk assessments, visiting their residences on a regular basis;
F. Integrate the health assistance team and the population of their area, taking into account collective and individual characteristics;
G. Promote health and perform preventive actions both in residences and in their communities, gathering information about the conditions of the area in which they work;
H. Keep in touch with families, in order to perform promotion of health and prevention of diseases, as well as supervising the effectiveness of welfare programs, as planned by their teams.

The activities listed above are interrelated, and their effectiveness relies on specific conditions and competencies. However, the fulfilment of all assignments depends upon the realization of patient visits. Figure 4-1 shows the control structure of the patient visiting process. The elements are organized in three levels: government level, i.e. the Ministry of Health, State, and City government, and policies; assistance level, i.e. where workers and their respective workplaces are situated; and client level that represents the assisted population. Higher levels perform control actions towards lower levels, while lower levels feedback higher levels with information on the performance of their work.

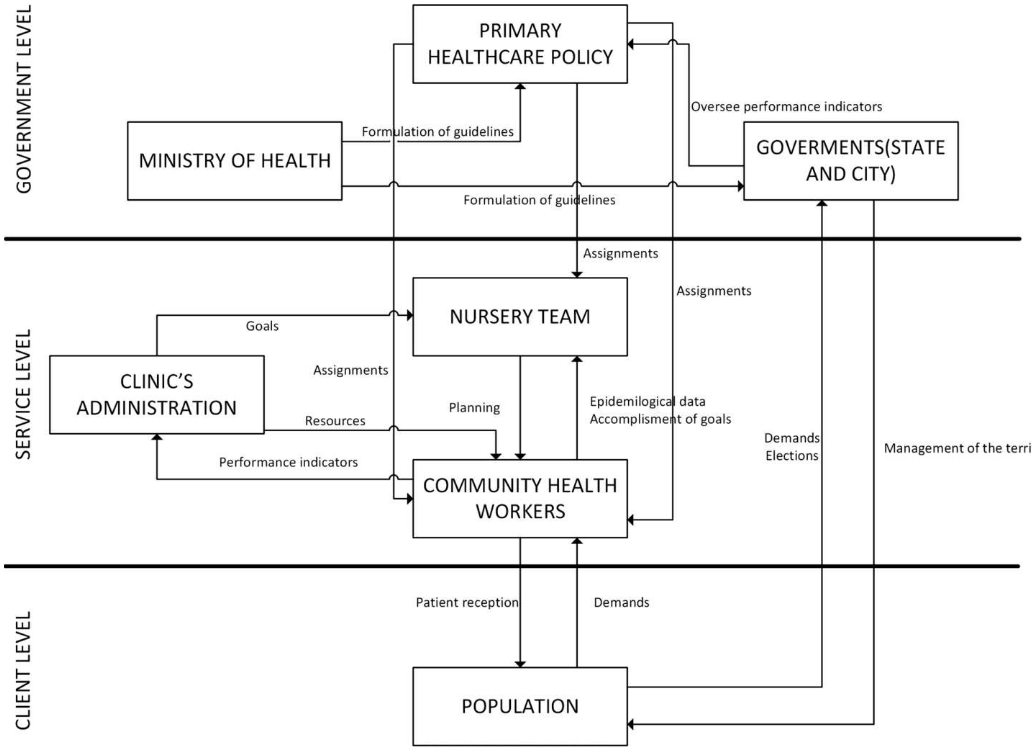


Figure 4-1 – Current control structure

Figure 4-1 illustrates community health workers as major articulators in the patient reception process. They work in three control flows oriented by the activities assigned by the primary healthcare policy, managed by the administration of the clinic:

- Definition of the range of their work (e.g. risk assessment);
- Continuous training (e.g. definition of protocols, discussion on work processes, and specific courses);
- Action planning (e.g. mapping of the territory, prioritization of visits).

The clinic's administration is responsible for the acquisition, maintenance, and provision of resources. Moreover, nurses that are accounted for making weekly planning and allocation of resources are the direct managers of community health workers. In addition, community health workers must feedback the clinic's administration with information about the accomplishment of predetermined assignments (set by the city government). Thus, the city government has an interface with the healthcare teams by following indicators of accomplishment of assignments, which take into account data collected by the community health workers—including epidemiological data.

The clinic's administration has also an interface with the city government, sending general information about the accomplishment of assignments related to the assistance of the whole territory—with indicators of promotion of health and prevention of diseases. Moreover, the Ministry of Health gets information on the accomplishment of assignments and health conditions indicators from clinics all over the country, and the city government deals—and negotiates—with the people their demands for healthcare services.

Thus, patient visits are the fundamental tool for mapping the living conditions of the territory, as well as enabling the bonding between health workers and the population, identifying people's complaints, demands, and health problems.

4.1.5 Methods

We carried out field studies to capture work-as-done (MYERS, 1999; NARDI, 1997), in a total of 60 h of fieldwork. We joined community health workers in patient visits in six poorly developed communities in Rio de Janeiro, Brazil. The names and directions of the communities are confidential due to ethics regulations.

Collecting empirical data while joining community health workers in patient visits enabled the observation of actual work settings, which entails social configuration, conflicts and negotiation, cultural constraints, and adaptations.

The next subsections describe the participants, steps, and procedures for data collection.

4.1.6 Participants

The two primary healthcare clinics studied cover 13 communities, each one assisted by on primary healthcare team. Clinic 1 covers seven communities and hosts seven primary care teams; Clinic 2 covers six communities and hosts six primary care teams. A primary healthcare team works with six community health workers, each one responsible for a single delimited space within a community—the micro-areas.

A total of 39 community health workers participated this study, 29 women and 10 men, approximately 50% of the 78 workers on both clinics. All 13 assisted communities were part of the field study. Table 4-1 summarizes the profile of the participants in this study.

Table 4-1 – Participant profile

< 5 years	5–10 years	> 10 years	Total
Work experience			
10	19	10	39
Undergraduate degree	Graduate degree	High school degree	
Academic background			
4	2	33	39

Regarding academic background, participant profile is uniform—most workers graduated high school; four participants graduated college; two are graduate students. Concerning work experience, 10 out of 39 have less than 10 years of experience as a community health worker; other 10 have more than 10 years of experience. The other 19 are between 5 and 10 years experienced.

4.1.7 Data collection

To assess workers' actual situations, we focused on data sources as suggested by Hollnagel (2015), including interviews on typical work practices, reports on specific cases, and field observations (accompanying workers during patient visits). Gathered data were then combined to make a preliminary diagnose of patient visit situations.

4.1.8 Framing

This study obtained ethical clearance from the ethics committee of the Sergio Arouca National School of Public Health/Oswaldo Cruz Foundation. Authorizations for performing fieldwork were given by the clinics' administrations, which showed interested in using the further results of the study as an instrument for improving work situations. Thus, the research group attended both clinics in order to make contact with community health workers, plan, and facilitate the process of joining them during patient visits.

This time in the clinic showed useful for gathering and analysing documentation on standard procedures and policies, making it possible to highlight the prescribed set of activities that community health workers should perform in the field. Technical documentation comprises the Brazilian National Policy for Primary Healthcare, official Manual of Procedures for Humanized Patient Reception, and particular procedural documents of the two clinics studied. We also participated the weekly meeting of the clinics' teams.

Moreover, we created a schedule of patient visits, and we decided—along with community health workers—which communities and micro-areas should be visited, and which workers would be observed.

4.1.9 Preliminary Analysis

All participants underwent semi-structured interviews. Interviews might enforce the pre-diagnosis of work problems and how people solve or circumvent these problems to do their tasks, set the focus of the analysis, and provide insights for the observations in the field.

Preliminary analysis helped decide the focus of intervention by understanding the context of the work situation, major constraints, aspects that distress workers, and some stories that illustrate problems faced by workers while performing patient visits in the territory.

In addition, the pre-diagnosis of work situations provided directions for operation modelling, especially on describing WAI, enhanced by indication of troublesome, harmful, or stressful occurrences in community health workers day-by-day work.

Collected material from observations and interviews enabled a preliminary diagnosis of patient visiting situations, coded by a description of WAD, as well as a discussion on workers' behaviour, strategies, interactions, information flow, and decision-making.

While modelling the operation, we highlight high-variability work situations triggered by territory/context issues that may result in problems in patient visits. These findings indicate aspects of variabilities and its relations to discrepancies between WAI and WAD.

4.1.10 FRAM

The Functional Resonance Analysis Method (FRAM) (HOLLNAGEL, 2009, 2012) is a method for modelling complex socio-technical systems by focusing the analysis on the functions of the systems that comprise their activities—as well as the couplings of these functions. The FRAM representation of potential variability in the system functions is an important issue in exploring the healthcare domain in which this study takes place, as different aspects of the work conditions, the domain itself, the environment, as well as experience, expertise, cultural values, impact the outcomes of patient reception (CHUANG; HOLLNAGEL, 2017).

FRAM has been used extensively on studying discrepancies between WAI and WAD as sources of disruptions in the system's performance, in diverse domains. These experiences include health care (CLAY-WILLIAMS; HOUNSGAARD; HOLLNAGEL, 2015; RABEN et al., 2017), energy and oil (CABRERA AGUILERA et al., 2016), manufacturing (ALBERY; BORYS; TEPE, 2016; ZHENG; TIAN; ZHAO, 2016), aviation (CARVALHO, 2011), and maritime operations (PATRIARCA; BERGSTRÖM, 2017). FRAM has showed useful on discussions on adaptive behaviour and understanding why WAI may not match WAD.

The FRAM suited our research materials and methods especially because of its qualitative focus, and its emphasis on the sources of variability, which enables the identification of major aspects that affect worker's performance within the system widely, as well as the impacts of re-designing individual functions of the system (SAURIN; ROSSO; COLLIGAN, 2017).

In order to better present the analysis, we categorize our models in visit planning and visit execution models. Afterwards, we identify and decompose functions, aspects and potential variability regarding time and precision (HOLLNAGEL, 2009, 2012).

4.1.11 Systemic analysis

Based on FRAM results, we carried out a systemic analysis according to the control system structure of Figure 4-1 to describe how variability coupling affects the way community health workers perform their activities to accomplish the primary healthcare policy objectives. The data collected from the field studies made feasible the analysis of the performance variability (also called actual variability), enabling us to evaluate how the actual variability can affect patient visit execution according to these couplings and, consequently, the set of assignments in the primary healthcare policy.

With this analysis, it was possible to identify problems and the strategies of the workers to solve these problems and observe how territory conditions influence in the execution of the functions. Finally, the results enabled us to propose modifications on control and feedback flow in the control structure for the patient visiting process, aiming at the improvement of the system's effectiveness and simultaneously reduce worker's occupational risks during visits.

4.1.12 Results

This section presents the results of the study: first, the modelling and analysis with FRAM; in addition, Section 4.1.14 brings the results of systemic analysis.

4.1.13 FRAM analysis

Figure 4-2 shows the FRAM model for visit planning, as Table 4-2 presents the descriptions of all its functions, including all of their aspects. In this model, our study takes the function "Execute patient visit" as the collapsed model for visit execution, which is presented later in this section.

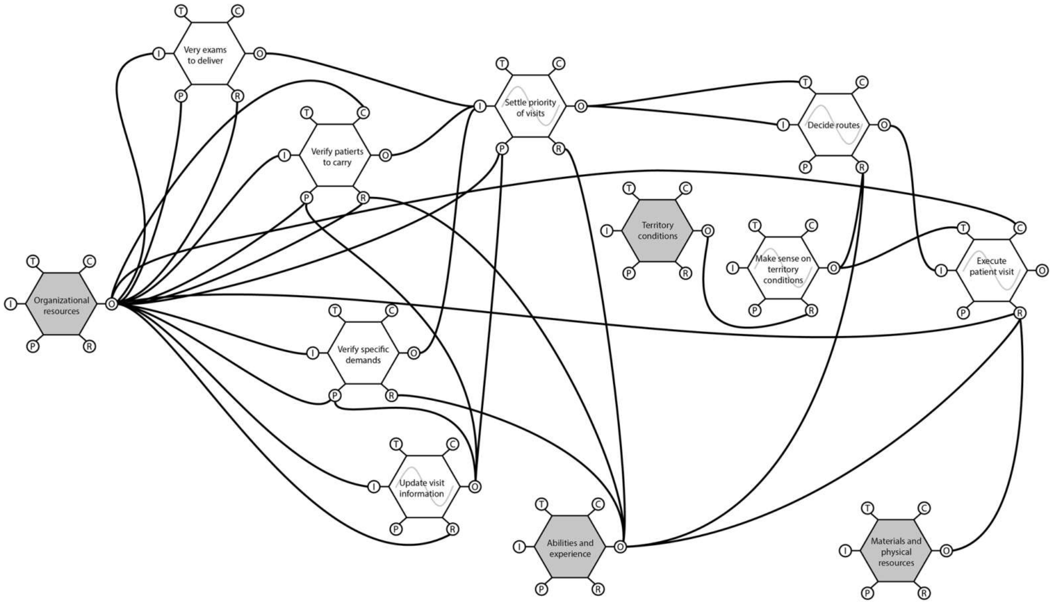


Figure 4-2 – FRAM model – visit planning

Moreover, Figure 4-2 shows four background functions for visit planning, as listed in Table 4-2. These background functions represent performance shaping factors, i.e. conditions that influence the studied events, as they affect the functioning of the system, shaping the context of work, providing elements to the foreground functions (HOLLNAGEL, 2009, 2012).

Table 4-2 – FRAM table – visit planning

Type	Function	Input	Output	Precondition	Resource	Control	Time
Foreground	Verify examinations to deliver	Deliverables	Examinations	Meeting with the team	Examinations regulation software	–	–
	Verify patients to carry	List of patients	List of patients to carry	Meeting with the team Patient records updated	Electronic patient records Knowledge of families	Standard procedures	–
	Verify specific demands	List of patients	List of demands	Meeting with the team Patient records updated	Knowledge of families	–	–
	Update visit information	Patient information	Patient records updated	–	Electronic patient records	–	–
	Settle priority of visits	Examinations List of patients to carry List of demands	Schedule of visits	Meeting with the team Patient records updated	Knowledge of families	–	–
	Decide routes	Schedule of visits	Patients and routes	–	Knowledge of the territory Sensemaking on territory conditions	–	Schedule of visits
	Execute patient visit Execute patient visit	Patients and routes	–	–	Uniform and Equipment Knowledge of the territory Knowledge of families Patient information	Standard procedures	Sensemaking on territory conditions
Background	Organizational resources	–	Meeting with the team Standard procedures Patient information Electronic patient records Deliverables List of patients Examinations regulation software	–	–	–	–
	Abilities and experience	–	Knowledge of the territory Knowledge of families	–	–	–	–
	Territory conditions	–	Urban infrastructure Public security Conditions of residences	–	–	–	–

The planning for patient visit requires several decisions made in collaboration with the rest of the healthcare team. To visit their patients, community health workers must verify whether there are any results of examinations to deliver, whether there are patients to carry from home to the clinic, and whether there are any specific demands. Moreover, they must update the electronic patient records with information on prior visits.

Table 4-2 (continued)

Type	Function	Input	Output	Precondition	Resource	Control	Time
			Conditions of temperature and humidity				
			Terrain stability				
	Materials and physical resources	–	Uniform and equipment	–	–	–	–
	Make sense on territory conditions	–	Sensemaking on territory conditions	–	Urban infrastructure	–	–
					Public security		
					Conditions of residences		
					Conditions of temperature and humidity		
					Terrain stability		

As shown in Table 4-2, both verification functions rely on the experience and abilities of community health workers, especially regarding the knowledge they have on the assisted families. The same happens in function “Settle priority of visits”, as knowing the families, their structure, and conditions contribute to the planning of visits. Such knowledge can only be obtaining with strong relationships with the assisted families. The selection of health workers from people that lives in the communities is a key issue to improve the quality of this function.

The “execute patient visit” function is the final function of the visit planning process. It also takes advantage of experience and abilities regarding families and territories and requires certain equipment, as listed in Table 4-2.

Prior to this function lies the upstream functions “make sense on territory conditions” and “decide routes”, acting as the link between visit planning and visit execution. These are pivotal functions in a way that they are bottlenecks, enabling all downstream patient visit activities.

Making decisions about the best route on the territory takes advantage of community health workers’ experience. However, as these decisions happen each morning as the community health worker prepares to leave the clinic, sensemaking on current territory conditions is crucial to avoid security and health risks while crossing the territory and remaining inside residences. Workers make sense on territory conditions in an adaptive and tacit way, using instant messages from personal contacts from people who live in the area on local safety, informal reports from colleagues, and general weather forecasting of the city. As we disclose later in this article, this configuration for the function can lead to higher variability in the patient visiting process.

The analysis with FRAM highlighted the potential variability in visit planning, as described in Table 4-3. The potential variability of the “Update visit information” function relies on the possibility of the update occur out of time. In these cases, it affects the function “Settle priority of visits”, as priorities cannot be set—or might be wrongly set—without the precondition of using updated patient data.

Table 4-3 – Potential variability – visit planning

Function	Output	Variability regarding time		Variability regarding precision	
		Range	Description	Range	Description
Update visit information	Patient records updated	Too late	Updates might not be done on time due different reasons like software malfunctioning or poor management. However, patient visits are still made	Precise	This is a relatively simple function with straightforward data processing and therefore only varies regarding time
Settle priority of visits	Schedule of visits	On time	This function is comprises a decision which consumes relatively little time and cognitive effort. Thus, the output is stable regarding time	Imprecise	Preconditions not set right generate a wrong schedule of patients to visit. However, patient visits are still made
Make sense on territory conditions	Sensemaking on territory conditions	Not at all	If available information is scarce or non-existent, output may not be produced at all	Imprecise	In the presence of less detailed or unupdated information, sensemaking can result as misleading/compromised
Decide routes	Routes and patients	On time	This function is comprises a decision which consumes relatively little time and cognitive effort. Thus, the output is stable regarding time	Imprecise	Depending on how thorough and updated is available information, setted routes may expose workers to risky situations
Visit patients	Visits made	Not at all	Misguided route setting might prevent community health workers from reaching residences. Thus, visits are not made	Imprecise	Gaps in sensemaking may miss potential risky conditions in the territory, increasing time pressure for the visit

Figure 4-3 shows the FRAM model for visit execution, including its background functions. As done in the previous model, Table 4-4 details the entire functions aspects. In this model, we see a new background function, specific for visit execution: “patient psychological conditions”. While performing visits, community health workers often have to deal with emotionally unstable patients, due mainly to families’ frequent precarious social conditions.

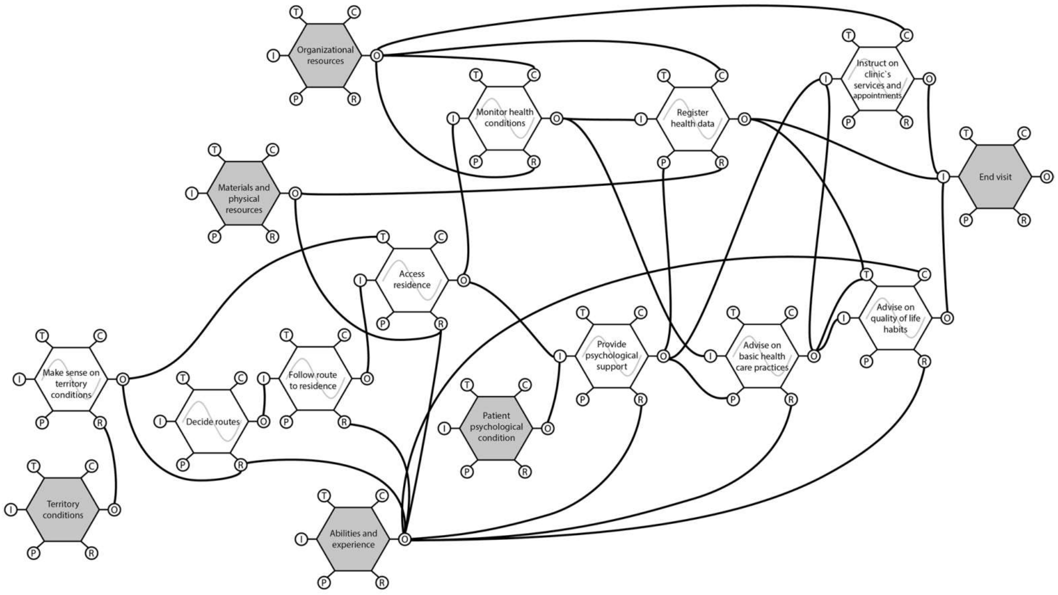


Figure 4-3 – FRAM model – visit execution

When needed, psychological counselling from workers is essential to strengthen the bonds between the primary healthcare teams and the territory’s population, as well as facilitate the ongoing and future patient visits. In cases when the worker concludes that the patient should seek help from a psychiatrist or a psychologist, he instructs the patient on the necessary steps to schedule an appointment at the clinic. This same function—“Provide Psychological Support”—is triggered whenever the worker perceives that patients need to attend to the clinic to follow-up various health conditions.

As shown in Table 4-4, “Monitor health conditions” is one of the central functions of patient visits execution and arguably the one that typically consumes most time during visits. It comprises a framing of the patients updated health conditions by the community health worker as well as several checkups related to medication, examinations, and medical appointments.

Table 4-4 – FRAM table – visit execution

Type	Function	Input	Output	Precondition	Resource	Control	Time
Foreground	Follow route to residence	Patients and routes	Arrival at residence	–	Knowledge of the territory	–	
	Access residence	Arrival at residence	Access granted to the residence	–	Knowledge of families	–	Sensemaking on territory conditions
		–	–	–	Bond with family	–	–
		–	–	–	Uniform and equipment	–	–
	Decide routes	–	Patients and routes	–	Knowledge of the territory	–	–
		–	–	–	Sensemaking on territory conditions	–	–
	Advise on quality of life habits	Good practices on health care explained	Patient diet habits checked	–	Knowledge in quality of life	Knowledge in basic healthcare practices	Good practices on health care explained
		–	Patient made aware of importance of diet and rest	–	–	–	Forms filled
		–	Recommendations on healthy eating habits	–	–	–	–
		–	Good practices on self-organization explained	–	–	–	–
	Make sense on territory conditions	–	Sensemaking on territory conditions	–	Terrain stability	–	–
		–	–	–	Urban infrastructure	–	–
		–	–	–	Public security	–	–
		–	–	–	Conditions of residences	–	–
		–	–	–	Conditions of temperature and humidity	–	–
	Instruct on clinic's services and appointments	Good practices on health care explained	Best practices to get medical appointments informed	–	–	Standard procedures	–
		Patient oriented to seek professional help	Attendance to clinic pre-scheduled	–	–	–	–
	Register health data	Frame of patients health conditions	Forms filled	Psychological support given to patient	Uniform and equipment	Standard procedures	–
		Appointment card checked	–	Respectful listening	–	–	–
		Possession of medication checked	–	–	–	–	–
		Match between prescription and medication	–	–	–	–	–

Table 4-4 (continued)

Type	Function	Input	Output	Precondition	Resource	Control	Time
		Drug dosage checked	–	–	–	–	–
		Accomplished examinations and examination requests checked	–	–	–	–	–
	Provide psychological support	Level of patient emotional stability	Strengthened bond with family	–	Knowledge of families	–	–
		Access granted to the residence	Psychological support given to patient	–	Bond with family	–	–
		–	Respectful listening	–	–	–	–
		–	Patient oriented to seek professional help	–	–	–	–
	Monitor health conditions	Access granted to the residence	Frame of patients health conditions	–	Patient information	Patient information	–
		–	Appointment card checked	–	–	Standard procedures	–
		–	Possession of medication checked	–	–	–	–
		–	Match between prescription and medication	–	–	–	–
		–	Drug dosage checked	–	–	–	–
		–	Accomplished examinations and examination requests checked	–	–	–	–
		–	Patient reminded on next medical appointment	–	–	–	–
		–	Prescription delivered to patient	–	–	–	–
	Advise on basic healthcare practices	Frame of patients health conditions	Good practices on health care explained	Strengthened bond with family	Knowledge in basic healthcare practices	–	–
		Appointment card checked	–	–	–	–	–
		Possession of medication checked	–	–	–	–	–
		Match between prescription and medication	–	–	–	–	–
		Drug dosage checked	–	–	–	–	–
		Accomplished examinations and examination requests checked	–	–	–	–	–
		Patient reminded on next medical appointment	–	–	–	–	–

Table 4-4 (continued)

Type	Function	Input	Output	Precondition	Resource	Control	Time
		Prescription delivered to patient	–	–	–	–	–
Background	Organizational resources	–	Standard procedures	–	–	–	–
		–	Patient information	–	–	–	–
	Abilities and experience	–	Knowledge of the territory	–	–	–	–
		–	Knowledge of families	–	–	–	–
		–	Bond with family	–	–	–	–
		–	Knowledge in quality of life	–	–	–	–
		–	Knowledge in basic healthcare practices	–	–	–	–
	Government entities	–	Urban infrastructure	–	–	–	–
		–	Public security	–	–	–	–
	Patient psychological condition	–	Level of patient emotional stability	–	–	–	–
	Territory conditions	–	Terrain stability	–	–	–	–
		–	Urban infrastructure	–	–	–	–
		–	Public security	–	–	–	–
		–	Conditions of residences	–	–	–	–
		–	Conditions of temperature and humidity	–	–	–	–
	Materials and physical resources	–	Uniform and equipment	–	–	–	–

Another central function is “Register health data”, in which the worker fills the required fields’ specific forms, either printed or displayed by a tablet. These forms are standard to all primary healthcare facilities in Brazil and gather information on themes such as health condition history, medication taken, patient social conditions, and life habits in general. They are useful to improve health promotion and treatment by the clinic’s healthcare teams, as well as to feed national primary care online databases.

In order to effectively access a residence and perform all these activities, a number of upstream functions are necessary. As shown in Figure 4-3, these include following the route previously set to the residence and entering the residence. As discussed in the next section, a number of elements frequently stand in the way of such actions, and this variability spreads downstream by the functions “Make sense on territory conditions” and “Decide routes”.

The potential variability for visit execution functions is presented in Table 4-5. Even if the worker reaches the residence successfully, he may have his entrance denied. This can happen for several reasons, one of the more common being conflicts created with the family in prior visits. Access to a residence may be restricted if territory conditions become hostile or escalate, while the visit takes place.

Table 4-5 – Potential variability – visit execution

Function	Output	Variability regarding time		Variability regarding precision	
		Range	Description	Range	Description
Make sense on territory conditions	Sensemaking on territory conditions	Not at all	If available information is scarce or non-existent, output may not be produced at all	Imprecise	In the presence of less detailed or unupdated information, sensemaking can result as misleading/compromised
Decide routes	Routes and patients	On time	This function is comprises a decision which consumes relatively little time and cognitive effort. Thus, the output is stable regarding time	Imprecise	Depending on how thorough and updated is available information, setted routes may expose workers to risky situations
Follow route to residence	Arrival at residence	Not at all	Any of the preconditions, if not accomplished, might prevent community health workers from going to the territory or reaching residences. Thus, visits are not made	Precise	The outcome of this function is binary with regard to precision
Access residence	Access granted to the residence	Not at all	Admission to the residence may be denied if residents are not at home, are unavailable (e.g. sleeping) or are opposed to the visit	Imprecise	Quality of access to residence depends on situated working conditions. The presence of certain conditions (e.g. hostile reception, patient with highly contagious infection) may imply that visit must be brief or not all activities can be conducted
Monitor health conditions	Frame of patients health conditions Appointment card checked Possession of medication checked Match between prescription and medication Drug dosage checked Accomplished examinations and examination requests checked Patient reminded on next medical appointment Prescription delivered to patient	On time	This function is central to the patient visits and there is no pre-defined restrictions regarding time window its completion. Thus, all outputs are typically produced within an acceptable time window	Imprecise	All the outputs are highly variable depending on how thorough and updated is patient information previously available to the community health worker. Thus, relevant aspects can be overlooked or misunderstood
Provide psychological support	Strengthened bond with family Psychological support given to patient Respectful listening Patient oriented to seek professional help	Too early	As the community health worker may not achieve effective balance between all the elements at stake while trying to accomplish this function, counselling may find an abrupt and early end	Imprecise	Negotiations and counselling may not only be frustrated but even create conflict between the community health worker and patients, with impacts on future interaction
Advise on basic healthcare practices	Good practices on health care explained	Not at all	If the community health agent is not able to bond with the family, recommendations may not be taken into account	Acceptable	Output quality is dependent on the worker's knowledge in basic healthcare practices, which oscillates mildly despite previous training

Table 4-5 (continued)

Function	Output	Variability regarding time		Variability regarding precision	
		Range	Description	Range	Description
Instruct on clinic's services and appointments	Best practices to get medical appointments Attendance to clinic pre-scheduled	On time	This function is central to the patient visits and there is no pre-defined restrictions regarding time window its completion. Thus, all outputs are typically produced within an acceptable time window	Imprecise	If standard procedures for patient visit are not updated patients may receive misleading information about opening times for the clinic's services or things to remember before attending to examinations
Register health data	Forms filled	On time	This function is central to the patient visits and there is no pre-defined restrictions regarding time window its completion. Thus, outputs is typically produced within an acceptable time window	Imprecise	Low patient availability can lead to incomplete or unreliable forms, while absence of needed equipment (form sheets or tablet) may prevent any data registration
Advise on quality of life habits	Patient diet habits checked Patient made aware of importance of diet and rest Recommendations on healthy eating habits Good practices on self-organization explained	Too early	All outputs are dependent on the time remaining after more central functions are completed. Thus, it is common for the visit to end before all aspects are thoroughly covered	Imprecise	The quality of recommendations varies upon knowledge of the themes by the community health worker. Since there is no formal training on such aspects, this level of knowledge oscillates heavily

4.1.14 *Systemic analysis*

Patient visits are pivotal to accomplish the specific assignments in the primary healthcare policy. In this sense, the functions "make sense on territory conditions" and "decide routes" are essential to patient visits once they act as a bottleneck to all activities performed during visit execution. Figure 4-4 represents these relations.

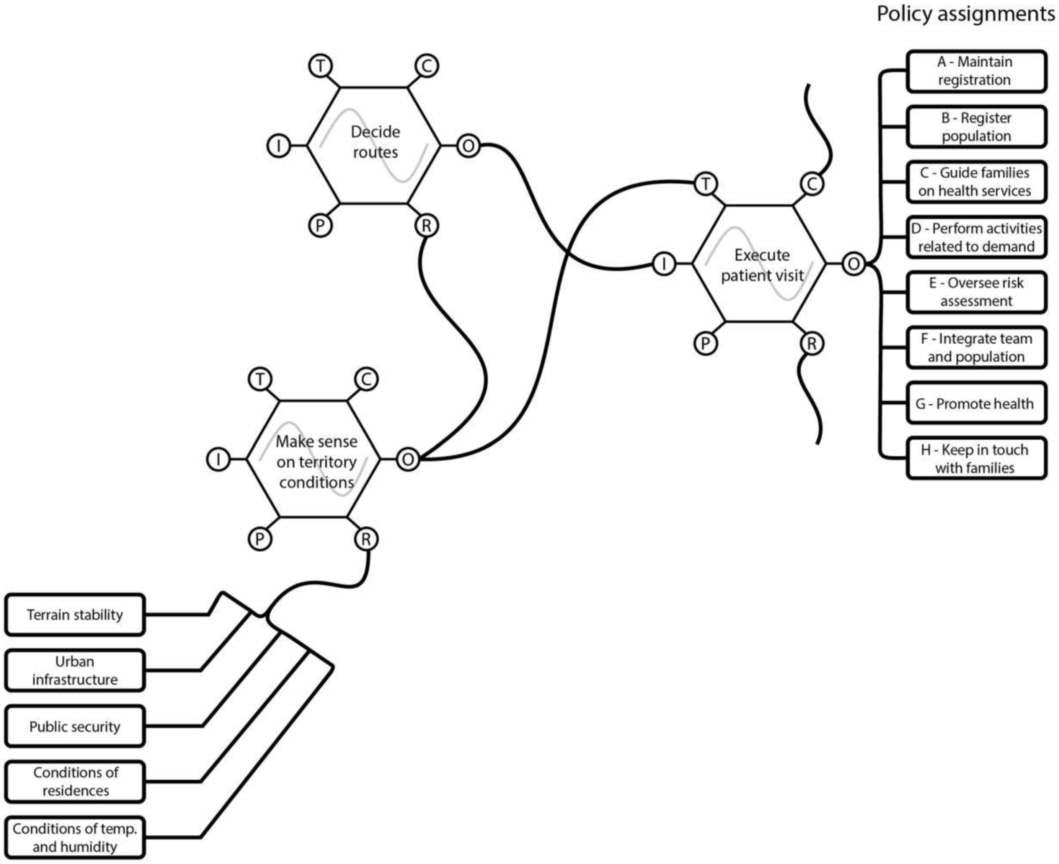


Figure 4-4 – FRAM and the primary healthcare policy

The field studies disclosed problems regarding territory conditions that have to go through cognitive processing by the community health worker in making sense of the situated working conditions. Table 4-6 describes such problems.

Table 4-6 – Problems from territory conditions

Function	Territory conditions	Problem
Execute patient visit	Terrain stability	Terrain is bumpy and irregular, hampering the access to residences
	Urban infrastructure	Urban infrastructure is very poor (e.g. bad sidewalks, leaking sewerage, potholes), vulnerable to natural occurrences like rain
	Public security	Intense urban violence e.g. constant gunshots, robbery, and drug traffic
	Conditions of residences	Residences are poorly built
	Conditions of temperature and humidity	Excessive heat and humidity

As described in the previous section, the worker typically receives scarce support to sensemaking, creating an output with high potential variability. The analysis found that this configuration produces the most critical variability couplings in visit execution. They take place between the functions “make sense of territory conditions”, “decide routes”, “follow route to residence”, and “access residence”, hampering the feasibility of reaching and remaining in residences for patient visits. Figure 4-5 illustrates the two different couplings at hand as derived from the FRAM model for visit execution. While variability coupling regarding resources can prevent community health workers to reach residences, variability coupling regarding time can degrade the level of access needed to conduct all downstream functions.

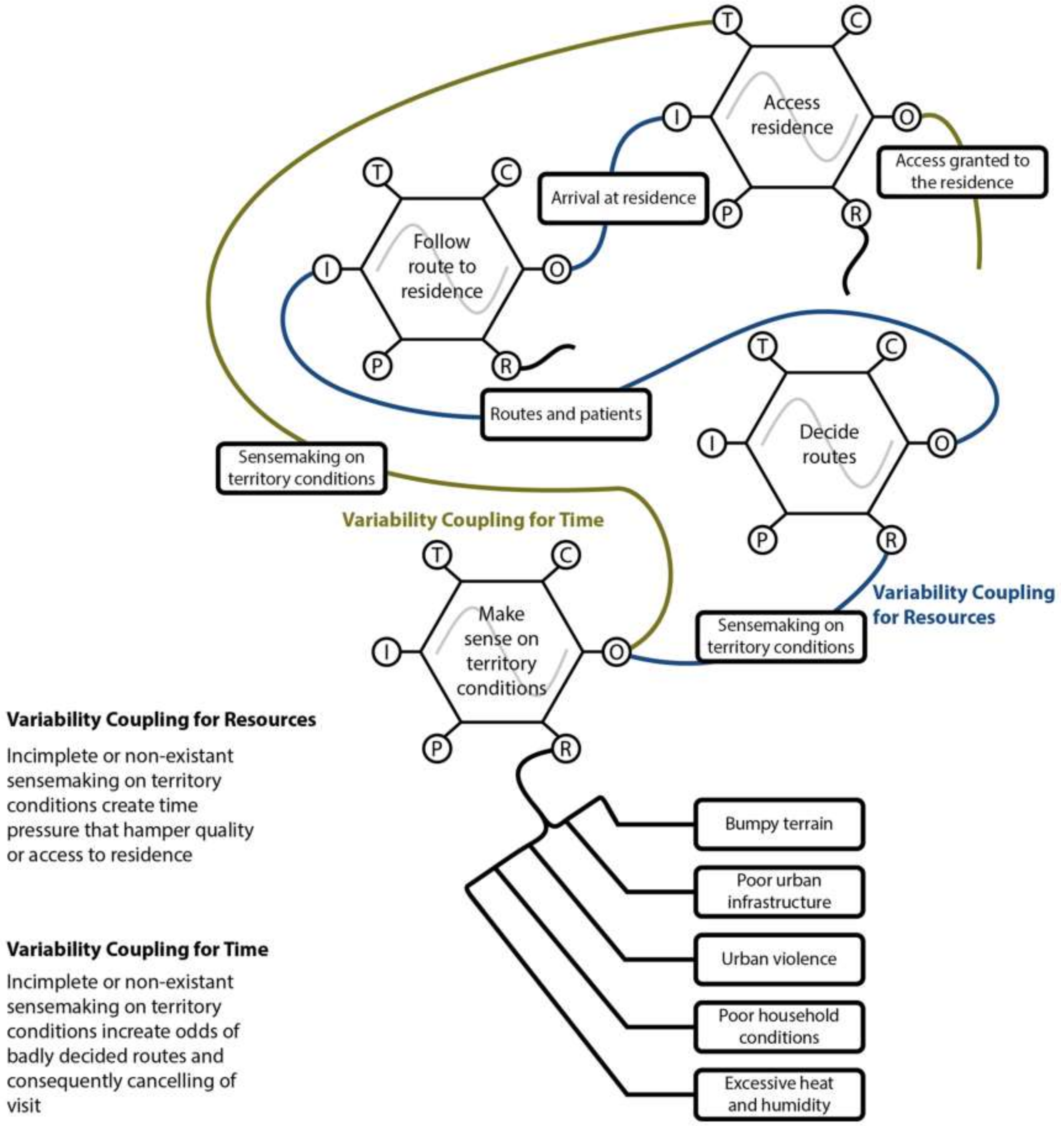


Figure 4-5 – Coupling for potential variability

Moreover, the analysis of collected data uncovered the manifestation of performance variability, linking the problems with the performance of the set of assigned tasks in the primary healthcare policy. The analysis shows incidents—specific events related to the problems listed—that occur on a regular basis, increasing workload, risking the adequate execution of downstream functions, and ultimately creating the odds for aborting the visit. We found out that perceived problems and their instantiations have significant and direct effects on the policy.

For example, *poor urban infrastructure* includes the sewerage of the area as it becomes difficult and dangerous for workers to reach patients that live in places when sewerage leaks along the way. The same occurs in areas where with garbage in the streets or alleys. Figure 4-6 shows pictures of sewerage leaking close to patients' residences, and Figure 4-7 shows garbage bags thrown along the alleys where community health workers must walk.

Figure 4-6 – Poor infrastructure of the territory - sewerage

Figure 4-7 – Poor infrastructure of the territory - garbage

Thus, looking at this specific event, the problem is instantiated when sewerage leaks, making it impossible for workers to perform patient visits in the affected area. Figure 4-8 shows the variability couplings for resources and time.

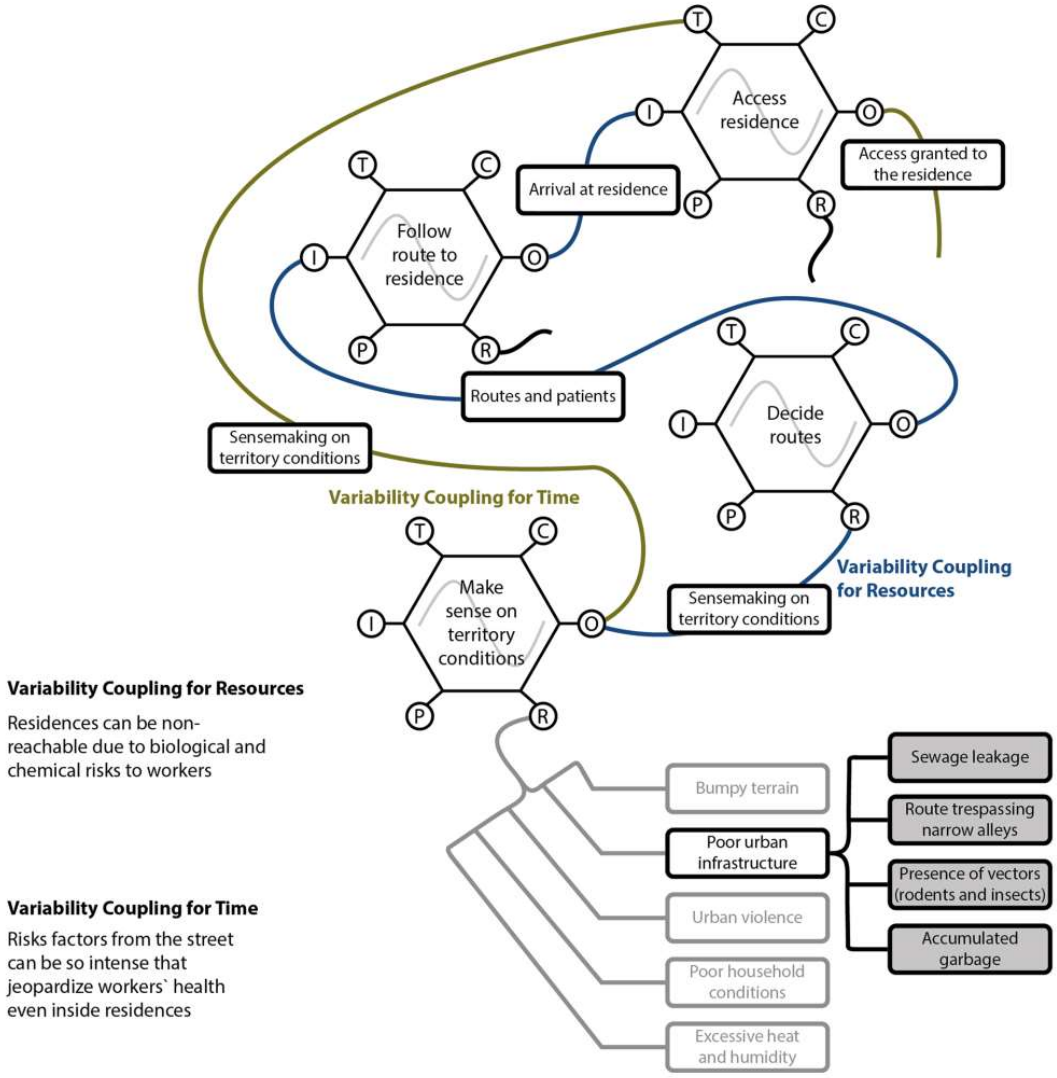


Figure 4-8 – Coupling for actual variability and instantiation – poor urban infrastructure

On the other hand, sewage leakages also affect the bumpy terrain in the territory, forming barriers to safe access, as shown in Figure 4-9. Figure 4-10 shows an open view of one explored community. Another prominent instance of bumpy terrain is heavy rain that seldom hit the communities, creating floods and sometimes changing terrain stability, making sectors of residences temporarily unreachable.

Figure 4-9 – Bumpy terrain on an alley

Figure 4-10 – Open view of one of the explored territories

(Photographer: Leo Correa, O. Dia)

In cases like this, workers cancel visits, and patients cannot get healthcare services, especially the ones regarding promotion of health and prevention of diseases, jeopardizing the policy assignments. Figure 4-11 illustrates the variability coupling for resources as consequences to this instantiation.

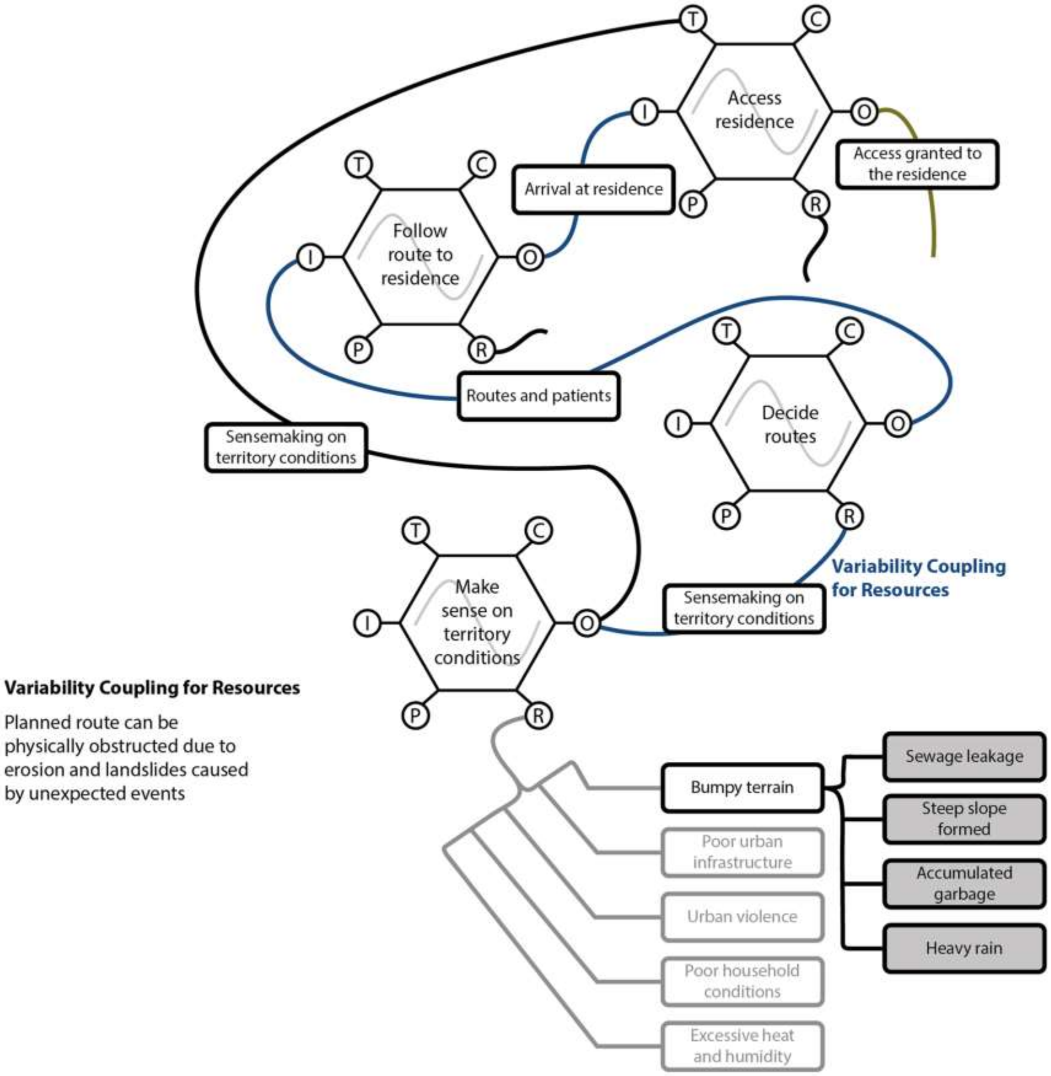


Figure 4-11 – Coupling for actual variability and instantiation – bumpy terrain

Some issues are metaevents, i.e. one instance relates to more than one problem. For example, “sewage leakage” relates to both “poor urban infrastructure” and “bumpy terrain”. Moreover, each problem can be instantiated differently (e.g. “heavy rain” and “sewage leakage” for bumpy terrain) and therefore compromise multiple workers’ tasks, like the performance of promotion actions and the registration of patients, for example.

Regarding *urban violence*, gunfight and police operations due to drug traffic are notable manifestations of variability that also prevents patient visits, since community health workers are unable to reach parts of the community. These high levels of urban violence have escalated over the past few years following the lack of public policies jeopardizing the achievement of primary healthcare policy assignments by community healthcare workers. Reports from workers disclosed moments when, during patient visits, they were surprised by intense gunfight that forced them to abort their planned route and hide among alleys or ask for nearby close residents for temporary shelter inside their houses.

Instantiation for urban violence and related variability couplings are shown in Figure 4-12.

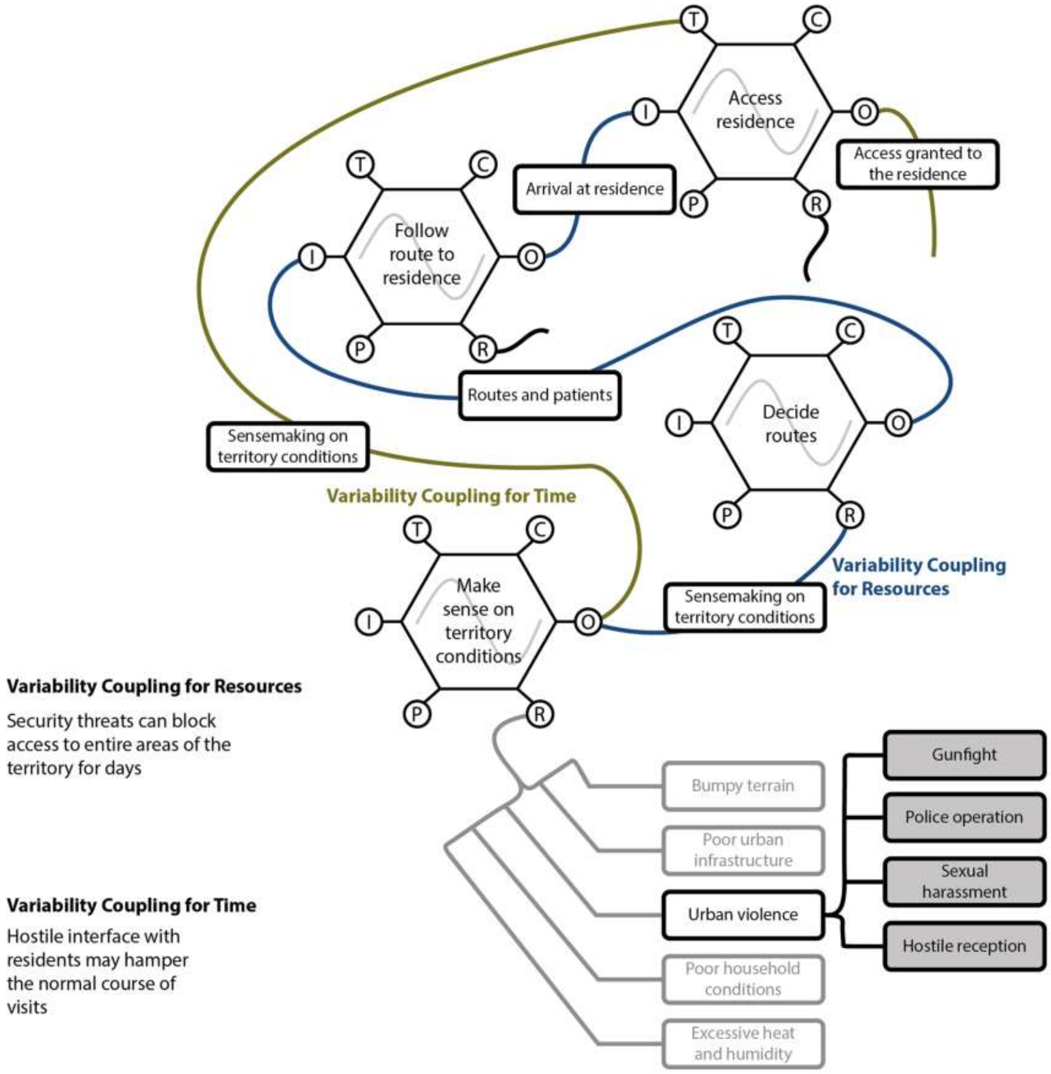


Figure 4-12 – Coupling for actual variability and instantiation – urban violence

The lack of basic sanitation in the territory is one of the factors that increase the workload for the community health workers. There are a growing number of *households built in without basic sanitation* services installed. Consequently, it is very common for the workers to visit families that do not even have toilets inside their homes. According to workers' reports, many of these residents use plastic buckets as toilets and discard all waste directly into the nearby river. Visits to these residences often uncover patients infected with parasitic and highly contagious infections, such as Hansen's disease and tuberculosis, which poses significant risk to workers. Figure 4-13 shows the actual variability (instances) and variability couplings formed.

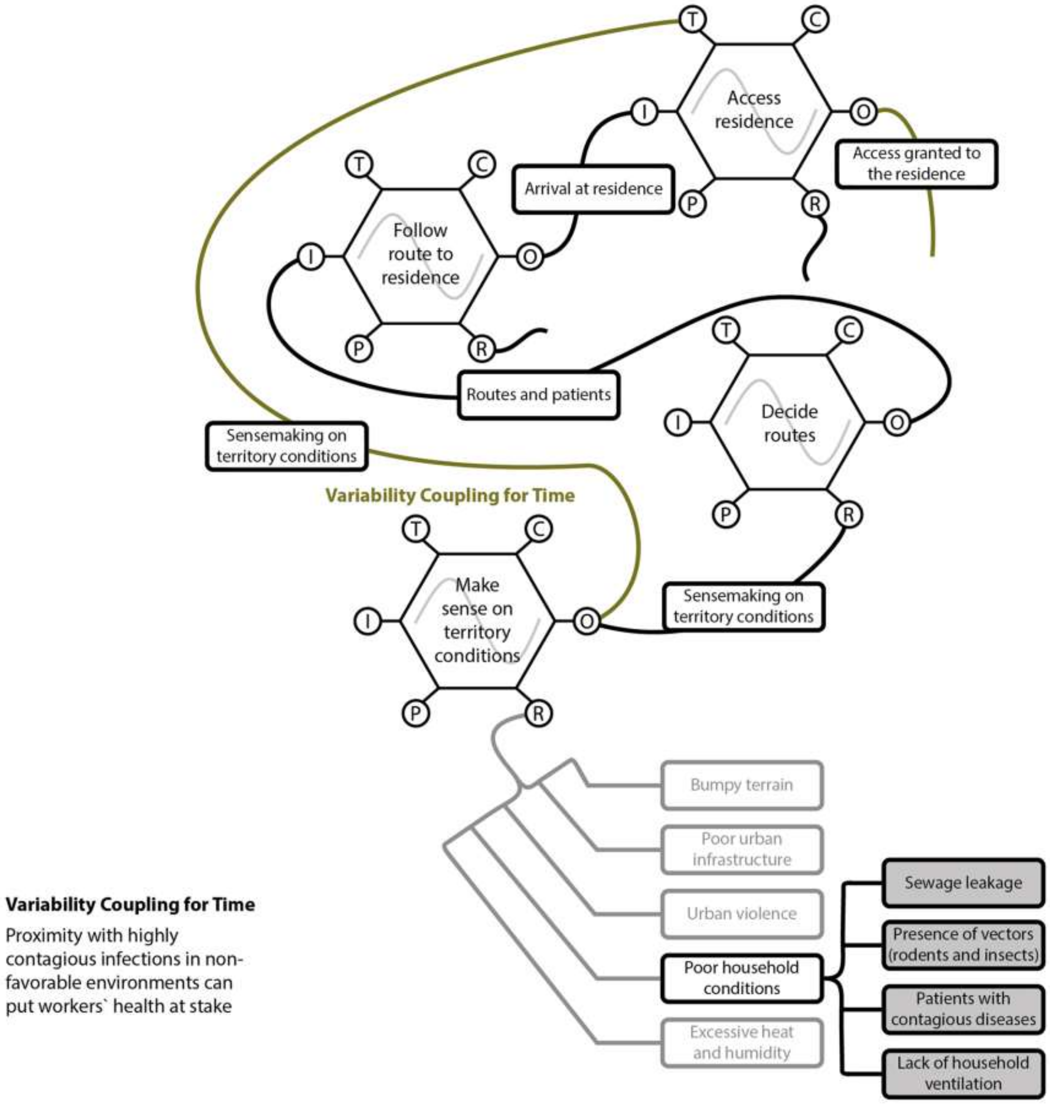


Figure 4-13 – Coupling for actual variability and instantiation – poor household conditions

The territory often faces *excessive heat and humidity*, which significantly affect workload during patient visits. A notable instance to this problem occurs when routes trespass narrow alleys, prolonging time and distance to cover before arriving at residences. Moreover, heavy rain creates large puddles that remain on streets for long periods, paving the way to proliferation of vector-borne diseases. Among these vectors are rats, cockroaches, and perhaps most alarmingly mosquitoes like Aedes Aegypti, which transmit dengue fever, chikungunya, and the Zika fever. Lack of adequate household ventilation is another instance that aggravates this context and exposes workers to health risks. Figure 4-14 illustrates these relations.

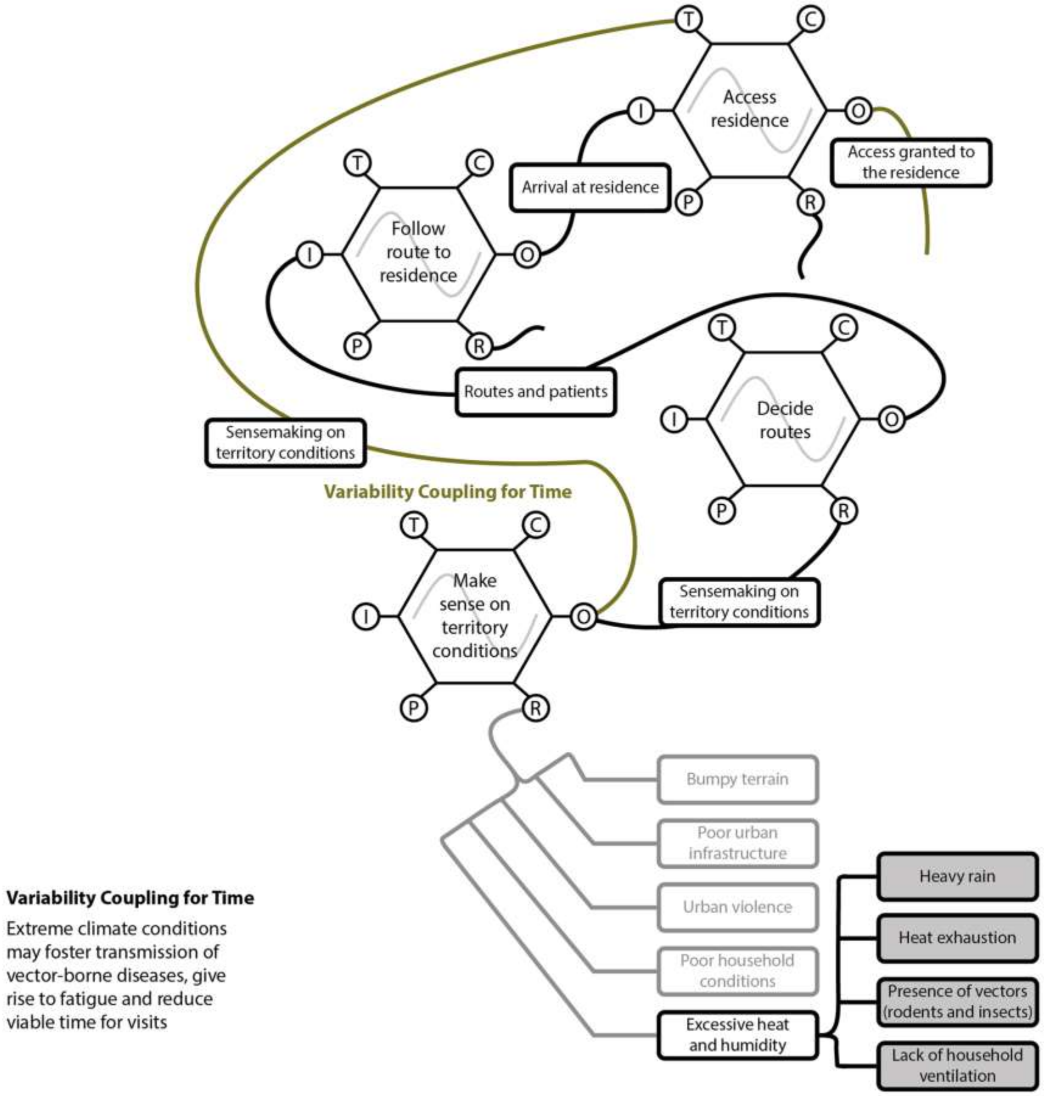


Figure 4-14 – Coupling for actual variability and instantiation – excessive heat and humidity

As each particular visit can be traced to specific policy assignments, it is sometimes possible to depict which instances had impact on tasks assigned to accomplish healthcare policy objectives. For example, we observed a community health worker, while he tried to visit a patient in an extremely precarious area, especially regarding sewerage. Moreover, the patient was critically ill—diabetic, with tuberculosis and AIDS, and the patient had his legs amputated—therefore unable to go to the clinic to get assistance. The visit was planned (assignment D in the Brazilian Primary Healthcare

Policy, as seen in Section 4.1.1 - Foreword) as a promotion action (assignment H). The visit should also enable the nursery team to run some procedures and to enforce the integration of the team with the family (assignment F). However, the team aborted the visit, since they could not reach the patient's residence as leaked sewerage surrounded it.

Further investigation showed that an excessive deviation of waste and garbage in the street that led to the patient's home has happened the day before the visit. In this case, instances of problems compromised two assignments prescribed in the primary healthcare policy, i.e. "sewerage leakage" and "accumulated garbage" compromised the assignments "promote health" (assignment H) and "integrate team and population" (assignment F).

4.1.15 Discussion

The effectiveness of a complex system like healthcare relies on the interplay between humans, technology, and the organization. In this case, a holistic approach is essential for the effective functioning of the system (CARVALHO, 2006; HOLLNAGEL, 2009, 2012; RASMUSSEN, 1974). Thus, understanding the system to transform it requires a systemic analysis, as the system as a whole is not necessarily the sum of its parts (HOLLNAGEL, 2004; HOLLNAGEL; WOODS; LEVESON, 2006; RASMUSSEN, 1980; UNDERWOOD; WATERSON, 2013). Fundamentals of complex systems indicate that one can understand the behaviour of a system only through knowledge of how its parts interact (CRICK, 1995; PAVARD; DUGDALE, 2006).

As Hollnagel (2014) points out, it is difficult for those in the blunt end of a complex system to grasp how much distance exists between WAI and WAD. According to the author, this happens either because existing data at the sharp end are: (a) filtered through several organizational layers and (b) delayed to those at the blunt end. As recent research has shown, even in military organizations—as the Brazilian Firefighter Corps—featuring detailed instructions on how to respond to crisis scenarios, field studies revealed that work is underspecified and adaptations are central to manage emergences (CARVALHO et al., 2018).

In this sense, a variability-based approach to the system is important in the way it enables us to understand variability as not only the reason why things sometimes go wrong but also the reason why things go right most of the time (VANDERHAEGEN, 2015). Patient visits are complex, unstable, and filled with many interdependencies.

Regarding interdependencies, we can cite the unveiled variability couplings between bottleneck and downstream functions. As such, performance variability is needed to accomplish (even if sometimes just partly) the primary healthcare policy goals.

Thus, Figure 4-15 summarizes findings concerning investigated instantiations, i.e. how the modelled functions behave when the problems from territory conditions trigger the couplings for actual variability. The functions variability is described regarding time (ViT) and precision (ViP). As the couplings shows, even in the face of poorly supported sensemaking, community health workers adapt by crossing obstacles on routes, negotiating access to residences and adjusting downstream functions in order to ensure the execution of the most critical activities.

	Variability Coupling for Resources	Variability Coupling for Time
Bumpy terrain	Planned route can be physically obstructed due to erosion and landslides caused by unexpected events	-
Poor urban infrastructure	Residences can be non-reachable due to biological and chemical risks to workers	Risks factors from the street can be so intense that jeopardize workers' health even inside residences
Urban violence	Security threats can block access to entire areas of the territory for days	Hostile interface with residents may hamper the normal course of visits
Poor household conditions	-	Proximity with highly contagious infections in non-favorable environments can put workers' health at stake
Excessive heat and humidity	-	Extreme climate conditions may foster transmission of vector-borne diseases, give rise to fatigue and reduce viable time for visits

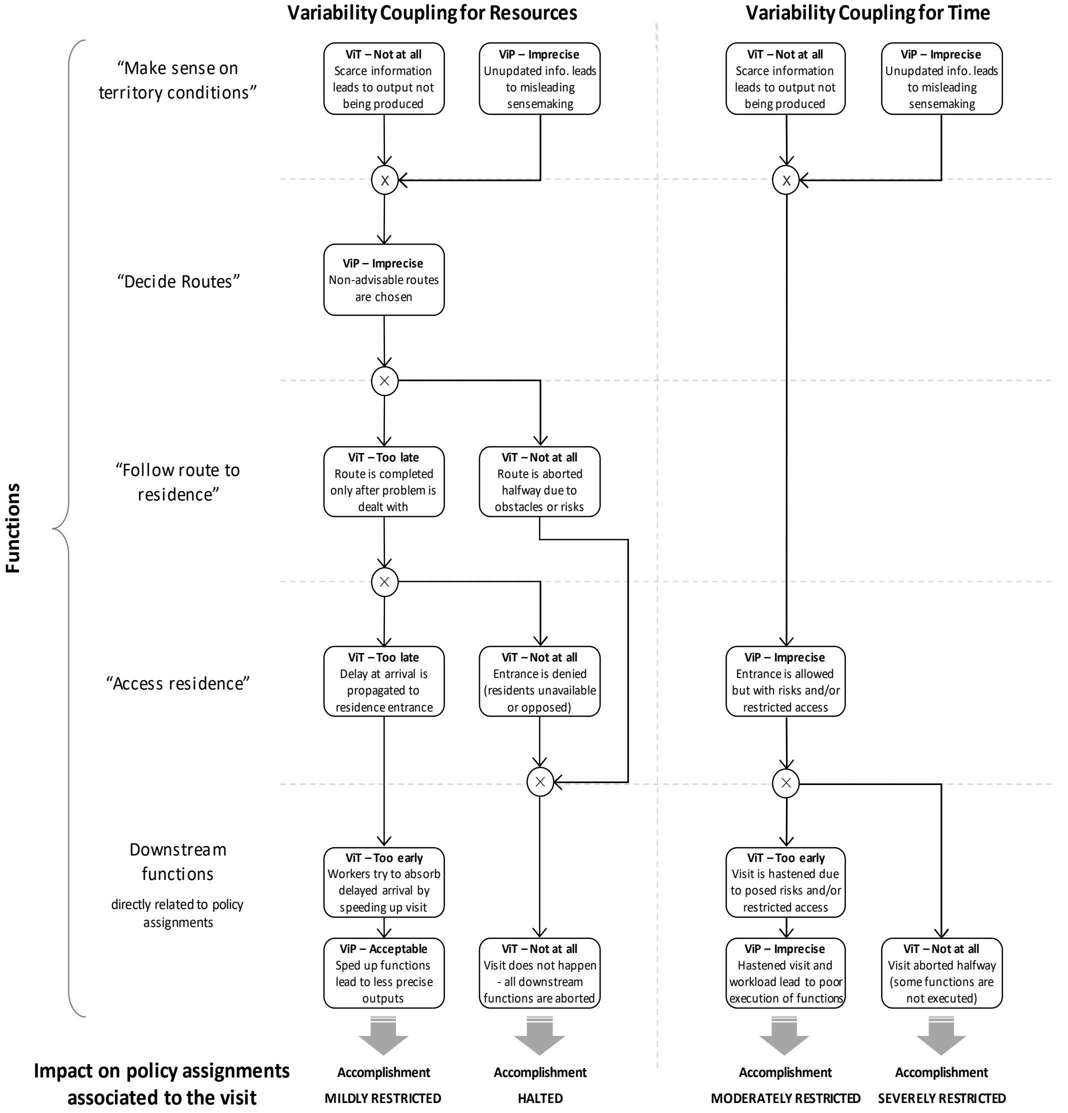


Figure 4-15 – Summary of couplings for actual variability

However, one can also argue that variability coupling for resources tend to be more dangerous to the system than variability coupling for time. This is so because the former can create two paths that lead to the visit abortion even before it starts. Moreover, this coupling can expose workers to occupational risks that are manageable by them to a lesser extent, once these risks rise when workers are still on their way to patients' residences. On the other hand, risks caused by coupling for time should be more manageable since the decision to take shelter inside the residence (e.g. in the case of gunfight) or leave it earlier by "trimming" less critical functions (e.g. in the case of lack of household ventilation and patients with contagious diseases) can protect workers to some degree.

One major finding of this study is that community health workers lack precise information on the current conditions of the territory. Observation of WAD revealed that workers only know the conditions of the territory when they actually get there. This implies that variations in the conditions often hamper the accomplishment of goals and the performance of the tasks, and even the workers' safety. Important information for community health workers' sensemaking arise inside the community; thus, the clinics' administrations might take advantage of information and communication technology and social media to connect with people who live in the assisted communities.

However, although the problems that our analysis demonstrated hamper the accomplishment of tasks, we could see that community health workers usually adapt and figure ways to perform their duties, even though it compromises its results and brings significant risks. This aggravates by the fact that specific clinic's qualitative and quantitative goals—set from policy assignments—are not flexible to accommodate fluctuations on tasks completion.

The analysis we present in this paper shows that, as the community health workers spend significant amount of time in patient visits, even though the instances of problems are transient, they have consequences to the management of their work and expose workers to occupational risks. Moreover, these same events bring significant losses to the patient reception process as a whole, compromising the execution of the policy, as we list:

- The transportation of the community health worker—and his team—to the clinic and to the area;

- The time spent planning the visit—including the effort in prioritizing the residences to visit;
- Mobilization of resources for use during visits;
- Mobilization of human and material resources in the clinic to support teams in the field.

Mitigation of the direct losses listed above relies on the reduction in cancels and withdrawal of ongoing patient visits. A valid solution for this should target the function "Make sense on territory conditions", because observed and reported actual variability in this function leads to unwanted couplings that jeopardize visit execution. In this sense, Figure 4-15 suggests that, among the listed problems, the instances of "poor urban infrastructure", "urban violence" and "bumpy terrain" are priority: the formers because they trigger both variability couplings for resources and for time, and the latter for the dangers it poses to both process and occupational safety, spawned by coupling for resources, as discussed earlier.

However, our field study showed that managers of the visiting process overlook the function "make sense on territory conditions". As disclosed earlier, currently the community health workers make sense on their territory conditions in an adaptive and tacit way—and when such individual efforts are misleading, they might expose workers to dangerous work situations. Moreover, the current control structure for the visiting process does not encompass a control and feedback flow that accounts for sensemaking.

In this scenario, improving communication channels between the communities and the primary healthcare clinic might be a feasible course of action, as shown in Figure 4-16. We propose the formal use of different vehicles like social media to keep the health assistance teams informed about usual problems when they occur (instances of problems). Thus, knowledge about the occurrence of problems would entail actions, e.g.:

- Reorganization of teams, scheduling of resources, realignment of visits according to different purposes;
- Reallocation of scheduled visits, freeing up space, and reducing waste of human and material resources.

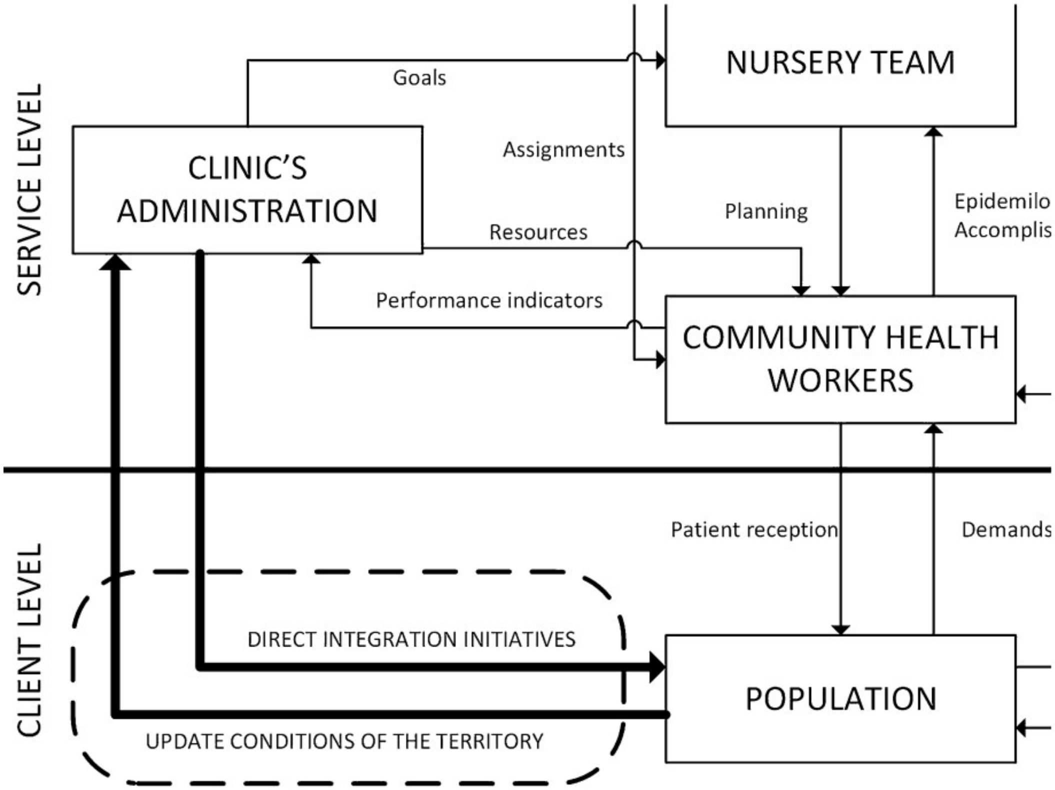


Figure 4-16 – Proposed control structure

Figure 4-16 shows the control and feedback flow we propose, promoting the following improvements:

- Oriented integration initiatives: the administration of the clinic must train the communities in order to raise awareness on the importance of keeping the clinic informed about the conditions and needs of the population of the communities;
- Updates on the patient reception conditions: population can send small pieces of information to the clinic's administration about eventual or temporary occurrences that might affect the schedule of patient visits.

In functional terms, this change of structure could enable a new background function to assist community health workers in sensemaking, as shown in Figure 4-17. If incorporated into WAD, the proposed communication network could potentially dampen the undesirable and sometimes dangerous variability coupling all the way from function "make sense on territory conditions" to "access residence", minimizing worker's exposure to risks and overall improving the system's effectiveness.

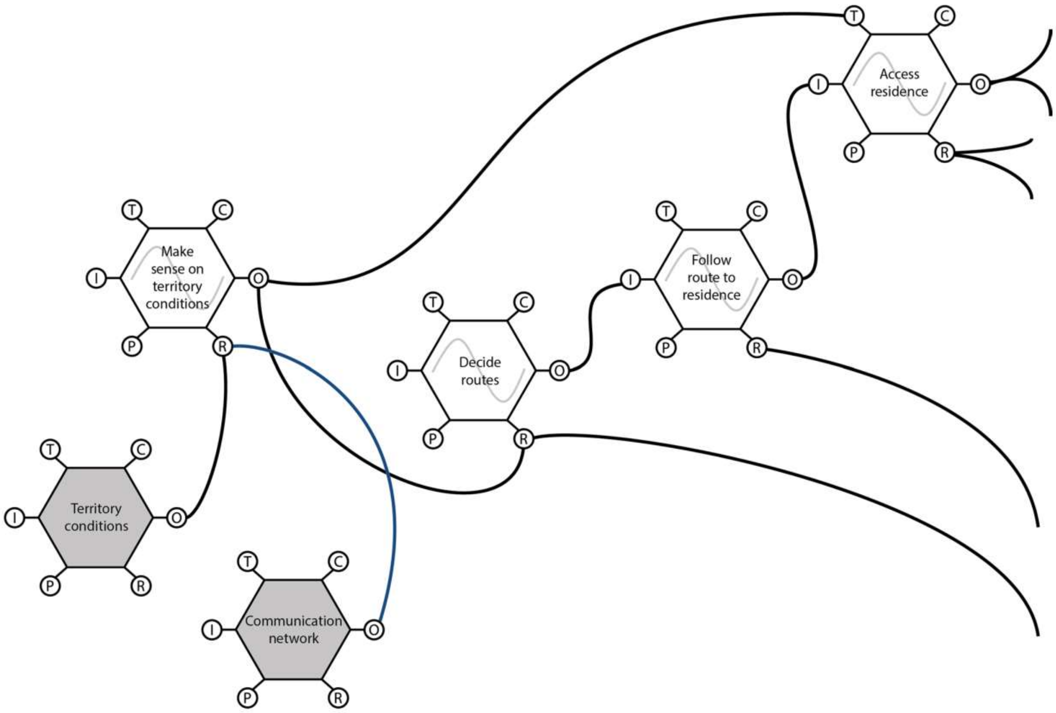


Figure 4-17 – Potential new function designed to dampen variability

Regarding methodology, all field study techniques employed—interviews on typical work practices, reports on specific cases, and observations of WAD—proved valuable to support the FRAM modelling regarding both potential and actual variability in the domain. These techniques provided critical model data, including how activities interrelate, how problems are instantiated and influence bottleneck functions, as well as the adjustments made by workers to deal with emergence in patient visits.

Thus, regarding methodology, one contribution of this paper is that with the identification of problems and their instances, one can understand: (a) how each of these couplings is triggered; (b) how downstream functions respond to it; (c) how the overall system objectives are put at stake accordingly; and finally (d) which problems should be prioritized when designing solutions. As such aspects are ultimately the source of variability that stream through foreground functions, their identification enables adequate reflection on the functioning of the organization.

By focusing on the practitioner's perspective, the applied research method enabled us to better model the system's complexity through aspects of emergence that significantly alter its capability to accomplish its expected goals. More specifically, the systemic analysis presented in this paper revealed that the work-as-done perspective could make significant contributions to redesign system functions taking into account a bottom-up fashion, especially concerning the management of variability couplings.

We believe that a more formalized conceptualization of system variability and emergence could foster the development of a grounded theoretical approach to redesign system functions and processes in a more robust way, addressing the following issues: How do we develop system interventions that open up for the emergent? How can system redesign favours the management of intrinsic (and often unavoidable) variability instead of simple attempts to dampen it? Which social, organizational, and technological devices can help us keep the process outputs under control, instead of strictly trying to control them?

4.1.16 Conclusions

When work analysis takes into account the way people work only as described in standard procedures or by the heads of organizations, there is a chance to leave behind significant aspects on how workers actually perform. Thus, the aim of our study was to understand WAI and WAD on patient visiting by community health workers and propose ways to reconcile both—by the perspective of the worker.

Combined with data collection focused on fieldwork, the systemic approach we proposed in this paper enabled the identification and description of the gap between community health workers' work as prescribed in the primary healthcare policy and the way they adapt to events that occur, while they are in the communities. The combination of structural and functional modelling proved useful at comparing WAI and WAD and proposing changes to improve on the system's overall effectiveness.

Then, we highlight the causes and impacts of these work situations in the health assistance of poorly developed communities, making primary care strategies less effective, unable to cope with adverse conditions. Moreover, our study highlights the importance of strong and direct information channels between the assisted communities and workers, as it might help planning and management, avoid the unnecessary waste of important resources for healthcare strategies, as well as improve work situations in the complex domain of primary healthcare.

As this study has shown promising results, new opportunities emerged. Further work is on development to gather information on how patient visits occur in other primary care clinics, identifying the opinions of community health workers about their working conditions, and what kinds of constraints hamper their work. This study aims at interviewing a stratified sample of 2000 community health workers based on the city of Rio de Janeiro, Brazil.

4.2 Article B: Gatekeeper family doctors operating a decentralized referral prioritization system: Uncovering improvements in system resilience through a grounded-based approach

4.2.1 Foreword

In this paper we address how the prioritization of referrals from primary care to specialized care, as was decentralized to operate from within primary care clinics, allowed the emergence of djustment maneuvers at the sharp end of medical work couple between themselves to tackle big-order issues of demand-capacity misalignments in the system.

This chapter resulted in one scientific article, with the following citation information:

Arcuri, R., Bulhões, B., Jatobá, A., Bellas, H. C., Koster, I., d'Avila, A. L., Vidal, M. C. R., Burns, C. M., & Carvalho, P. V. R. de. (2020). Gatekeeper family doctors operating a decentralized referral prioritization system: Uncovering improvements in system resilience through a grounded-based approach. *Safety Science*, *121*, 177–190. https://doi.org/10.1016/j.ssci.2019.08.023

4.2.2 Introduction

Healthcare systems are expected to provide adequate treatment in an acceptable time, to the right patient, and through varying levels of care. This entails referring patients between these different levels, but one major challenge for managing referrals in public healthcare systems is that resources are usually limited. Such a challenge is especially evident in developing countries. In the Brazilian health care system, demands for health care assistance typically exceed the availability of resources, making it impossible to provide adequate and timely care to all patients.

Adequate prioritization of referrals is thus strategic to public health systems. Investigations on the advantages and drawbacks of different referral prioritization models have been an extensively explored topic in North America, Europe and Brazil (ASKILDSEN; HOLMÅS; KAARBOE, 2011; MACCORMICK; COLLECUTT; PARRY, 2003; MARINHO DA SILVA; SANTOS; BORENSTEIN, 2010; SABIK; LIE, 2008; SALTMAN; RICO; BOERMA, 2006). In recent years, Brazilian public healthcare policies have oriented the referrals from primary care to specialized ambulatory care to be organized and prioritized from within primary care clinics, framing a so-called referral prioritization system for ambulatory care. As in other parts of the world, primary healthcare in Brazil is characterized by actions for health promotion and disease prevention through assistance clinics (primary care clinics) that provide care in defined territorial ranges. On the other hand, ambulatory care comprises specialized procedures such as consultations with medical specialists, elective surgeries and exams, which are to be held mainly outside primary care at specialized clinics and at hospitals' wards. As primary care physicians in Brazil have gradually become responsible for prioritizing the use of resources and taking patients to other levels of care (ALMEIDA et al., 2013; VARGAS et al., 2016), primary care has mostly become responsible for care coordination.

In the city of Rio de Janeiro, which is the second-largest in Brazil and home to 6.7 million inhabitants, reforms in the health care sector began in 2009. Changes in healthcare raised primary care coverage from 7% to 70% in 2016 (SORANZ; PINTO; PENNA, 2016). In 2012, referral prioritization for ambulatory care was restructured to operate from primary care, in accordance to national-level policies. This means that the referral requests to specialized care which are originated from primary care clinics across the city stopped being forwarded to a municipal referral center for authorization, prioritization and scheduling. Instead, those decisions were decentralized to the primary care clinics themselves, being assigned to the lead family physician of each primary care clinic, and sometimes shared with a small group of family physicians from the same clinic.

These physicians thus assumed the role of gatekeepers for each clinic's referral requests, regulating access of local patients to specialized ambulatory care offered outside

– both by public and private specialized care providers, as enabled by contracts between the public and private sectors. However, this organizational change took place without a detailed review on the physicians' work activities under their new role as gatekeepers. Although a 20% salary raise was approved for the new gatekeepers, no dedicated time for operating referral prioritization was granted to them within their weekly work schedule. Gatekeepers are thus expected to manage referral requests “on the go”. This is especially noteworthy for lead family physicians, who previously already accumulated the roles of family doctor (performing appointments and coordinating a primary care team), lead physician of the clinic, and in many cases also residency supervisor. The same situation occurred with the available technological resources, as they were given to learn and use the same IT system previously used for centralized referral prioritization.

Nonetheless, the decentralization of referral prioritization in Rio de Janeiro produced promising results, with the number of booked specialized procedures increasing by 86% between 2011 and 2015, from 790,091 to 1,469,771 procedures. Further, the number of specialized procedures booked within an adequate time frame - measured according to priority levels assigned to the referral requests - also increased amongst all priority levels, raising from 89% to nearly 96% between those years. According to managers of the system, no-shows have also plummeted.

However, many aspects are involved in prioritizing and referring patients, including the interplay of policies, decision-making processes, presence of professionals with distinct backgrounds, as well as the challenges of assisting vulnerable populations in poorly developed territories (JATOBÁ et al., 2018). Moreover, the referral prioritization system in Rio de Janeiro services more than 3 million patients, thus being very difficult to describe completely and to specify what physicians should do in order to handle every situation that occurs. In this sense, the Resilience Engineering framework states that one cannot prescribe the system’s performance as policy makers and system designers imagined, and some degrees of variability, flexibility, and adjustments are required to keep the system functioning well. Workers’ adaptations are crucial for the proper functioning of this complex sociotechnical system, and people at the blunt end need to know what occurs within the system. Moreover, worker’s adjustments are the reason for both acceptable and unacceptable outcomes, embedding capabilities into the system design, and preventing a common temptation to seek adequate functioning by constraining performance variability (HOLLNAGEL, 2015, 2017).

This means that in truly resilient systems, it is not possible to completely realign Work-as-Imagined (WAI) and Work-as-Done (WAD). As such, this gap should be acknowledged, and adaptations that lead to good outcomes should be supported (HOLLNAGEL, 2017). While WAI can be considered the attempt to align a system's capacity with its demands by the organization (ANDERSON et al., 2016; ANDERSON; ROSS; JAYE, 2017), demand and capacity really can never be fully aligned due to the complex dynamic interplay between them. Therefore, WAD comprises adjustment maneuvers needed to cope with mismatches, generally leading to success but sometimes also leading to failures.

In this study, we used the Resilience Engineering perspective described above to investigate the challenges in operating a decentralized referral prioritization system, through a case study in the newly reformed public health system of the city of Rio de Janeiro, Brazil. Specifically, we studied the sharp end of referral prioritization in ten primary care clinics to understand how work is done by family physicians assigned as gatekeeper doctors.

Thus, we address how WAD creates resilient and brittle performance within public referral systems in large cities, and specifically how adjustments to tackle both new and inherited demand-capacity misalignments are employed, increasing comprehension of the elements that affect the resilience capabilities of healthcare systems covering large populations.

The aim of the current study was to develop a theoretical model of the referral prioritization system to improve everyday work practices and to understand how these adjustments lead to both resilience and brittleness.

4.2.3 Methods

The research design focused on investigating the decentralized referral prioritization system for ambulatory care in the city of Rio de Janeiro, Brazil. Data collection and analysis were based on the grounded theory framework (CORBIN; STRAUSS, 2015; GLASER; STRAUSS, 2017). This study was conducted following the ethical principles of the Resolution n° 466/2012 of the Brazilian National Council of Health Care/Brazilian Ministry of Health and approved by ethics committees. Therefore, all participants were asked to review and sign an informed consent document that described the risks and benefits of participating in the study.

4.2.4 Data collection

Data was collected from interviews with gatekeeper doctors within clinics, as well as key-positioned managers of the public health system. A literature review was also conducted, which included a review of scientific papers, technical documentation, norms, and procedures related to the topic. Due to difficulties in reaching physicians for participating in the study, a combined approach of purposive and snowball sampling was used (GOODMAN, 1961). Moreover, when authorized, doctors were observed while operating authorization, prioritization and scheduling of referral requests.

4.2.5 Literature review

A narrative literature review (BAUMEISTER; LEARY, 1997) was conducted, which included an attempt to understand the restructuring of the referral prioritization system, as well as standard procedures in government levels. This step comprised the review of scientific and official technical documentation, including those of different typologies, such as policies, resolutions, manuals, protocols, folders, and guides.

4.2.6 Fieldwork: participants, interviews and observations

Fieldwork for the current study was comprised of two sets of interviews, along with direct observation of work to a minor extent. The research design for the interviews included semi-structured, face-to-face interviews with both managers and gatekeeper family physicians of the referral prioritization system in Rio de Janeiro. The two interviews with managers were conducted as a first stage of fieldwork and aimed at modeling a control structure for the decentralized referral prioritization system.

The city of Rio de Janeiro is subdivided into ten health regions, which are called programmatic areas (see Figure 4-18). We conducted twelve interviews with gatekeeper doctors from 10 primary care clinics in nine different health regions within the city. From this sample, the research group defined the most feasible units to develop a pilot research approach. Three units took part in the pilot approach for validating the semi-structured interview script. After a few changes, the material was consolidated and added to the research results.

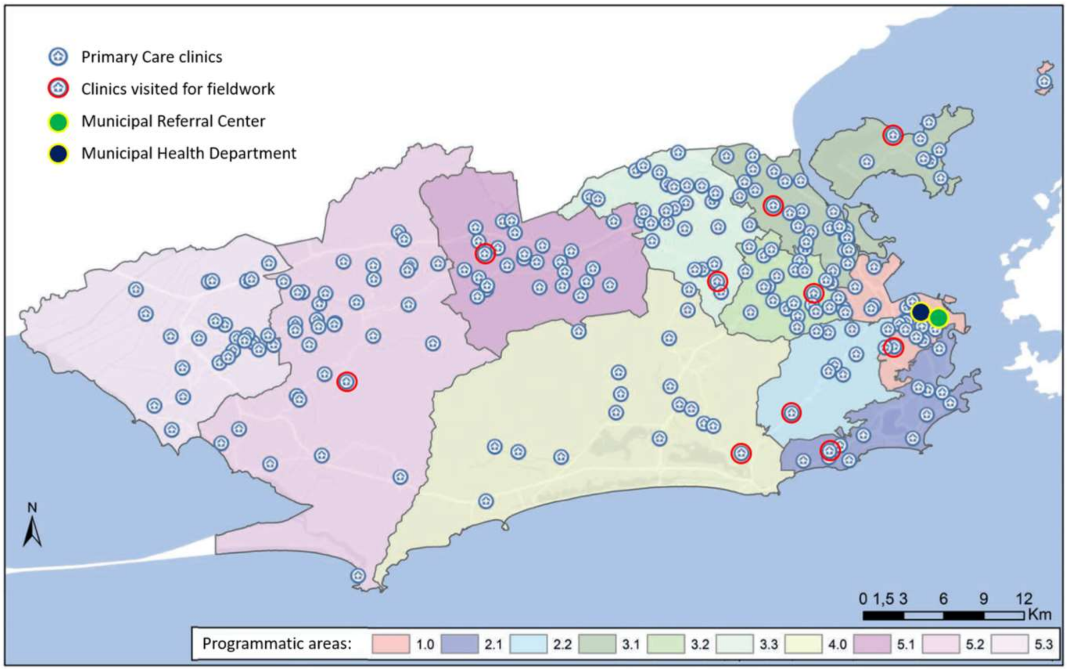


Figure 4-18 - Fieldwork sites in the city of Rio de Janeiro

(adapted from Municipal Health Department, 2017)

It is worth noting that each of the visited facilities is responsible for coordinating care for between a few thousand to several thousand residents in their territory. Because clinics rarely have more than eight family doctors assigned as gatekeepers, each gatekeeper authorizes and schedules referral requests for a large number of individuals. Whenever approved by gatekeepers, the research team was also able to observe their work. Due to time constraints and the collaborative nature of part of the WAD in referral prioritization, the observation was focused on the use of the IT referral system.

4.2.7 Data modeling

Modeling was comprised of two main steps: the compilation and analysis of data from the interviews using concept maps (NOVAK, 2010) and a subsequent phase for framing WAI and WAD. WAI was framed through control structures for the centralized and decentralized arrangements for referral prioritization, while WAD was framed via analysis of the interplay between disclosed adjustment maneuvers, categorized according to the four Hollnagel's resilience cornerstones – Learning, Anticipation, Monitoring, and Responding (HOLLNAGEL, 2011). To bridge resilience cornerstones and maneuvers, we used the Functional Resonance Analysis Method (FRAM). As socio-technical systems are eventually intractable, one must look for a suitable method for analyzing aspects of such systems (HOLLNAGEL, 2012). In this sense, the use of FRAM enables the description of system outcomes using the idea of coupling between different functions, creating paths through wich operators may adapt their performance to cope with shortcomings that are posed throughout daily work routine. Finally, we explored how various maneuvers couple among themselves to counter demand-capacity misalignments.

4.2.8 Concept maps

Concept maps are graphical tools used for organizing and representing knowledge. This work used concept mapping as a way for representing and eliciting knowledge (CRANDALL; KLEIN; HOFFMAN, 2006; NOVAK, 2010). Interview maps were built to represent two focus questions: "How does the referral prioritization for ambulatory care occur in your clinic?" and, "What is your assessment on the decentralization of referral prioritization in Rio de Janeiro?" The answers to these questions and how their defining concepts were interrelated to build the direction map (see Figure 4-19), which was used to guide the research group through the construction of interview maps.

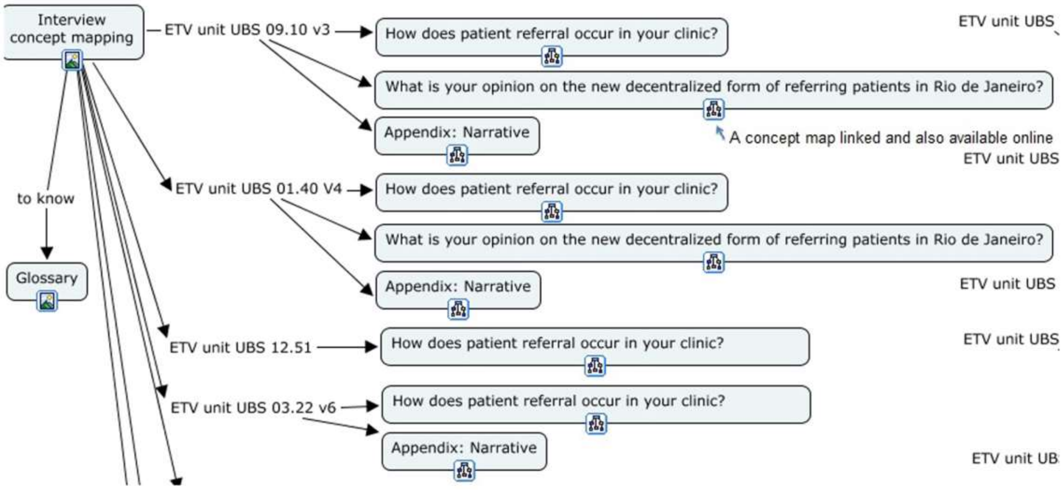


Figure 4-19 - A partial view from the direction map

As it can be seen in Figure 4-19, the focus questions generated not only the respective concept maps, but also appendixes to highlight the interviewees' narratives of specific events. As grounded theory recommends, some categories were created to reduce the number of overall units perceived. Related to the main concepts of the focus question, "How does referral prioritization for ambulatory care occur in your clinic?" six classes were created: WAD, Obstacles, Support Mechanisms, Innovations Proposals, Workload, and Information Technology. A color code was created to represent each central concept and its set, as shown in Figure 4-20. Each interview map has its own set of main concepts.

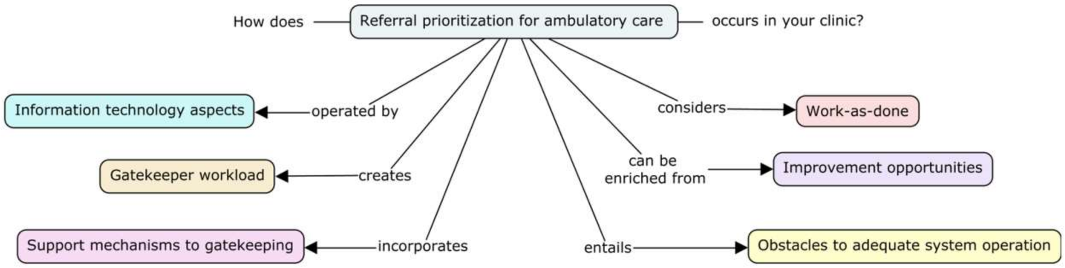


Figure 4-20 – Outpatient priority referral color code.

The WAD category refers to variability, strategies employed, and peculiarities of how referral prioritization is organized within a clinic. The set of concepts for the WAD category is shown in light red. The Obstacles category refers to the obstacles to adequate system operation, as stated by the interviewed doctor. Its set of concepts is shown in yellow. The Support Mechanisms category presents the aspects that improve the resilience of the patient referral activity by assisting the doctor, as shown in pink. The Improvement opportunities category represents the potential solutions or innovation paths for the obstacles experienced in referral prioritization, and are shown in purple. The Workload category, shown in orange, encompasses the elements that increase or decrease the physical or cognitive workload of gatekeepers in their everyday practice. Finally, the Information Technology category, shown in cyan, is representative of software aspects such as functionality and usability. Differently, the maps referencing the focus question, "What is your opinion on the new decentralized form of referring patients in Rio de Janeiro?" were categorized by periods of public management in the city. This enabled researchers to situate the analysis of the operation of referral prioritization into a bigger picture, municipality-wise.

4.2.9 Framing WAI and WAD

The concept maps revealed key misalignments between demand and capacity generated within WAI, as well as failures derived from these misalignments, which can be framed according to a recursive model of organizational resilience (ANDERSON et al., 2016; ANDERSON; ROSS; JAYE, 2017). Further analysis of the concept maps was also conducted. It highlighted an interplay between situated work practices, support structures, improvement propositions, workload, information technology and the problems faced by the system agents, disclosing adjustment maneuvers carried out by gatekeepers and primary care teams in clinics to bridge demand and capacity.

These maneuvers were framed – along with their respective goals – according to Learning, Anticipation, Monitoring, and Responding, the four resilience abilities (HOLLNAGEL, 2011). Also, they were divided between those already latent before the decentralization of the referral prioritization system and those performed to counter issues conveyed by the decentralization itself. Finally, analysis of the concept maps allowed us to frame the joint employment of these maneuvers in five higher-level strategies, each aiming to counter one of the key disclosed misalignments. Finally, the Functional Resonance Analysis Method (FRAM) (HOLLNAGEL, 2012) was used to analyze the couplings between the four resilience abilities and their respective maneuvers.

4.2.10 Results

After employing the snowball sampling technique, 14 family physicians - who were all gatekeeper doctors - were invited to participate in four months of field research. Eight of the physicians also worked as medical residency supervisors, one physician also worked as the lead family physician for the primary care clinic and five physicians accumulated the three roles: gatekeeper, residency supervisor and lead family physician. All physicians agreed to participate in the interviews. Only one participant denied recording the interview. In total, approximately 35 h of interviews were recorded. Analysis of the interview recording was validated in weekly research team meetings. Twenty concept maps were created, mostly comprising the internal workflow in clinics and their relationships with health services providers and patients, enabling a framing for WAI and WAD.

4.2.11 Framing WAI: Main referral flow and control structures, demand-capacity misalignments and derived failures

The referral flow, both for the previous centralized system and for the current decentralized one, works according to the following broad sequential steps:

- Patient goes for a medical appointment with their family doctor (requesting physician) at their primary care clinic;

- Family doctor requests a referral through the IT system, which includes typing a justification for the referral request and assigning an initial priority level;
- Gatekeeper assesses (and changes, if needed) the priority level of the referral request, based on the typed justification, on the patient records, and according to a standard protocol for assigning priority levels to referrals;
- Given the priority level, the current and forecast scenario of vacancy availability, and the particularities of the patient condition, the gatekeeper chooses whether to authorize the request. If the authorization is not granted, the gatekeeper can either return the request to the family doctor (asking for an improved justification) or deny it, cancelling the request altogether;
- Gatekeeper schedules authorized requests according to available (open) vacancies across the city;
- Requesting physician then prints the related documents for the scheduling, which later must be physically delivered by the patient to the specialized care provider at the time of the ambulatory pro cedure appointment;
- Requesting physician delivers the documents to a community health worker from their team;
- Community health worker informs the patient of the scheduling details, deliver the documents to them and afterwards inform the requesting physician of the patient's attendance status (i.e. whether they will be able to attend the procedure);
- Patient attends the specialized procedure and comes back to primary care afterwards for a follow-up appointment with their family physician.

Chief among the documents the patient has to physically deliver to the specialized care provider is the so-called "referral form", which is filled by the family physician detailing the referral. This form has a stub, called "counter-referral form", which is to be filled by the medical specialist detailing the outcome of the specialized procedure. In turn, the counter-referral form functions like a feedback to primary care, and has to be physically delivered to the family physician by the patient, so as the family doctor will be informed of what went on at the specialized procedure. In this way, the patient acts as the main channel for information exchange between the different levels of care, once the referral form and counter-referral form are the only means of formal communication between the family physician and the medical specialist.

The control structure for the centralized system, as it was designed before changes were made to improve adaptation capabilities, is shown in Figure 4-21. In this system, all the gatekeepers assigned to manage the referrals from across the entire city worked from a municipal referral center in downtown Rio de Janeiro, at a place thus physically detached from primary care clinics.

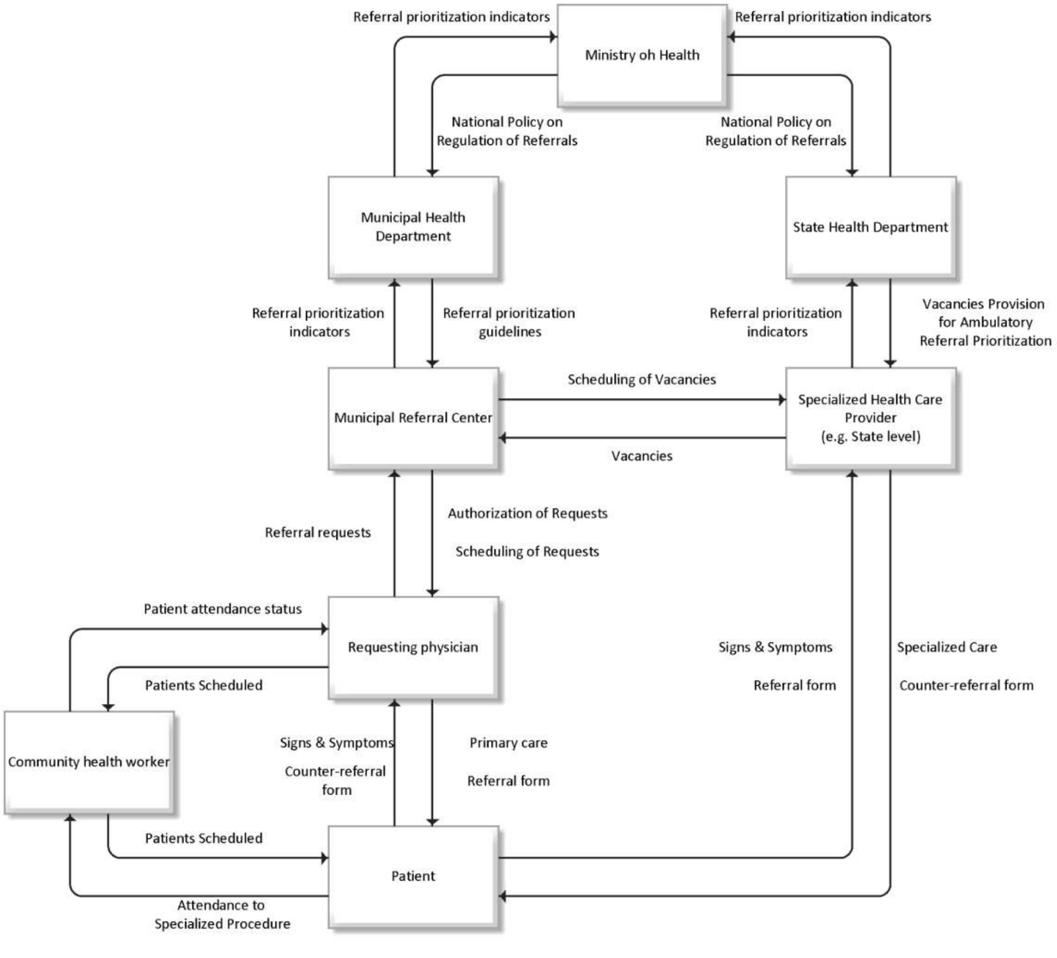


Figure 4-21 - Control structure for centralized referral system.

On the other hand, the control structure representing WAI for the decentralized referral prioritization system – the arrangement currently in place - is shown in Figure 4-22. Two additional agents were designed to enable decentralization: the gatekeeper physicians at primary care clinics and also the local referral centers, which were created to aggregate and organize referral prioritization flows within each of the city's programmatic areas.

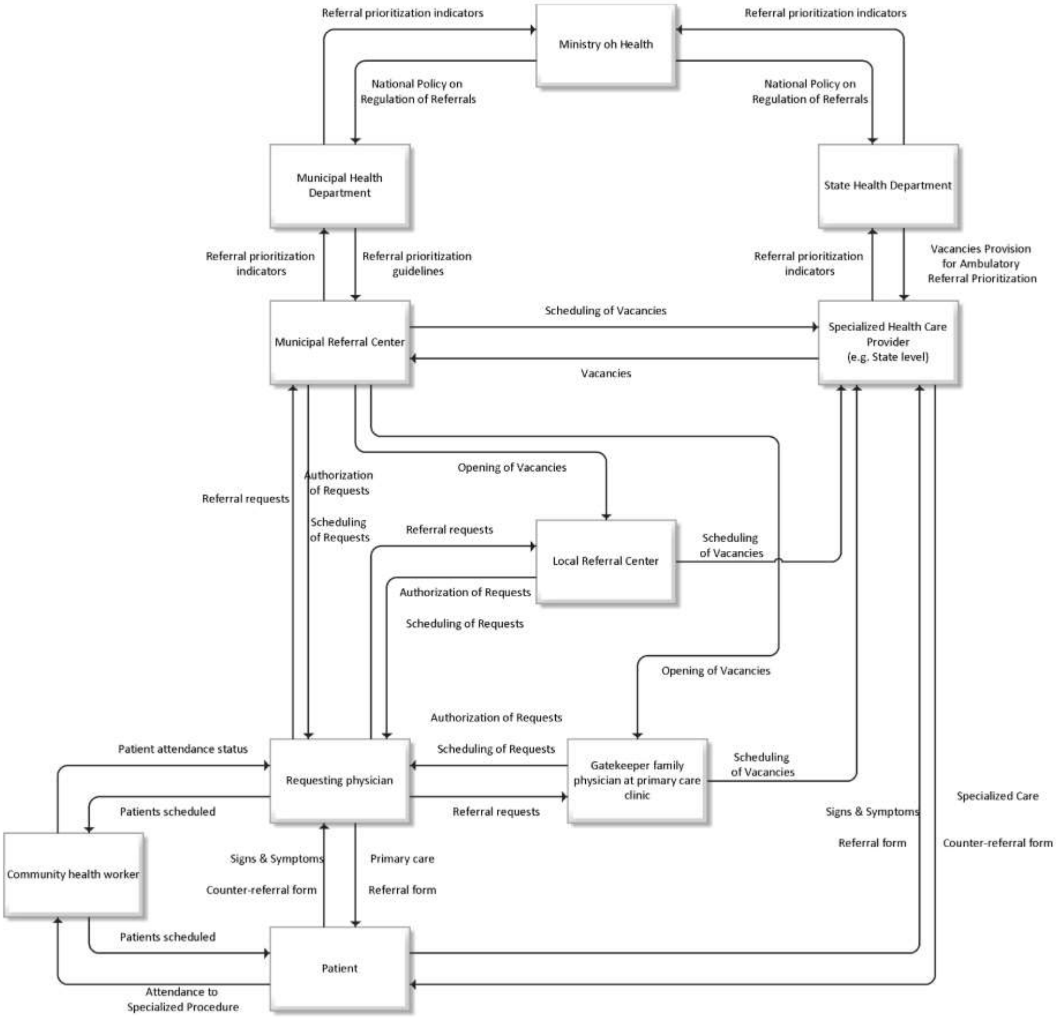
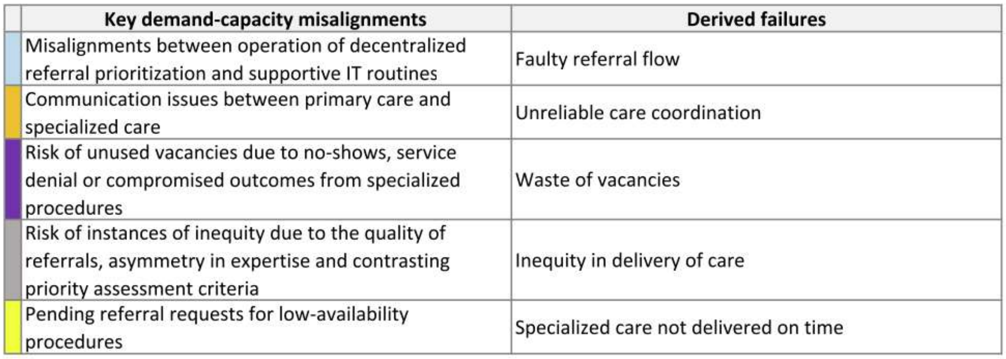


Figure 4-22 – Control structure disclosed for decentralized referral system

It is important to notice that in the current decentralized arrangement, the municipal referral center (along with its team of gatekeepers) continues to exist. Therefore, the requesting family physicians at primary care clinics who request referrals do so not only to gatekeepers at their clinics but also to the local and municipal centers, depending on the procedure aimed at the referral request. This is due to a decision, by the municipal health department, that several low-availability and usually highly-specialized procedures are to be kept processed as centralized referrals within local or municipal level.

Applying the recursive model (ANDERSON et al., 2016; ANDERSON; ROSS; JAYE, 2017) to the domain of primary health care in Rio de Janeiro, it was possible to identify the factors shaping demand for referral prioritization, including the targets/goals for referral prioritization in the city, as well as characterizing referral requests themselves, which are influenced by epidemiological and socio-economic needs of the local population. On the other hand, the system's capacity is shaped by the referral prioritization prescribed processes and guidelines, vacancies provided for scheduling, IT system, as well as clinics' human and material resources in general. Also, through the analysis of interview maps, we identified adverse outcomes (failures) to system functioning that derive from key demand-capacity misalignments. The correspondence between the misalignments and the failures is presented in Table 4-7.

Table 4-7 - Key demand-capacity misalignments and derived failures for decentralized referral system

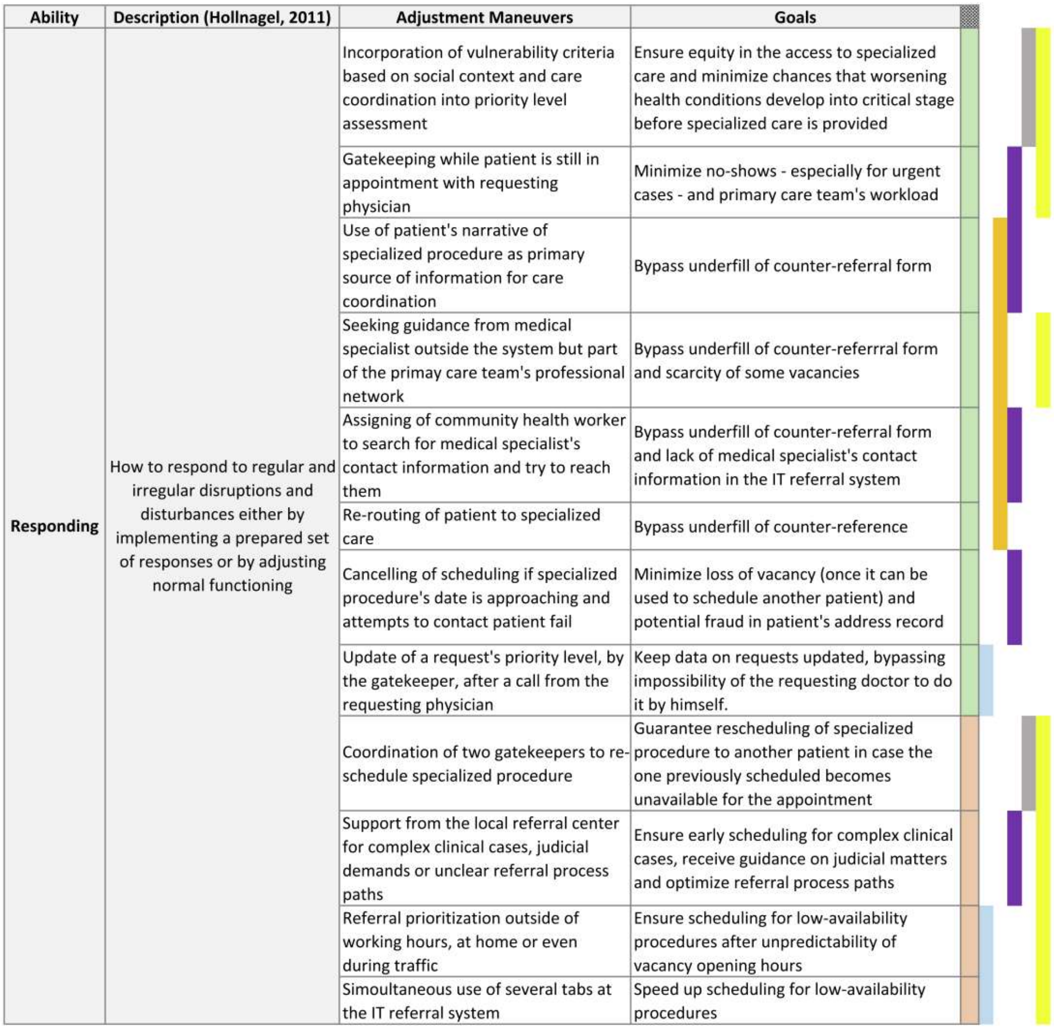


	Key demand-capacity misalignments	Derived failures
🟦	Misalignments between operation of decentralized referral prioritization and supportive IT routines	Faulty referral flow
🟧	Communication issues between primary care and specialized care	Unreliable care coordination
🟪	Risk of unused vacancies due to no-shows, service denial or compromised outcomes from specialized procedures	Waste of vacancies
▒	Risk of instances of inequity due to the quality of referrals, asymmetry in expertise and contrasting priority assessment criteria	Inequity in delivery of care
🟨	Pending referral requests for low-availability procedures	Specialized care not delivered on time

4.2.12 Framing WAD: Adjustment maneuvers employed to realign demand-capacity in case scenarios

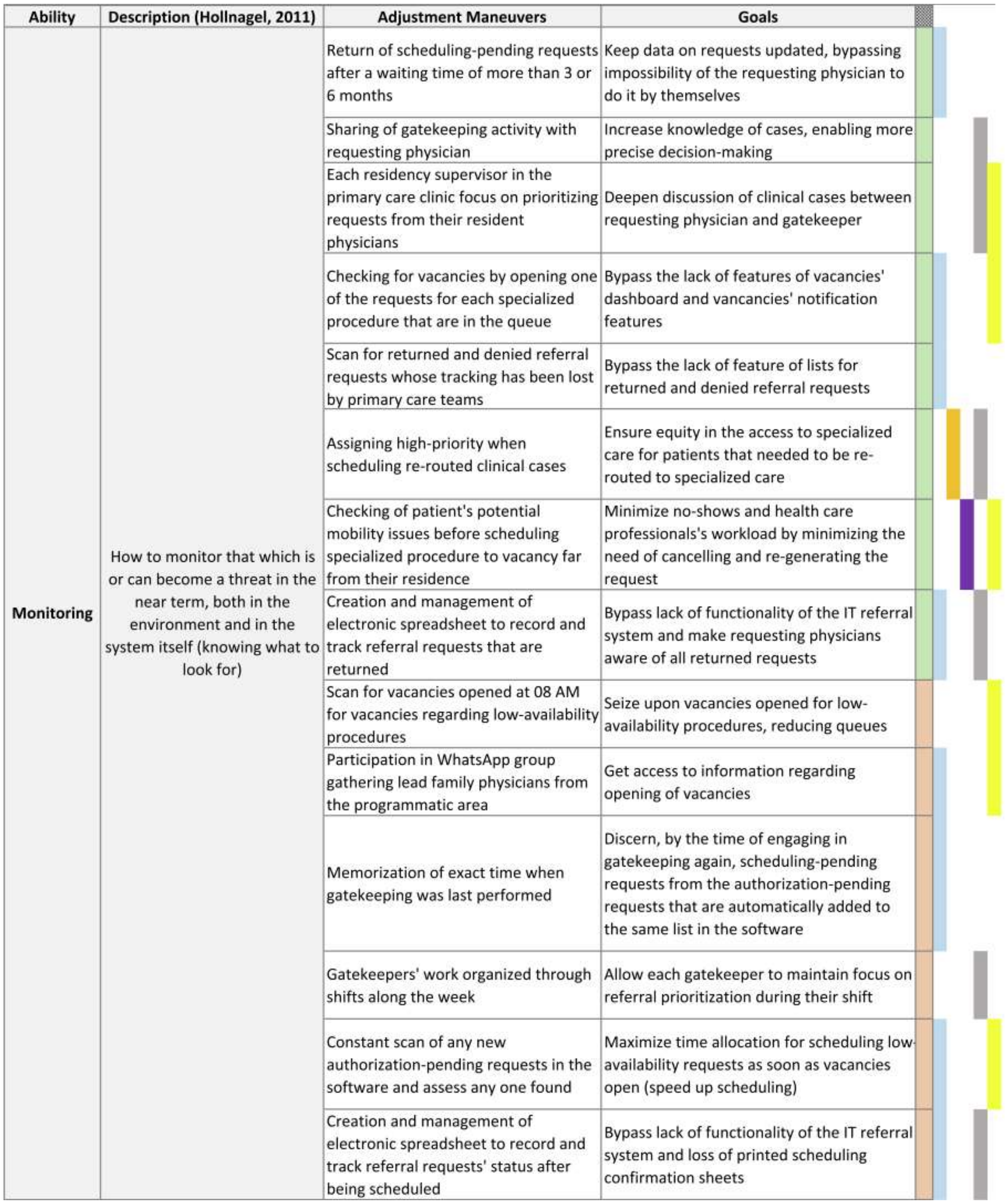
Interview maps also revealed many actions performed by gatekeeper doctors and primary care teams that aimed at increasing adaptive capabilities of the system, as they face shortcomings not covered by WAI in everyday operation of referral prioritization. These actions are hereby referred to as adjustment maneuvers. Also, analysis of concepts and links on the maps made it possible to assert the goals of these actions. Overall, the findings indicate that the decentralization enabled maneuvers employed at the sharp-end, with a focus on overcoming demand-capacity misalignments. Table 4-8, Table 4-9 and Table 4-10 group the maneuvers according to the resilience abilities they manifest. The color code at the first column (left to right) used faded green to represent maneuvers employed to cope with demand-capacity misalignments already faced before decentralization and faded red to represent maneuvers employed to cope with new demand-capacity misalignments, conveyed by the decentralization itself. The other colors in the tables, each one assigned to a column, represent the misalignment cases for which the maneuvers are employed, so as to prevent respective system failures to happen. Below we describe in depth three of those cases.

Table 4-8 - Adjustment maneuvers and respective goals for the Responding cornerstone



Ability	Description (Hollnagel, 2011)	Adjustment Maneuvers	Goals	▨
Responding	How to respond to regular and irregular disruptions and disturbances either by implementing a prepared set of responses or by adjusting normal functioning	Incorporation of vulnerability criteria based on social context and care coordination into priority level assessment	Ensure equity in the access to specialized care and minimize chances that worsening health conditions develop into critical stage before specialized care is provided	🟩
		Gatekeeping while patient is still in appointment with requesting physician	Minimize no-shows - especially for urgent cases - and primary care team's workload	🟩
		Use of patient's narrative of specialized procedure as primary source of information for care coordination	Bypass underfill of counter-referral form	🟩
		Seeking guidance from medical specialist outside the system but part of the primay care team's professional network	Bypass underfill of counter-referrral form and scarcity of some vacancies	🟩
		Assigning of community health worker to search for medical specialist's contact information and try to reach them	Bypass underfill of counter-referral form and lack of medical specialist's contact information in the IT referral system	🟩
		Re-routing of patient to specialized care	Bypass underfill of counter-reference	🟩
		Cancelling of scheduling if specialized procedure's date is approaching and attempts to contact patient fail	Minimize loss of vacancy (once it can be used to schedule another patient) and potential fraud in patient's address record	🟩
		Update of a request's priority level, by the gatekeeper, after a call from the requesting physician	Keep data on requests updated, bypassing impossibility of the requesting doctor to do it by himself.	🟩
		Coordination of two gatekeepers to re-schedule specialized procedure	Guarantee rescheduling of specialized procedure to another patient in case the one previously scheduled becomes unavailable for the appointment	🟧
		Support from the local referral center for complex clinical cases, judicial demands or unclear referral process paths	Ensure early scheduling for complex clinical cases, receive guidance on judicial matters and optimize referral process paths	🟧
		Referral prioritization outside of working hours, at home or even during traffic	Ensure scheduling for low-availability procedures after unpredictability of vacancy opening hours	🟧
		Simoultaneous use of several tabs at the IT referral system	Speed up scheduling for low-availability procedures	🟧

Table 4-9 - Adjustment maneuvers and respective goals for the Monitoring cornerstone



Ability	Description (Hollnagel, 2011)	Adjustment Maneuvers	Goals
Monitoring	How to monitor that which is or can become a threat in the near term, both in the environment and in the system itself (knowing what to look for)	Return of scheduling-pending requests after a waiting time of more than 3 or 6 months	Keep data on requests updated, bypassing impossibility of the requesting physician to do it by themselves
		Sharing of gatekeeping activity with requesting physician	Increase knowledge of cases, enabling more precise decision-making
		Each residency supervisor in the primary care clinic focus on prioritizing requests from their resident physicians	Deepen discussion of clinical cases between requesting physician and gatekeeper
		Checking for vacancies by opening one of the requests for each specialized procedure that are in the queue	Bypass the lack of features of vacancies' dashboard and vancancies' notification features
		Scan for returned and denied referral requests whose tracking has been lost by primary care teams	Bypass the lack of feature of lists for returned and denied referral requests
		Assigning high-priority when scheduling re-routed clinical cases	Ensure equity in the access to specialized care for patients that needed to be re-routed to specialized care
		Checking of patient's potential mobility issues before scheduling specialized procedure to vacancy far from their residence	Minimize no-shows and health care professionals's workload by minimizing the need of cancelling and re-generating the request
		Creation and management of electronic spreadsheet to record and track referral requests that are returned	Bypass lack of functionality of the IT referral system and make requesting physicians aware of all returned requests
		Scan for vacancies opened at 08 AM for vacancies regarding low-availability procedures	Seize upon vacancies opened for low-availability procedures, reducing queues
		Participation in WhatsApp group gathering lead family physicians from the programmatic area	Get access to information regarding opening of vacancies
		Memorization of exact time when gatekeeping was last performed	Discern, by the time of engaging in gatekeeping again, scheduling-pending requests from the authorization-pending requests that are automatically added to the same list in the software
		Gatekeepers' work organized through shifts along the week	Allow each gatekeeper to maintain focus on referral prioritization during their shift
		Constant scan of any new authorization-pending requests in the software and assess any one found	Maximize time allocation for scheduling low-availability requests as soon as vacancies open (speed up scheduling)
		Creation and management of electronic spreadsheet to record and track referral requests' status after being scheduled	Bypass lack of functionality of the IT referral system and loss of printed scheduling confirmation sheets

Table 4-10 - Adjustment maneuvers and respective goals for the Anticipation and Learning cornerstones

Ability	Description (Hollnagel, 2011)	Adjustment Maneuvers	Goals	▨					
Anticipating	How to anticipate developments, threats, and opportunities further into the future, such as potential changes, disruptions, pressures, and their consequences	Scheduling of high-availability procedures no closer than 15 days prior to the vacancy time slot	Minimize no-shows in case patient is not informed of scheduling in time or cannot attend on that day (thus allowing scheduling to another patient and informing them)	🟩			🟪		
		Coordination with social workers and local mail office to issue official IDs for patients	Minimize denial at procedure execution by specialized health care provider because of absence of documents showed by patient	🟩			🟪		
		Production of written warning on the importance of cancellation by patient in case of unavailability	Minimize no-shows	🟩	🟦		🟪		🟨
		Coordination with local neighborhood association for offer of physioterapy sessions	Minimize no-shows through offer of physioterapy sessions closer to patient's homes	🟩			🟪		🟨
		Write special letter for medical specialist to convince them to properly fill the counter-referral form	Tentative of minimizing the risk of underfill of the counter-referral form after the patient has already been impacted by it	🟩		🟨	🟪		
		Delivery of referral form and scheduling confirmation sheet to patient only at the month to which the specialized procedure is scheduled	Minimize no-shows	🟩			🟪		
		Local solutions and task assignments for storage and delivery of referral forms and scheduling confirmation sheet s	Minimize loss of sheets and risk of losing track of referrals	🟩	🟦				
		Avoiding returning referral request (thus instead talking to requesting physician and then directly editing them)	Minimize loss of tracking of referral request once returned requests are not easy to display and edit by requesting physicians	🟩	🟦			⬜	
		Keeping first work hour in the mornings free of medical appointments	Increase availability to perform scheduling for vacancies opened at 08 AM	🟧	🟦				🟨
		Detach priority level asessment/ authorizing from scheduling activities	Ensure all priority level assessment and authorizations are through by the time each batch of vacancies open	🟧	🟦				🟨
Learning	How to learn from experience, in particular how to learn the right lessons from the right experience—successes as well as failures	Training for family physicians on managing specific clinical cases	Reduce unnecessary requests and denied requests, increasing equity in accces to specialized care and reducing health care professionals' workload	🟩				⬜	
		Training for requesting physicians and community health workers in guiding patients throughout the referral process	Minimize no-shows and health care professionals' workload	🟩			🟪		
		Team meeting on implications of recently received counter-referrals to gatekeeping	Increase understanding on how Specialized health care provider copes with specific clinical cases	🟩		🟨		⬜	
		Constant fine-tuning between primary care clinic's gatekeepers in regard to priority level assessment	Ensure equity in the access to specialized care	🟧				⬜	
		Mapping of most likely times during the week for specific vacancies to open	Increase monitoring of potential opening of vacancies for low-availability procedures	🟧	🟦				🟨

4.2.13 Case 1 – Faulty referral flow: misalignments between the operation of decentralized referral prioritization and supportive IT routines

The IT system used for prioritizing and scheduling referrals was designed before the healthcare system reform, at a time when referral prioritization was centralized. The findings show that even during that time there were already important misalignments between the demands of gatekeeping operation and the routines available at this web-based platform. However, following decentralization this distance got wider, as the software would not support many new aspects of the new arrangement. The main misalignments currently existing between the work process for decentralized referral and the IT system workflow, as identified during direct observation of activity and as reported by interviewees were:

- The time window for vacancies opening (8 AM to 8 PM) is wider than working hours (8 AM to 5 PM or 9 AM to 6 PM, depending on the clinic);
- There is no standard time for vacancies to become available. Different vacancies open at different times of the day, but in an unpredictable way. Some vacancies may take weeks or months to open. The criteria used to distribute the vacancies opening in a day and throughout different hours of a day is not disclosed to gatekeepers or to primary health clinic teams in general;
- The IT system does not embed a notification feature to warn gatekeepers as vacancies are fed into the system by specialized care providers;
- The IT system does not differentiate authorization-pending referral requests from scheduling-pending requests – it suppresses a queue for scheduling-pending requests. This means that gatekeepers can only authorize a request if they proceed with scheduling it right away and in a single action. Since most vacancies are available for a relatively short window of time, the consequence of this design is that doctors are not able to mark requests as authorized (as there usually are no vacancies open for a specific request at the time of its assessment and authorization by the gatekeeper);
- The IT system does not embed a dashboard feature that allows gatekeepers to see what vacancies are open at a given moment. Information regarding vacancies availability is only displayed within an individual referral request navigation script (after authorizing the request);
- The IT system does not include any criteria to hold vacancies to better distribute scheduling for opened vacancies among clinics in an equity-prone way. Once the vacancies become available, scheduling of authorized referral requests is processed on a first-come, first-served basis by gatekeepers across the city. More specifically, once a number of

physicians from different clinics become aware of vacancies, they must compete to schedule their own authorized referrals before vacancies run out. Especially for low-availability procedures, operating scheduling has been described as “an experience akin to a button masher videogame”;

- After a referral has been requested, only gatekeepers (rather than requesting physicians) will be allowed to change its priority criteria in the IT system. This is a problem – especially for low-availability procedures - because referral requests can typically remain in queue for months. Therefore, though patients’ health conditions will invariably change during such long waits, the requesting physicians (who have the most direct interface with patients and can track their health conditions through follow-up appointments) are not able to update the status of the clinical cases in the software.

The functions and couplings for this case are shown in Figure 4-23.

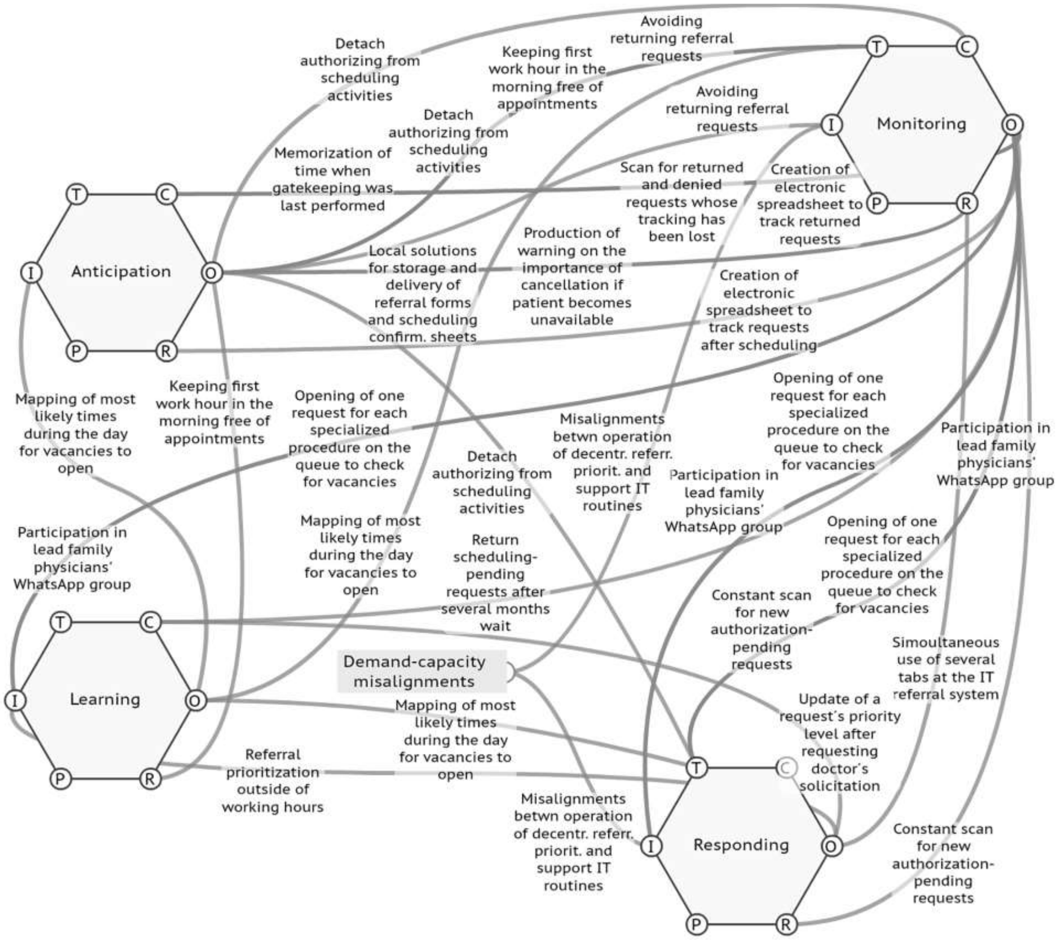


Figure 4-23 - FRAM model of the resilience abilities and respective maneuvers for coping with misalignments between operation of decentralized referral and IT routines

Responding to the wider time window for vacancies entails the need to perform referrals after working hours (e.g., at home, at personal or professional appointments, and during daily personal activities, sometimes including even driving). According to interviewees, this is necessary to ensure that some high-priority referral requests from their clinics get scheduled when vacancies come about, once those can take weeks or months to open, depending on the procedure requested. This maneuver is an input to the learning ability once it triggers the knowledge-building process of mapping typical times when different types of vacancies open. To speed up the scheduling of low-availability procedures, physicians will also prepare the use of the IT system by opening several tabs before 8 AM, which is the time at which the majority of vacancies open each day. In this manner, navigating through scheduling scripts in the IT system can be optimized. Also, since requesting doctors cannot change a referral request description or priority level after it has been authorized, gatekeepers will change these fields themselves after receiving calls from requesting physicians on updates in the clinical scenario.

Disclosed misalignments between work process and IT workflow also trigger the monitoring ability, which embeds several maneuvers. Since the requesting physicians cannot change referral status after a referral has been requested, some gatekeepers will return previously authorized requests that have spent three to six months in the queue to enable requesting physicians for new requests. To cope with the absence of a dashboard of open vacancies and a lack of a notification feature to show vacancies, gatekeepers will often check for vacancies by employing two maneuvers. The first maneuver consists of opening one of the requests for each specialized procedure that has pending requests and clicking on the "authorize" button, which will display any open vacancies. Because this maneuver has to be completed on an individual referral request basis, and queues with hundreds of requests are not uncommon, interviewees stated that this maneuver can be time-consuming. The second maneuver refers to monitoring a WhatsApp™ group in which gatekeepers from the programmatic area share daily alerts about new vacancies as they are identified.

Both maneuvers are coupled with the responding ability, as they create (trigger) a time pressure for scheduling, even beyond working hours. The latter one also triggers the learning ability. To maximize time allocation for scheduling as rare vacancies open, gatekeepers also constantly scan for new requests so they can assess their priority level and decide on their authorization before a vacancy for that procedure becomes available. This maneuver functions as a resource to the responding action of referral prioritization outside of working hours, since it filters which requests are better suited to be handled in this manner. It also allows more time to focus on scheduling of low-availability procedures, reducing the need of the responding maneuver of using simultaneous tabs for scheduling.

Anticipation maneuvers couple with the three other resilience abilities. The decision to detach priority level assessment and authorization from scheduling activities ensures the most cognitive demanding and time consuming part of the referral prioritization activity (priority level assessment and authorization) is completed by the time vacancies do open, alleviating time pressure from responding maneuvers. On the other hand, that decision controls how monitoring maneuvers (such as scan of new requests and memorization of time at which the last referral prioritization activity iteration ended) will operate, while setting specific time frames for them. The situated arrangements and task assignments (involving gatekeepers, requesting physicians, community health workers, and the administration staff) for storage and delivery of referral forms (filled by family physicians) create a physical database of referral requests. This database is used in monitoring maneuvers, such as the scanning of returned and denied referral requests whose tracking has been lost by primary care teams, and the management of electronic spreadsheets that aim to keep track of both scheduled and returned referral requests.

Avoiding returning referral requests will reduce the amount of time needed to manage the external spreadsheet regarding returned requests. However, whenever it is necessary to return a request, this will trigger that same monitoring maneuver.

Finally, keeping the first hour in the morning free of medical appointments is also an important anticipation action. It allows for a dedicated time window for all monitoring maneuvers (thus coupling with this ability regarding time) and creates better conditions to identify when vacancies are more likely to be open (thus coupling with the learning ability regarding resources).

In this case, the learning ability means creating a mental map of which are the most likely daily times for specific vacancies to become available in the IT system. Although these time slots during the day (as is also the case for weekly and monthly frequency of openings) are ultimately not predictable, experienced gatekeepers have become aware of some critical times during which most vacancies seem to open. These are mainly at the start of the day (8AM) and during early afternoon hours. This knowledge has motivated some gatekeepers to change clinic schedules in such a way as to allow them time during the early morning to dedicate themselves to referrals, thereby employing this anticipation maneuver. The creation of a mental map regarding most likely opening times for vacancies has also allowed gatekeepers to better prepare for referring, and particularly scheduling, as described in the other abilities. Therefore, the learning cornerstone establishes stricter time windows for increased attention of scanning for vacancies and scheduling requests, thus coupling with the time aspect for both monitoring and responding.

4.2.14 Case 2 – Unreliable care coordination: communication issues between primary care and specialized care

Although information for scheduling of referrals mostly occurs within the IT referral system, the communication between primary care and specialized services providers, which is crucial for care coordination between levels of care, surprisingly does not happen within the IT system. Particularly, the communication between those two levels of care does not make use of the "justification for referral request" filled by the requesting physician in the IT system. Instead, communication between levels depends on the "Referral" and "Counter-Referral" forms. Neither forms are embedded in the IT referral system, meaning they must be printed out as partially filled forms from a separate electronic medical record system and completed in paper and pen format afterwards. As stated earlier, the referral form is filled by the requesting doctor and taken by the patient to the medical specialist/specialized clinic. The counter-referral is a stub to the referral form, filled by the medical specialist and routed back to the primary health clinic by the patient. Interviewed gatekeepers assessed that over 95% of counterreferral forms are underfilled. According to them, they either lack on:

- diagnosis remarks;
- treatment guidelines;
- prescription of a future consultation with other specialists;
- prescription of medication and exams;
- any written information whatsoever (reported as the most common case).

In this scenario, some of the maneuvers disclosed in the current study aims to deal with communication issues and common information gaps between family doctors and medical specialists. The functions and couplings for the resilience cornerstones are shown in Figure 4-24.

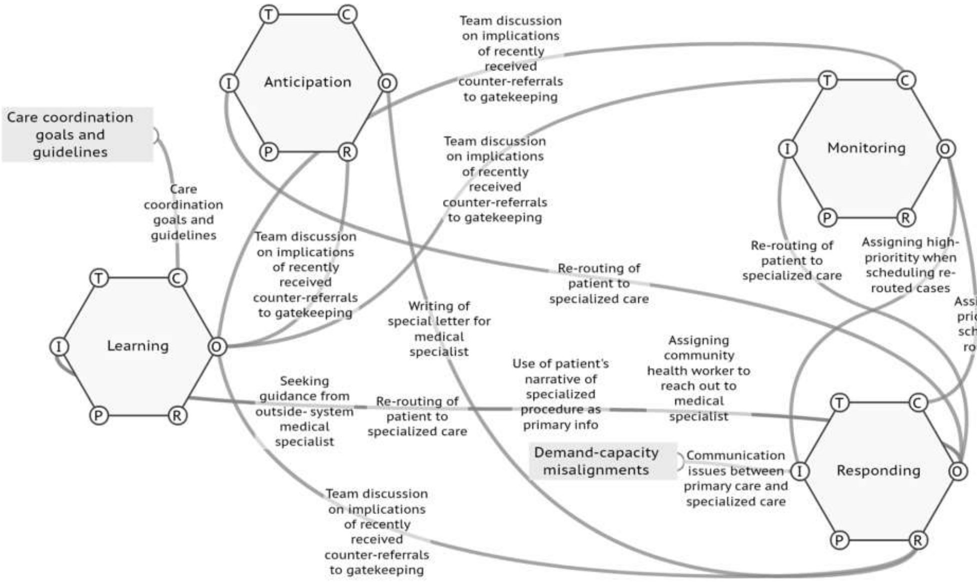


Figure 4-24 - FRAM model of the resilience abilities and respective maneuvers for coping with communication issues between primary care and specialized care

Maneuvers from primary care teams employed in response to communication issues between levels of care include:

- depending on the patient‘s narratives for the performed specialized procedure;
- seeking guidance from medical specialists that are external to the referral prioritization system but part of the gatekeeper’s professional social circle;
- assigning available community health workers to search for the medical specialist‘s contact information and reach out to them for information;
- making the decision to re-route the patient to specialized care.

If a patient is re-routed to specialized care, both anticipation and monitoring maneuvers are triggered. Either way, any responding maneuvers will also trigger the learning ability.

Anticipation in this case means writing a special letter to the medical specialist – to be taken to them via the patient - compelling them to properly fill the counter-referral form. This action will in turn act as a resource for adjusting future responses to repeated underfilling of the counter-referral form when needed. For example, if a medical specialist will not fill the counter-referral form even after receiving a special letter, further employment of responding maneuvers (e.g. rerouting the patient to the same specialized service provider or assigning a community health worker to contact the medical specialist) might be turned down in favor of other actions. The monitoring relating maneuver employed involves starting to scan for vacancies for the re-routed clinical case while granting an artificially high-priority status for the case within its respective original priority level. This is done to minimize inequity since the patient has already gone through the queue once and the IT system always automatically places a new entry at the end of the queue. Therefore, this action will act as both an input (trigger) and a control aspect for the continuing responding maneuver of re-routing the patient to specialized care.

Learning assumes the form of discussions between gatekeepers and requesting physicians on implications of received counter-referral forms to requesting and referring activities. This is done in line with general care coordination goals and guidelines and enables the clinic's team to increase understanding of how specialized health care providers deal with and report specific clinical cases. This maneuver is a resource to the anticipation ability in the sense that actions such as the writing of a special letter to the medical specialist are at first collectively created.

4.2.15 Case 3 – Inequity in delivery of care: risk of inequity due to quality of referrals, asymmetry in expertiseand contrasting priority assessment criteria

According to the interviewees, one of the major benefits generated by the decentralization of referral prioritization is the possibility of carrying out “continuing education” practices within clinics, which amount to actions coordinated by gatekeepers that aim at fostering the quality of referrals and improving equity of care delivered to patients. To cope with possible inequity along the referral flows in the system, the resilience abilities and respective maneuvers organize themselves as shown in Figure 4-25.

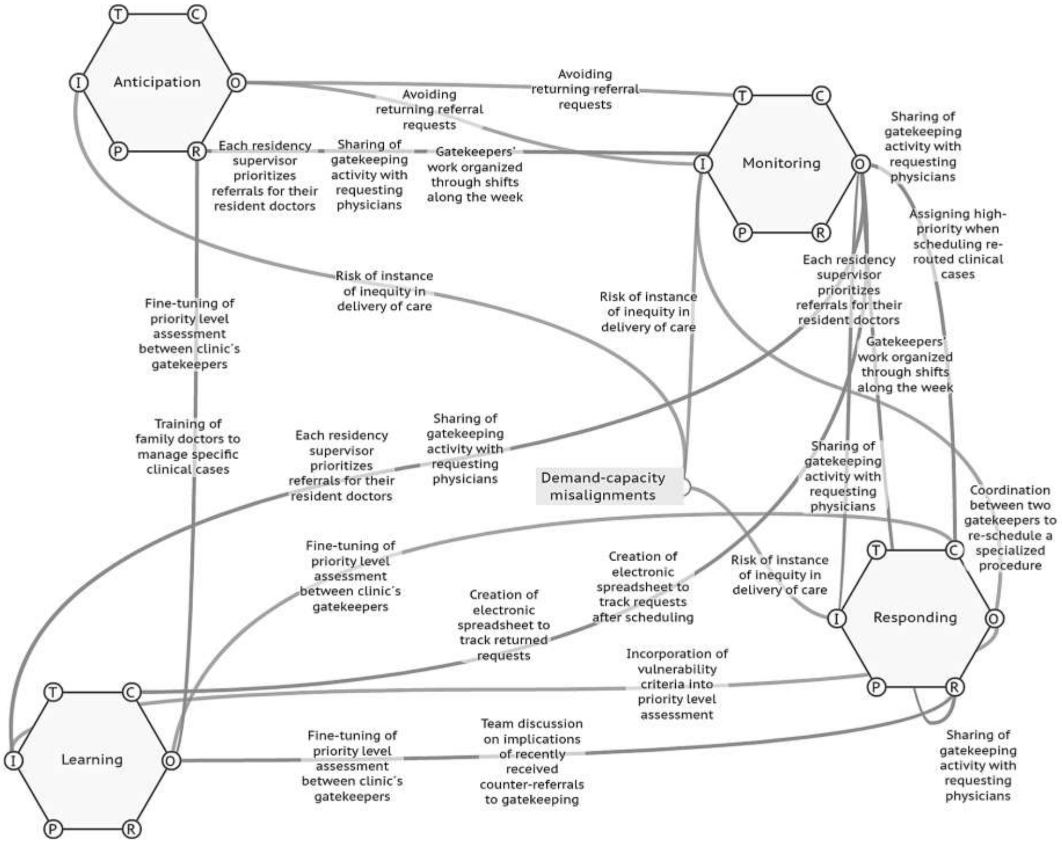


Figure 4-25 - FRAM model of the resilience abilities and respective maneuvers for coping with risk of instances of inequity in the delivery of care

Responding manifests itself mainly in the incorporation of vulnerability criteria into priority level assessment – a maneuver that triggers the learning ability. These criteria can either refer to social contexts (e.g., a patient with a disease whose symptoms are intensified by hot and humid conditions in communities with low urban infrastructure) or to care coordination factors (e.g., a patient with cancer that is entering a metastasis phase, which is a condition that cannot be handled within primary health care). This also indicates that for some clinical cases (e.g., cataracts), a long wait for vacancies (e.g. anything from two years of wait onwards, in the case of cataracts) can trigger a decision from the gatekeeper to increase the case's priority level even without a new appointment in primary health care. Another maneuver takes place when a patient from the clinic's area, previously scheduled for a low-availability procedure, cancels the scheduling. In this case, to be able to keep that vacancy and offer it to another patient, two gatekeepers work in different computers at the same time: one will cancel the appointment while the other is positioned at the scheduling screen to immediately claim the vacancy, before any other gatekeeper in the city is able to claim it first.

The monitoring cornerstone highlights some critical continuing education practices such as the possibility to discuss and share the referral activity with the requesting doctor. According to interviewees, this discloses an inside view of the patients' clinical conditions to the gatekeepers, who then are better able to make decisions regarding priority level assessment, authorization, and scheduling. This sharing has an impact as a trigger, a resource, and a control aspect to the maneuver of incorporation of vulnerability criteria. Monitoring also presents situated ways to organize referral prioritization, such as day-shifts of gatekeepers along the week (during which a physician will manage referrals for the whole clinic‘s patients) and an arrangement adopted in some clinics that host medical residence, where each gatekeeper (who in this arrangement is also a residency supervisor) will manage referrals for their respective resident physicians. It was reported that the former mentioned arrangement aims to create conditions that allow gatekeepers to have deeper focus in this activity, while the latter mentioned model makes it possible to deepen the discussion of clinical cases between the gatekeeper and requesting physicians. This action triggers the learning cornerstone by enabling training of fellow primary health care teams and functions as a resource to increase the effectiveness of the anticipation ability.

Finally, learning occurs as three continuing education practices. The first practice is the training of family doctors on managing specific cases that gatekeepers perceive as prevalent or critical in the territory's communities, thereby reducing unnecessary referral requests and denials, reducing health care professionals' workload, and increasing equity within the locally generated requests. Another maneuver is the promotion of staff meetings to discuss requests and prioritization of referrals in the clinic in light of recently received counter-referral forms and also based on how specialized care providers cope with clinical cases by specialized care levels. A third practice is a constant finetuning between the gatekeepers in the clinic regarding priority level assessment, both considering the formalized referral prioritization protocol and the vulnerability criteria incorporated into WAD. These maneuvers enable the learning ability to act as a resource to better support responses to risks of inequity. Also, the fine-tuning of priority level assessment also functions as a control to the same responses.

4.2.16 Discussion

The decentralization managed to increase the adaptive capacity of the system so demands can now trigger new strategies and processes from system agents, changing the model of competence. Moreover, those decisions are made at the sharp-end by gatekeepers themselves. For instance, acute health cases that emerge from the territory and come to need open vacancies for low-availability procedures trigger direct contacts from gatekeepers to the local referral center, asking for prompt intervention.

Our study demonstrated evidence that the success of performance indicators for referral prioritization after the decentralization may be due to adjustment maneuvers created in the new environment. Particularly, the findings show that these maneuvers are able to couple among themselves to create paths for resilient strategies that can effectively tackle higher-order issues. A great contributor to this is the so-called "continuing education" that was fostered among family doctors in primary care clinics after referral prioritization was decentralized. Comprising a number of compound maneuvers itself, the reason for its positive impact lies in the fact that, because gatekeepers work closely with requesting physicians in their everyday work, and because they are also requesting doctors themselves, it is more feasible to hold local initiatives aimed at fine-tuning the criteria for referrals and the quality of the referral requests within each clinic.

Maneuvers developed and employed to handle WAI misalignments sharpen the resilient capabilities of sociotechnical systems. For instance, maneuvers employed to solve the information gap between levels of care stimulate system agents (in this case, physicians) to learn where and how to look for information that is not readily available. One of the major obstacles set by referral prioritization decentralization, according to physicians, is the inequity regarding authorization and scheduling of referrals between different clinics, hampering the delivery of care to patients. Authorization inequity refers to instances where referral requests that could actually be solved within primary health care clinics - and therefore should be returned to requesting physicians - are instead authorized and later referred, occupying vacancies that are crucial for more complex cases. Scheduling inequity comprises instances when heavy work schedules and buildup of responsibilities handicap some gatekeepers from their time availability for referral prioritization, hindering their number of scheduled referrals as compared to other gatekeepers.

Two factors play a major a role in this regard. Firstly, the capacity and demand of clinics are significantly different. Secondly, the municipal health department forbids a formal dedicated schedule for referral prioritization activities, as previously mentioned. Doctors are thus instructed to carry it out "between appointments with patients" or "during idle moments of the weekly schedule". Those two factors combined might accentuate both kinds of inequity between different clinics and were even reported to take place among clinics in proximity (i.e., assigned to different parts of the same community/neighborhood). Analysis of WAD did not disclose any compound strategies or even single maneuvers to deal with this issue. This might be somewhat expected, since the increased autonomy of family doctors after decentralization is still bound to their respective clinic borders. Nevertheless, the participation of gatekeepers in WhatsApp™ groups at least potentially contributes to reducing some asymmetry in scheduling inequity. In the same way, the anticipation ability for the case of mitigating the risk of unused vacancies should be interdependent from the monitoring and responding abilities.

Interventions to improve the functioning of complex work processes, such as the referral prioritization system, must appreciate the positive contribution of performance adjustments and dynamic trade-offs made by domain practitioners that succeed at delivering production goals. Therefore, a grounded approach based on resilience engineering concepts appears to be a way to improve the work processes under the situations faced by the doctors in this system. When investigating WAD to enable further reflections among practitioners on the different ways the system operates, one should look for:understanding what goes right (even when coping with misalignments or adverse situations);

- focusing on the most frequent events;
- finding practical ways to improve resilient abilities and its relations;
- introducing new ideas on artifacts to improve functionality such as the use of better computerized support systems, and even work procedures.

The approximation of the policy makers from government levels with the referral prioritization configuration and practices enable the creation of new learning loops, where the issues identified can be discussed and policies reframed. External-learning loops employing feedback mechanisms from the policy-makers back into the sharp-end led to the development of new practices, devices, and even projects to improve the resilient potential of the referral prioritization system.

4.2.17 Conclusions

The Brazilian Constitution states that the entire population should have free access to health care throughout all levels. However, due to the extensive population and lack of resources available for delivering health care services, Brazilian Primary Health Care is not able to fulfill adequate care for all. Therefore, referral prioritization has become strategic for the success of public health care in the country.

In the current study, we studied the sharp-end of referral prioritization for specialized ambulatory care, decentralized to operate from within primary care, to understand how work is done by gatekeepers and correspondent primary care teams. The use of grounded methods in data collection and concept maps coupled with control structure modelling enabled us to understand how the decentralization was designed and also how it allowed WAD in individual clinics to cope with the challenges posed by that new organizational design. On the other hand, using the FRAM to analyze resilient performance allowed for building insight on exactly how different resilience abilities are manifested through adjustment maneuvers that establish couplings among themselves to counter notable shortcomings in system design. Thus, we believe this approach led to an increased comprehension of the elements that affect resilient performance in this healthcare system.

A limitation of this study is the fact that it has been done only in Rio de Janeiro, and so this brings a need to study referral prioritization in other cities to identify possible similarities, compare centralized × decentralized systems functioning, and the potential generalization of the results. Therefore, the investment necessary to carry out further studies in other large cities is very important.

Another set of limitations was the difficulty in accessing physicians that represent the primary care facilities in the city's different programmatic areas, in making direct observations of the physicians' work activities, and in disposing of great time/resources to produce transcriptions. The decision for snowball sample was chosento cope in the best way possible with the access limitation, while the interviews' analysis through concept maps attend to the other limitations. Results from the current study highlight the importance of the decentralization of referral prioritization in redesigning the working system to include much higher proximity between family doctors, gatekeepers, and residency supervisors. Specifically, findings demonstrated that increased proximity enabled the emergence of resilient strategies and collaboration to counter demand-capacity misalignments and their respective potential system failures, originated both before and after that change, improving overall system performance.

4.3 Article C: Information Technology Systems at the sharp end of medication therapy management

4.3.1 Foreword

In this paper we address how shortcomings from information technology supporting medication therapy management create challenges for pharmacists while assessing prescriptions and dispensing drugs, eventually contributing to escalating trade-offs between precision and timing into a sacrifice dilemma where pharmacists cannot choose thoroughness over efficiency.

This chapter resulted in one scientific article, with the following citation information:

Li, R. C., Arcuri, R. M. P., Jatobá, A., Vidal, M. C. R., de Carvalho, P. V. R., Grindrod, K., & Burns, C. (2019). Information Technology Systems at the sharp end of medication therapy management. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *63*(1), 698–702. https://doi.org/10.1177/1071181319631502

4.3.2 Introduction

E-health services can reduce waiting times and support the communication efforts of prescribers, such as family physicians and nurse practitioners, with pharmacists (THARMALINGAM; HAGENS; ZELMER, 2016). In Canada, prescribers' work is supported to some degree by information technology, mainly through office-based electronic medical records and regional electronic health records (EHR). These health records contain hospital data (e.g., discharge summaries), laboratory data, diagnostic imaging, and sometimes dispensing information (CHIN et al., 2018). Pharmacists use a pharmacy management system, and some may have access to the information in the EHR to support medication reviews, and the identification of adverse drug interactions.

However, there is little opportunity for direct information exchange between the systems, requiring in many cases manual data entry from one system to another. For Ontario pharmacists, access to clinical data and medical information variate by the type of practice (e.g., community, health team and hospital pharmacies) (CHIN et al., 2018; KERESTECIOGLU; BURNS; GRINDROD, 2016). The communication gap has a more significant impact on the medication management at community pharmacies, where 71% of the licensed pharmacists in the province work (NATIONAL ASSOCIATION OF PHARMACY REGULATORY AUTHORITIES [NAPRA], 2019).

When community pharmacists assess the appropriateness of the medication before dispensing, they either need to ask the patient or contact the prescriber to ask to clarify the reason for use or rationale for the prescription (LI et al., 2019a). This communication frequently occurs in an asynchronous way, and takes place through fax machines, phones, receptionists of physician offices, or patients, taking a vast amount of time and effort within the healthcare team, and also delaying the patients' treatment (CHIN et al., 2018; KERESTECIOGLU; BURNS; GRINDROD, 2016; LI et al., 2019a; MERCER et al., 2018). Physicians might also face similar challenges when a medication is prescribed by another physician, such as a specialist. In these cases, they must review the old consult notes or contact the specialist's office to identify the historical reason for the medication, given that their office-based health records are not linked and the regional EHR does not include this information in the prescription databases (KERESTECIOGLU; BURNS; GRINDROD, 2016).

Previously, medication management has been studied using the Team Cognitive Work Analysis (Team CWA) framework to identify shared goals, task distributions, and information exchange to better understand the constraints of the system (CHIN et al., 2018; GRINDROD; TRAN; BURNS, 2015; KERESTECIOGLU, 2017). Like CWA, resilience engineering is another approach that originated from a cognitive systems engineering perspective and has recently seen numerous applications in health care (PATRIARCA et al., 2018). Further, resilience engineering applications to medication management systems are starting to emerge (FYLAN et al., 2019; PHIPPS; ASHCROFT;

PARKER, 2017). Resilience engineering can complement CWA by adding an understanding of system brittleness and showing how particular functional changes may be causing behavioral adaptations. In this way, we see the joint use of resilience engineering and CWA as an effective and thorough way to explore the domain of medication management.

4.3.3 Method

This research design focused on uncovering the impact information technology has on the medication management main processes in three locations of southwestern Ontario: Toronto, Mississauga, and Kitchener-Waterloo. These communities are at similar stages of EHR implementation, and thus convey the same settings for communication possibilities between the electronic systems studied.

Particularly, this was done by looking at functional variability and discussing ways to redesign EHRs, physician medical records, and pharmacy management systems that would lead to positive outcomes, while discouraging dangerous outcomes. The work discussed here is limited to dispensing activity and pharmacy management systems.

The data collection included three stages. First, a document analysis reviewed the scientific and technical literature in the field, and the regional and national reports issued by the government and policymakers. Second, a semi-structured interview was held with a pharmacist expert to define key aspects of medication management across health service systems in Canada and southwestern Ontario and to map the main processes. Third, semi-structured interviews of pharmacists, prescribers, and patients were coded to identify the everyday medication management practices, the use of information technology, and the role of specific information, like the reason for use in medication management (LI et al., 2019a). The prescription's reason for use was previously identified in CWA models as relevant information that was often missing from the health record (MERCER et al., 2018).

These data were used to build a FRAM model (HOLLNAGEL, 2012) of medication management. Potential variability regarding timing and precision was disclosed, according to the FRAM´s so-called Simple Solution for characterizing variability, and the socio-technical system's behavior analyzed based on the model. Then, the influence of information technology on medication management was examined.

4.3.4 Results

The process narrative, somewhat simplified, is presented in Table 4-11, along with the major functions. All functions and couplings are displayed in the FRAM model of Figure 4-26. The role of the information technology systems is highlighted using a color code within the FRAM model.

Table 4-11 - Major stages in medication management and related functions as modeled through FRAM

Stage	Description	Major system functions associated (performed by various agents)
1	During medical consultation, the prescriber gathers information from the patient identifying a diagnosis or confirming a previous one.	Gather information from the patient (including physical assessment); Gather information from medical record; Gather information from EHR; Update patient data in the medical record; Identify diagnosis
2	The prescriber issue a prescription based on the diagnosis, enters it in the medical record, and might schedule a follow-up consultation later. Prescribers lead these steps with the clinical pharmacist's guidance if there is a clinical pharmacist in the office.	Gather information from the medical record; Gather information from EHR; Guide physician/nurse practitioner in prescribing; Prescribe medication; Register prescription in the medical record; Support prescriber in scheduling follow-up
3	The prescription is forwarded via fax to the dispensing pharmacist or handed to the patient while at the appointment. The prescription is received by the dispensing pharmacist, registered and stored until the patient arrives, or delivered by the patient to the dispensing pharmacist.	Fax the prescription to dispensing pharmacist; Receive a faxed prescription from prescriber; Register prescription in the pharmacy management system; Store prescription
4	After the patient arrives at the pharmacy (due to a new prescription or a refill), the dispensing pharmacist gathers information, checks medication appropriateness, and might decide to contact the prescriber for any clarification needed.	Gather information from the patient; Gather information from pharmacy management system; Gather information from EHR; Assess prescription's appropriateness for the patient; Call the prescriber to clarify doubt; Receive clarification from the prescriber
5	The availability of the medication is checked. The prescription is filled, and medication is dispensed. The dispensing pharmacist might decide to contact the prescriber to ask for additional refills later.	Gather information from the pharmacy management system; Dispense medication; Request additional refills from the physician's office
6	Dispensing pharmacist counsels the patient about the dispensed medication, including how to take it and any relevant side effects, and a follow-up call might be scheduled. The patient is dismissed.	Schedule follow-up phone call; Counsel patient

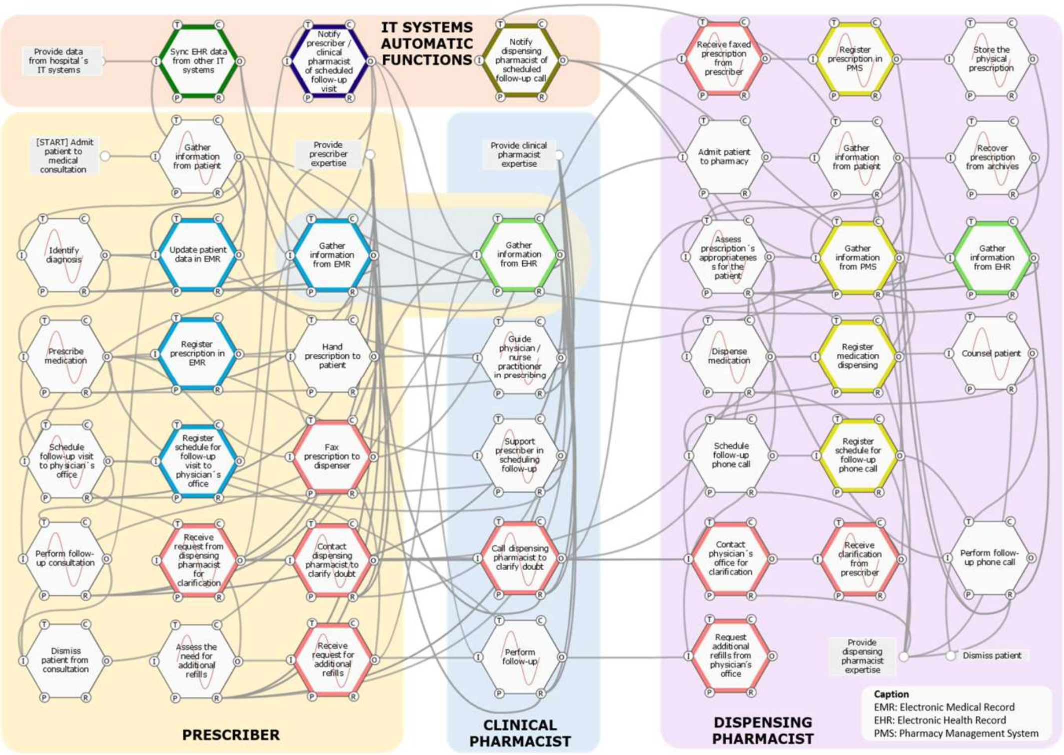


Figure 4-26 - FRAM model of medication management as performed by community pharmacists in southwestern Ontario.

The graph shows how functions' outputs (O) are used by other downstream functions (i.e., ones that take place next and depend on previously executed) as either their input (I) (i.e., trigger), precondition (P), resource (R), time (T) or control (C) elements, creating couplings which allows variability propagation between them. The

background functions are represented as rectangles and those exhibiting performance variability using a red sine wave icon. The colored hexagons depict functions supported by technology, representing the technologies used to exchange information: blue corresponds to EMR, green to EHR, yellow to PMS, and red to phone or fax. The color accent identifies actions undertaken by people (lighter) from those triggered by the automatic technology functions (darker).

4.3.5 Discussion

The FRAM model, in Figure 4-26, shows how the functions of medication management employ the information technology systems. Data outputted from the medical record, pharmacy management system, and EHR is either triggered by the request of a user or by automatic notifications. Also, this data is responsible for framing patients' health conditions, supporting decision making, and triggers follow-up contacts. Most of the functions performed by the information technology do not display variability themselves; however, the system limitations require a variety of downstream adjustments, which can occasionally contribute to dangerous variability couplings, either directly or indirectly. Table 4-12 highlights these potential variabilities in terms of timing and precision for the dispensing pharmacist, as illustrated in the FRAM model.

Table 4-12 - Potential variability identified for the dispensing pharmacist role in community pharmacies of southwestern Ontario

No	Function	Variability regarding timing		Variability regarding precision	
		Range	Description	Range	Description
1	Receive a faxed prescription from the prescriber	Omission	Prescriptions faxed may be lost altogether, especially during workload peaks in the pharmacy, as the function gets postponed.	Precise	The precision outcome of this function is binary, i.e., given that the prescription is received, precision does not vary.
2	Register prescription in the PMS	Omission	Failure to receive the prescription will be reflected in its registration as well.	Acceptable	Due to the hard-to-read prescriber's handwriting, the data entered in the pharmacy management system could differ from what is recorded in the prescriber's medical record.
3	Store the physical prescription	Omission	Failure to receive the prescription will be reflected in its storage as well.	Acceptable	Physical disposition of the pharmacy's archives could lead to flaws in stored data arrangement, especially if coupled with the high workload from the dispensing pharmacist, thus hampering storage.
4	Recover prescription from archives	Too late / Omission	Prescriptions stored may take too long to be found or lost altogether, due to the upstream-downstream coupling of resources.	Precise	The precision outcome of this function is binary.
5	Gather information from the patient	On time	This function consumes relatively little time in the general process; thus, the output is considered stable regarding time.	Imprecise	Patients often omit information on the reason for use, past dispensing, or health conditions due to confusion, forgetfulness, or concerns about privacy.
6	Assess prescription's appropriateness for the patient	Too late	The function starting time can be impacted by delays in recovering prescriptions from archives and receiving clarification from prescribers. Since checking medication appropriateness is paramount in terms of safety and quality of care, the output may be delayed.	Imprecise	Couplings for resources and time can propagate faulty outputs from various upstream functions. The need for making educated guesses arises from the limited information available in the EHR, imprecise outputs from functions 2, 5 and 7, and output omission from function 7. Further, this is amplified by time pressure due to late outputs from functions 4 and 7, and imprecise outputs from function 7, shortening the time window for the assessment.
7	Receive clarification from the prescriber	Too late / Omission	Using fax creates lateness to receive a reply (even reaching days or failing altogether) and dispensing pharmacist confusion about whether the prescriber received the request for clarification.	Acceptable	Once the prescriber's reply has successfully received the answer sent is usually clear enough to support the final assessment of the prescription.
8	Dispense medication	On time	Typically occurring under time-pressure, i.e., while the patient is at the pharmacy or on the phone, this function is prone to trade-off mechanisms favoring time over precision.	Imprecise	Late, omitted, and imprecise outputs from upstream functions can drive the dispensing pharmacist to intensify natural trade-offs, especially when there is a need to select an alternative medication.
9	Counsel patient	On time	Typically occurring under time-pressure, i.e., while the patient is waiting at the pharmacy or phone, this function is prone to trade-off mechanisms favoring time over precision.	Imprecise	The short time window left to perform counseling, caused by the lateness of upstream functions, can render the counseling imprecise. Also, an imprecise output from function 6 will reflect in this function's output.

In medication management, dispensing pharmacists need to engage in adaptations during task execution (previously designed in the blunt end) to fill gaps in technology systems and achieve the expected results. For example, the dispensing-related functions are only triggered by the arrival of the patient; imposing a time pressure on downstream functions, which can lead to upstream-downstream variability couplings among those functions. That is, the dispensing pharmacist needs to do everything they can to ensure the patient spends the shortest possible time at the pharmacy and leaves with an appropriate, effective, safe, and acceptable medication regimen.

In this context, it is crucial for a pharmacist to assess the quality and safety of the prescribed medication adequately. Although Figure 4-26 shows that this assessment needs various types of data, the interviewed dispensing pharmacists reported that they were often missing data and required to ask patients or make educated guesses to complete the task (LI et al., 2019a; MERCER et al., 2018). Dispensing pharmacists are often missing the reason for use or past dispensing that has taken place in other pharmacies, as displayed in Table 4-12, function 6. Such pieces of information are not available in the information systems nor the prescriptions, and when patients are asked for this information, they might omit it due to confusion, forgetfulness, or concerns about privacy. This scenario can lead to an imprecise output, which can put patients at risk.

As previously stated in the introduction, direct communication between prescribers and dispensing pharmacists is not supported. The variability of one communication function, e.g., “receive faxed prescription from prescriber” is described in Table 4-12, function 1. This function requires the prescription to be stored, which in turn might create a possible delay in finding it when the patient arrives (upstream-downstream coupling for resources), as shown in Table 4-12, function 4. Other dispensing pharmacist functions without technology support are asking prescribers for clarification or requesting refills from the prescriber’s office. In this case, the reliance on fax threatens the receipt of timely information. In the worst-case scenario, it can lead to the failed attempt to contact prescribers leaving the patient without access to their medication, as previously disclosed by Keresteciogl u (KERESTECIOGLU; BURNS; GRINDROD, 2016) and described in Table 4-12, function 7, putting on hold downstream functions.

Beyond the communication functions, the dispensing action itself (see function 8 in Table 4-12) comprises cognitive processes which are, at first glance, less critical than the pharmacist’s check of the prescription’s appropriateness. However, at this step, dispensing pharmacists can actively engage in medication management by using their full scope of practice to alter prescriptions to suit the needs of the patient.

To do this, the dispensing pharmacist uses their expertise, all the information they can gather from the patient, their assessment of the prescription's appropriateness for a patient, and current information of medication stock at the pharmacy. Table 4-12 portrays how output variability in terms of timing and precision spreads from upstream functions to shape the act of dispensing (function 8). On the flip side, the dispensing function becomes important to dampen those potentially dangerous courses of action, which are triggered by weaknesses in technology support such as scarce information on medical history from the regional EHR and inaccurate information on past prescriptions from the pharmacy management system.

From those couplings leading to function 8, the one that triggers it – coming from function 6 – is a critical one. The analysis of function 6 showed that, besides outputting the prescription appropriateness' assessment itself, this function creates a mental model of restrictions regarding the patient's clinical condition and overall profile. The model is particularly relevant if, while performing function 8, the dispensing pharmacist identifies the need to select an alternative medication to suit the same restrictions. They must cope then with factors leading to this need by engaging in a dampening mechanism (within function 8) to attenuate such disturbances.

As already noticed in other FRAM models, when a function faces an exogenous or endogenous disturbance, dampening mechanisms are triggered to avoid its transmission and amplification to the next functions (i.e., the immediate downstream functions). These mechanisms are thus function-specific manifestations of performance variability, aiming at stabilizing its output in the face of disturbance. For function 8, both an exogenous and endogenous disturbance are potentially present. The exogenous one occurs when the prescribed medication does not suit the restrictions regarding the patient's clinical condition and overall profile (disclosed at function 6). The endogenous disturbance occurs when the prescribed medication is found to be appropriate (function 6) but is not available at the pharmacy. The mechanism to tackle both is the same, consisting of looking for an optimal (or at least suitable) alternative medication available at the pharmacy.

At the same time, given that it is vital to ensure that patients leave the pharmacy with the medication, the dispensing pharmacist - while accomplishing function 8 - must cope with the sporadic output variability related to upstream functions (see Table 4-12, function 8). Consequently, the combination of output variability regarding lateness, the omission of information, and imprecision from those functions will make it increasingly difficult for them to engage in the described dampening mechanism.

In fact, the dispensing pharmacist might need to escalate trade-offs between timing and precision, which are present in everyday practice, into a sacrifice dilemma, similarly to what has been previously reported in healthcare literature (PERRY; WEARS; ANDERSON, 2006) and in other safety-critical domains (GOMES et al., 2009; WOODS, 2005). In contrast to those reports, though, here it is not possible to opt for thoroughness over efficiency since the patient must leave the pharmacy with a medication.

This setting entails that the output of function 8 will be rendered significantly more imprecise to make room for its on-time delivery, meaning a less-than-optimal alternative medication dispensed. This mechanism may help to explain why adding the reason for use to prescriptions has been found helpful for pharmacists to make more accurate decisions and better interventions (WARHOLAK et al., 2014); however, critical challenges to its implementation remain (KRON et al., 2018).

In agreement with the resilience engineering approach, the conceptual design of solutions should stem from strengthening dampening mechanisms. For function 8, it means freeing time pressure on the dispensing pharmacist to enable a more informed and in-depth decision about the best alternative medication. Solutions aiming at the short term should consider two major limitations still in place: (1) the medical records and the pharmacy management system cannot exchange information directly, and (2) only certain health information can be shared through the EHRs.

Recently, a limited number of places in southwestern Ontario have been piloting an information technology system called PrescribeIT, allowing direct communication between electronic medical records and pharmacy management systems, including sharing prescriptions. In short to medium-term, this could become a solution to dampen dangerous variability that originates from the use of phone and fax.

Long-term solutions must allow dispensing pharmacists to access relevant information shared in the regional EHR directly through their system – freeing time and cognitiv resources otherwise invested in logging in and navigating systems' workflow logic. However, any such implementations may bring challenges of human, organizational, and technical nature.

Using a functional variability approach may shed light on ways to support medication management. Future research efforts for this domain could benefit from a retrospective analysis of medication management, through further fieldwork that enables the investigation of instantiations of work-as-done. As of now, it seems clear that the FRAM model can inform – at least up to a certain point - new technology features to support necessary performance adjustments and dampen potential paths leading to functional resonance.

4.4 Article D: Understanding and improving safety in artisanal fishing: A safety-II approach in raft fishing

4.4.1 Foreword

In this paper we address how fishermen build their everyday safety by continuously adjusting their work performance while carrying out artisanal coastal fishing using rudimentary rafts and scarce resources.

This chapter resulted in one scientific article, with the following citation information:

Saldanha, M. C. W., de Carvalho, R. J. M., Arcuri, R., Amorim, A. G., Vidal, M. C. R., & Carvalho, P. V. R. de. (2020). Understanding and improving safety in artisanal fishing: A safety-II approach in raft fishing. *Safety Science*, *122*, 104522. https://doi.org/10.1016/j.ssci.2019.104522

4.4.2 Introduction

The artisanal fishing system studied in this paper – raft fishing in Brazilian Northeast coastline – has no formal safety system (no external safety-inspections, instructions, or any other formal safety instructions) as in the traditional industry sectors. This is an activity primarily based on personal knowledge (on fishing, raft navigation, and safety), consisting of a replicable, orally transmitted set of specialized skills, and culturally shared practices and beliefs that have stood the test of time (DIEGUES, 2002). Therefore, the levels and kinds of risks to health and safety depend on the environmental, social, economic, and cultural context. Interactions among these factors can contribute to increasing or diminishing risk perception (e.g. leading fishermen to abort fishing due to weather or sea conditions), which in such a loosely-controlled work space is very important for workers' safety. Under such characteristics, the Safety-II perspective appears to be the more adequate way to analyze and improve safety.

Morel, Amalberti e Chauvin (2008) investigating decision-making of professional sea-fishing skippers concluded that traditional safety measures improve safety is done in "detriment of self-managed safety" (MOREL; AMALBERTI; CHAUVIN, 2008, p. 14). They also envisioned the need of new safety methods that cope with "the two types of safety, constrained on one hand, and self-managed on the other" (MOREL; AMALBERTI; CHAUVIN, 2008, p. 14). Nowadays, it is becoming clear that the Safety-II (HOLLNAGEL, 2014; SUJAN; HUANG; BRAITHWAITE, 2017) framework has the concepts and methods under such a holistic vision of safety could be created. Safety-II can be viewed as system and/or people abilities that keep the system functioning under varying conditions, in order to have the higher possible number of intended and acceptable outcomes (HOLLNAGEL, 2014). From a Safety-II perspective, the purpose of the safety management in artisanal fishing systems, like the one described in this research, is to facilitate as much as possible the ways in which things can go right, in the sense that fishermen have safe fish capture expeditions.

Therefore Safety-II issues on raft fishing are related to the navigation abilities with very small boats (the rafts) in the ever-changing maritime environment. Fishermen navigate along the coast (3–10 km) in expeditions of around 8 h with sail and/or small motor propulsion, and there is a risk to be adrift (when propulsion fails), to turn the raft, and occupational injuries due heavy load and physical demands of the activity. Safety in this situation involves complex processes, especially in decisions to abort or continue navigation due to weather, sea, or raft conditions. The major part of understanding whether safe conditions still exist relies upon the sensemaking (KLEIN et al., 2007; KLEIN; MOON; HOFFMAN, 2006), or common sense (THORVALDSEN, 2013) of fishermen. In this work environment, the Safety-II perspective providing conditions for fishermen to succeed under expected and unexpected conditions, according to their actual work conditions, appears to be the most adequate way to improve safety in artisanal fishing settings.

The main research question that drove this study was:

How a Safety-II perspective can improve the understanding of safety in artisanal fishing, enabling the development of useful, practical and applied safety measures?

Other research questions needed to answer the first one are:

- What is the current context, practices, and functions involved in the safety of fishing expeditions?
- What are the existing sensemaking behaviors that inform decision-making during fishing expeditions?
- How can workers' safety actually be improved considering the environment in which artisanal fishing is situated?

4.4.3 Background and literature review

4.4.4 Artisanal fishing with rafts at Ponta Negra beach

Brazil fishes at sea about 580 thousand tons per year (CASTELLO, 2010). The fishing communities represent a population of approximately 800,000 artisanal fishermen, involving 2 million people who produce about 55% of the national fishery production (CALLOU, 2010). In 2007, 28.8% of the national fish production occurred in the Northeast coast (Figure 4-27) and artisanal fishing was responsible for 96.3% of this production (CASTELLO, 2010). An important part of artisanal fishermen uses the "jangada" (raft), a secular sail-vessel with dimensions ranging from 3 up to 8 m that is suitable for the type of sea, wind and sandy coast found in the area (DIEGUES, 2002).

Figure 4-27 – Map of Brazilian Northeast region

This study was done in the Ponta Negra beach located in the Rio Grande do Norte (RN) State. Rio Grande do Norte, in its 410 km of coastline, has 25 coastal municipalities, 97 fishing communities and about 13,000 fishermen who carry out the activity for subsistence and commercial purposes. Of the RN registered fishing fleet, 28.5% (1071) are rafts, which in 2007 have caught 2175t of fish (IBAMA, 2007). Of the 381 vessels registered in the Colonia Z-04 Fisheries and Aquaculture of Natal, where Ponta Negra is located, 22.8% (87) are rafts.

The Ponta Negra fishing community was chosen for this study because it is one of the main raft fishing communities of Natal, capital of Rio Grande do Norte State, the city where is located the university and the research group who developed this research. This community lies and has its fishing based at the most famous tourist beach of the state, the Praia de Ponta Negra. Artisanal fishing still represents an important participation in the production and commercialization of the fish in Natal city, whose main consumers are the restaurants and hotels of the city. It is a traditional community, similar to many others existing in Brazilian Northeast coast, where raft fishing occurs. Ponta Negra was initially populated by artisanal fishers, very small farmers, and currently by artisanal fishermen, workers, street vendors, and public employees. Another important issue for the choice of Ponta Negra concerns the demands on the safety and health of fishermen that appeared after a screening on Natal poor communities (SALDANHA et al., 2012). Figure 4-28 shows the raft used for fishing at Ponta Negra measuring from 3.6 to 5.14 m in length and 1.4 to 1.7 m in width, weighing around 642 kg, accommodating 2 crewmembers: the captain or master and a helper or bowmen that carries out different functions.

Figure 4-28 – The raft used for fishing at Ponta Negra

Rafts were originally designed to be propelled by sail, but the use of a small fuel engine for propulsion began in 2005. Currently, rafts design was adapted to use engine propulsion (ways to attach the engine to the Captain seat and a shaft added to the propeller) and most of the fishermen prefer to use the engine. It reduces the dependence of wind conditions and navigation time, thus reducing working time and improving the quality of the fish caught. The use of the engine decreases physical workload (required for sail navigation) and reduces the shipwreck events. When the engine is used, the master (captain) drives the vessel almost by himself, reducing the need for help from the bowman. However, with the engine, the costs of the shipment were increased. Fuel consumption varies from 4 to 6 L per shipment.

The fishing expeditions occur from Tuesdays to Saturdays. The weather and sea conditions during the summer (December-March) are more favorable than during the winter season (June-September) – characterized by intensive period of rains – resulting in more productivity on summer season. A 2010 study on fishing production with 11 rafts in January and 12 rafts in June showed that in January the 11 rafts completed 81 expeditions capturing 2854.5 kg of catch, averaging 35.24 kg per expedition. In June, the 12 rafts completed 106 expeditions, capturing 1211 kg of catch, averaging 11.42 kg per expedition (CELESTINO et al., 2012).

Figure 4-29 shows the steps of the fishing expeditions. The raftsmen depart to the sea either in the small hours (2:00 a.m.), returning in the morning (between 8:00 a.m. and 9:00 a.m.), or in the afternoon (2:00 p.m.), returning after dusk (between 8:00 and 9:00 p.m.). The duration of the expedition varies from 3.5 to 9 h, depending on propulsion type (motor or sail), meteorological conditions (wind speed and direction), sea conditions (mainly tides), location of fishing grounds, number of nets placed into the sea (17–30 nets of 100 m can be placed, covering 1700–3000 m of the sea), catch effectiveness (quantity of fish caught by placed nets), and even the presence of algae stuck to the nets.

Figure 4-29 - The fishing expedition steps: after the decision to go fishing, they walk to the beach, organize raft, move the raft into the sea, and begin the navigation to the fisheries. After fishing they return home in similar steps

Source: Jaeschke and Saldanha (2012)

There is a strong physical component in the fishing activity due the heavy loads carried on, the ways to put the raft into/out the sea, the movements done during the launch and removal of nets, and the raft navigation itself (including the efforts to turn the raft over if needed). The raft fishing in Ponta Negra is made only by men. In the Brazilian fishers' communities, in general, the women either take care of the home-work and their families, fish shellfishes or oysters, work making handcrafts, work in agriculture, work for other families, or work in restaurants, bars and hotels.

The learning is done on the job. The apprentices follow the masters in the expeditions and begin to carry out the procedures, practices, and strategies, becoming initially bowman (helper) and then becoming a master or captain: "*It is a difficult activity to learn … but with enough fishing time, the person learns and he only learns by going* *there*" (Fisherman) (JAESCHKE; SALDANHA, 2012). To be considered as a master or captain, a fisherman must master the navigation techniques that comprise: knowledge about the weather (rain, winds) and sea conditions (waves, tides, moons and winds), navigation and safety (management of the raft) involving the use of the rudder, placement of sails, engine, triangulation and location of fishing spots, and fishing techniques (laying, withdrawal and storage of fishing nets, identification and storage of fish), raft maintenance skills etc.): "*For everything you have to have a wisdom, it is not only to know how the wind goes, the places to go, the ways ... you have to know everything at the same time to be a good master*" (Fisherman) (JAESCHKE; SALDANHA, 2012).

There are no formal records on accidents/incidents on artisanal fishing with rafts at Ponta Negra Beach. The data briefly described here is gathered from Saldanha et al. (2017) and compiled based on reports from the raftsmen. Most of raftsmen reported work-related accidents when the raft is at sea, and 2 fatalities were remembered. All of them reported that they have already had their raft turned in at least one capture expedition.

Being adrift was also reported as a major problem, mainly because the communication and response actions in this situation are very precarious. The Port Authority and the Fire Department start search only after 24 h of the first communication, which makes it more difficult to locate the vessel or people adrift. In many cases, fishers themselves have taken the initiative to look, on their own, for vessels or colleagues who have not returned, with success.

Fishermen recognize that they do not always follow Maritime Authority Standards for vessels used for inland navigation, a category in which the rafts are inserted. Under this category, vessels are only allowed to sail up to around 5 miles from the coast. However, rafts go beyond this limit in search of more distant fisheries, because fish are scarcer in the areas near the coast. Fishermen report that they do not wear the life jackets during expeditions. The vests are used only after the raft turns, while the raftsmen were adrift. They explain the non-use of jackets due to the difficulty of movements with the vest. For this reason, they keep the lifejackets on the raft tied by a rope or stored in the internal compartment of the vessel. This last option makes the access to vests even more difficult when the raft turns.

4.4.5 Safety-I and Safety-II in artisanal fishing

Available worldwide statistics indicated that fishing is a very dangerous activity (CASEY; KRAUSS; TURNER, 2018). Fishers are susceptible to work accidents, injuries, and death (LUO; SHIN, 2019). Death and injury among workers in the fishing industry all over the world occur at much higher rates than national averages: about 24,000 deaths occur every year in fishing, and an estimated 24 million non-fatal accidents every year (FAO, 2001; JENSEN; STAGE; NOER, 2006; ZYTOON, 2012). Roberts (2010) indicated that Britain's most hazardous occupation is commercial fishing that had from 1996 to 2005 higher work accident rates than all other UK industries.

Some studies have been conducted to assess and improve safety on artisanal fishing. Piniella and Fernández-Engo (2009) developed a preventive checklist to be applied before the fishing expeditions. Perez-Labajos (2008) recognized the dangerous aspect of fishing proposing a legal framework of reference for organizations policies and measures to improve safety in the fishing sector.

These articles are according to the Safety-I approach, in which safety management requires an organized effort to obtain safety requirements, to design a safety management structure and processes aiming at the definition of tasks, rules, and prescriptions to fit the pre-defined safety requirements (LI; GULDENMUND, 2018). Almklov, Rosness e Størkersen (2014) argue that safety management systems, based on generic safety management principles under the compliance perspective (Safety-I), do not take into account – and even marginalize – the situated safety knowledge developed by the workers during their activities.

Such characteristics of Safety-I indicate that this approach should not be used to improve safety in work environments where workers at the sharp end have established safety practices that pervade work activities themselves, which could be argued to comprise roughly all existing work environments. Particularly, Safety-I approach can be misleading where there is no formal safety management, no detailed description of the work process, and where the work activities occur under highly variable and dangerous conditions, such as the case of artisanal fishing with rafts.

The complexity and the ever-changing characteristics of maritime environment, the need of constant interactions, their potential to produce resilient performance, and their influence on the safety of workers indicate the need for a holistic, socio-technical approach based on system and resilience engineering to understand the health and safety issues of workers involved in fishing (UTNE, 2006), according to the Safety-II perspective.

In accordance to these ideas, recent studies have pointed out new approaches more related to Resilience Engineering and the Safety-II perspectives. For instance, an investigation of how Norwegian coastal fishermen deal with occupational risks led by Thorvaldsen (2013) indicated that, in spite of the development and enforcing the use of safety regulations in the European Union, there is a lack of compliance to regulations. She concluded that professional fishermen deal with risk as a balancing act, carrying out continuous assessments and decisions related to sea and weather conditions, fish, profits and safety (THORVALDSEN, 2013).

Davis (2012) showed that among Maine (US) commercial fishing vessel captains there is a trend to undervalue occupational risk. Her study also disclosed that the ones more likely to downgrade fishing risk are those who are middle-aged, less educated, those who come from a fishing family, and those whose vessels were found to be non-compliant with formal safety regulations. The characteristics of most Brazilian raft fishermen match almost entirely the Davis' profile of fishermen that undervalued their occupational risk. And for those who undervalue risk, to follow formal safety regulations elaborated far from their everyday work does not make sense.

In their study in Nordic countries, Thorvaldsen et al. (2018, p. 101) found that "fishers do appear to appreciate measures that are practical and obvious in their everyday work" and they recommend involving fishers in the development and implementation of safety measures. This is because safety measures are only effective if they are implemented, and that depends on how workers perceive such measures (THORVALDSEN et al., 2018).

While studying commercial fishermen in North Carolina (US) who work in non-industrialized settings and do not have access to industry formal safety regulations, McDonald and Kucera (2007) related that their safety is based on work practices and attitudes. The study also identified specific safety measures such as "appropriate gear and boat maintenance, weather decisions, and working cooperatively when ocean fishing" (MCDONALD; KUCERA, 2007, p. 289).

Størkersen (2018), in her study on how the International Safety Management Code affects Norwegian coastal transport, concluded that “full potential for safety management with practical procedures” (STØRKERSEN, 2018, p. 7) are not fully exploited due to audit requirements, and that “companies, and operational personnel would benefit from safety measures less concerned with auditability and more focused on safety itself” (STØRKERSEN, 2018, p. 7).

4.4.6 Methods

The research described in this paper followed the Action Research iterative process (ARGYRIS, 1993), from fact-finding to understanding the problems, action/solution planning, solution implementation, evaluation and reflection. After workplace studies based on observations, interviews, conversational actions (DE CARVALHO et al., 2016) to collect data on raftsmen work activities, the Functional Resonance Analysis Method – FRAM (HOLLNAGEL, 2012) was used to analyze the safety of fishing expeditions. The Functional Resonance Analysis Method (FRAM) models socio-technical systems based on the analysis of the systems functions and their couplings. FRAM follows the concepts and precepts of Resilience Engineering (HOLLNAGEL; WOODS; LEVESON, 2006) and had been used in different domains ranging from healthcare (JATOBÁ et al., 2018), up to highly regulated safe-critical systems like energy & oil (CABRERA AGUILERA et al., 2016), aviation (CARVALHO, 2011), and maritime operations (PATRIARCA; BERGSTRÖM, 2017).

FRAM was selected when the research group realized that safety in artisanal fishing with rafts would not be improved only by understanding the hazards, risks and providing recommendations through new rules, procedures and safety prescriptions, and decided to follow a Safety-II perspective. In fishing expeditions, safety is constructed and balanced according to the experience, expertise, cultural values, and personal needs of workers in a changing environment, which renders safety prescriptions or procedures very difficult to elaborate and even more difficult to follow. Under this environment, the use of FRAM enabling the understanding and reflection on safety-related function variabilities, seems adequate to fulfill the aims of a Safety-II based analysis. Along the research this comprehension was proven to be needed to produce safety-related interventions that make sense under disclosed raft fishing work situations.

The main steps of FRAM as used in this study were (HOLLNAGEL, 2012):

- Setting the goal – fishermen safety – for modeling and describing the situations to be analyzed;
- Identifying the main functions of fishing expeditions, and characterizing them, according to input, output, preconditions, resources, time, and control, using the FRAM Model Visualizer;
- Characterizing the variability of functions, with the participation of fishermen;
- Aggregate functions searching for safety-critical paths, based on potential/actual couplings among functions.

The data to create the functional resonance models came from Ponta Negra community, where fishing activity using rafts was undertaken by a group of 42 fishermen, from which 22 agreed to participate in this research. 38% were fishermen between 41 and 50 years old; 29% of the population is from 31 to 40, and 24% is from 51 to 60 years old. The youngest group (21 to 30 years old) represents 7% of the raftsmen.

The group involved in data collection and analysis are formed by professors of two Brazilian federal universities with long experience in ergonomics and safety, along with graduate students. Research was conducted in a two-way interaction process where: (a) researchers understanding how safety is created or jeopardized; and (b) extensive discussion with workers on alternative ideas to improve safety. Researchers were instructed to document as much as possible the interactions through field notes, hot reports, audio/video records, and photos.

The method can be divided into several phases with different objectives which are highly interconnected. Due to the situated or grounded approach of the research and its evolution over time, research activities were not carried out in subsequent linear steps. Rather, many of the research activities had overlapping focus, so that parts of each phase also influence findings in other phases in a bootstrap way (DE CARVALHO et al., 2016). The main research phases were:

- **Social construction**. This phase enabled the involvement of the research team with the Ponta Negra beach community, as shown in Figure 4-30.

- **Investigation of existing formal documentation**. Although there are no detailed work prescriptions for fishing with rafts due, there are some rules issued by Brazilian port authorities (NORMAN-02/DPC, 2005).
- **Data collection on work activities in fish capture expeditions**. Data collection procedures included direct observation of the preparation and launch phases of fishing expeditions, as well as conversational actions with fishermen on topics like navigation, fishing and safety. Additional sources of data included: think aloud verbalizations during simulations of fishing activities with the raft on land; films of the fishing expeditions made by the researchers near the coast; and films made by the fishermen themselves in their own raft far from the coast during fishing expeditions.
- **Data compilation, participatory confrontation, and analysis**. Data from observation, conversational actions, simulations and films were confronted alongside fishermen to investigate variability within expedition phases, as detailed in Section 4.4.6.
- **Modelling of fishing expeditions using the Functional Resonance Analysis Method (FRAM)**. Based on the prior steps, system functions and their potential variability were represented in FRAM diagrams.
- **Validation with fishermen and recommendations**. Focal groups were established within the local fishing community discussing and validating the results, paving the way for the kick-off of a program of safety workshops and the development of projects aiming at improving safety and production goals through a systemic perspective.
- **Safety Workshops and Ongoing Projects**. A program of workshops to discuss safety issues was established along the development of specific projects to address the issues revealed by the analysis. The safety workshops were aimed at sharing and validating research results among all the members of the fishing community, as well as a participatory development of recommendations. The workshops were held at least in two moments for each safety measure (see Section 4.4.9). In the first moment data was reviewed and validated. In the second moment of the workshop, collective solutions were conceived, based on the following question: “What can we do to improve this/such aspect?” The timeline of

workshops depends on the evolution of action planning and safety measures to be implemented.

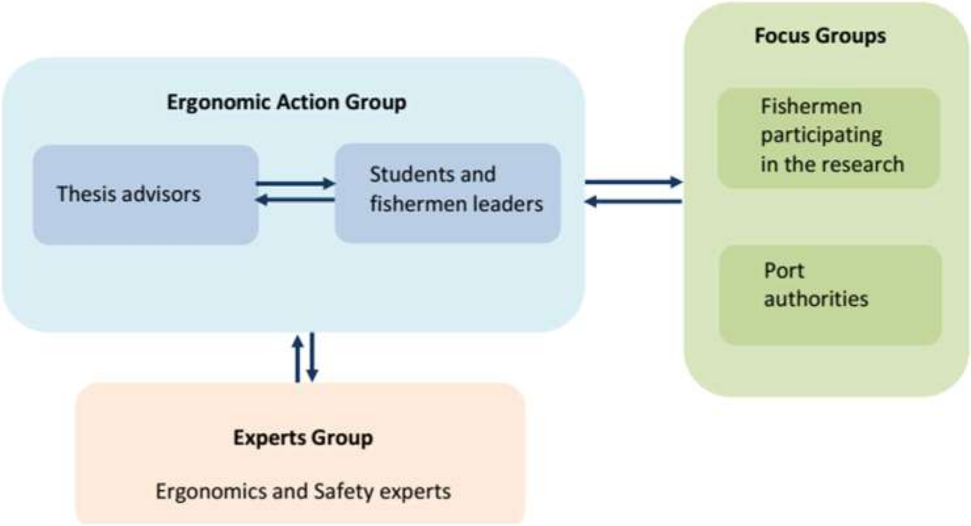


Figure 4-30 - Social construction diagram. The Ergonomic Action Group was composed of people involved from university and the community. Focus groups were formed by people who provided data and information and/or participated in the validations. The experts group was made up of people with extensive experience in ergonomics and safety research.

4.4.7 Study limitations

The application of Action Research disclosed paths to improve the safety of raft fishermen through reflection on several safety-related measures proposed along the research (see Table 4-15 at the end of the Results section). However, there were difficulties and delays to implement some of the proposed safety-related measures using only the people directly involved in this research. This limitation was partially solved incorporating actors from other university departments for the design and construction of the new wheelbarrow to transport the rafts to the sea, the new prototype of rafts, and computer applications. To avoid unnecessary delays in action plans, making the iterative action research process too long, members of these groups should be incorporated into the research as early as possible. Another limitation was the practical impossibility to make direct observations of the fishing activities during fish capture expeditions. To overcome this limitation, fishermen were instructed to take photos and to film the expeditions. The interviews, simulations of activities, and collective validations were also used to cope with this limitation.

4.4.8 *Results*

The fish capture expedition was divided in two FRAM models. Figure 4-31 presents the basic couplings among functions regarding the preparation and launch phases of the expedition, and Figure 4-32 the functions during navigation. Both FRAM diagrams were organized around the function “Make sense of conditions for navigation and safety” highlighting the central role played by the fisherman’s sensemaking in the safety of the expedition. This function represents a cognitive process that happens during a very short time period (typically taking seconds or minutes at most) and transforms holistic inputs into a mental mapping output of the current situation for navigation, based on fisherman expertise and personal conditions.

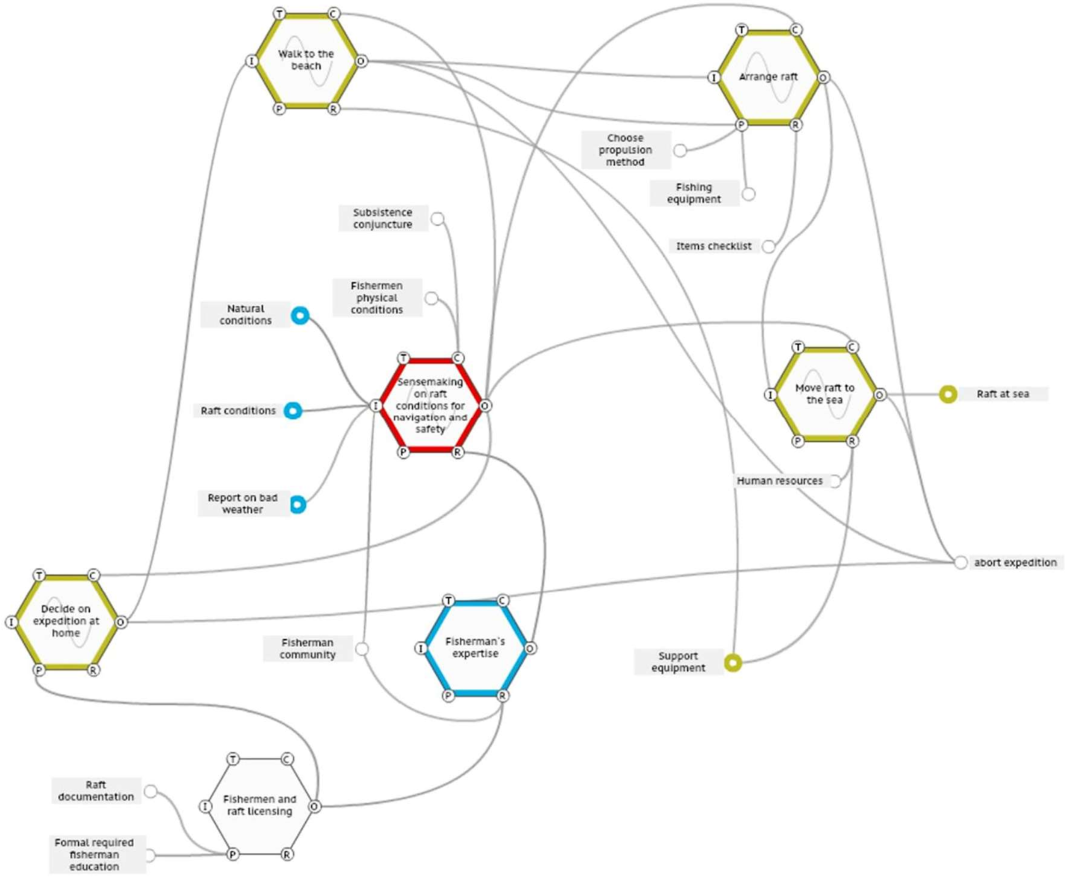


Figure 4-31 - FRAM diagram from the decision to go up to launch of the raft into the sea

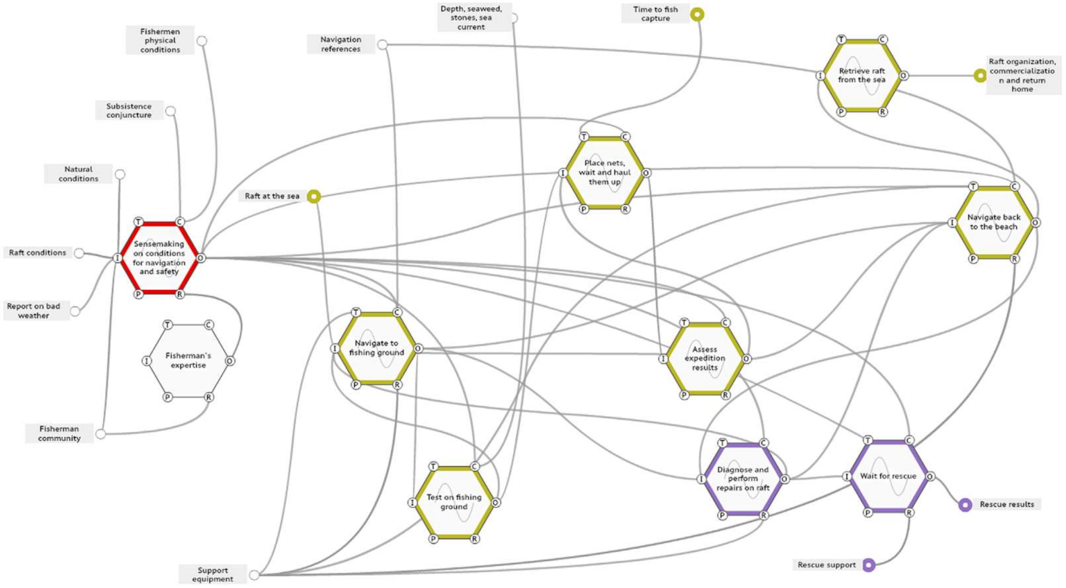


Figure 4-32 – FRAM diagram for navigation and fishing

The inputs of sensemaking functions are the current contextual information available for the fishermen from where they extract appropriate cues that may disrupt their previous understanding, leading them to a phase of pattern recognition. Fishermen's expertise is the main resource they have to identify patterns, to activate action scripts, and to make mental simulations using their mental models. The output of sensemaking function "conditions for navigation and safety evaluated" controls the safety decisions to abort or finish the expedition (it is the control input for nearly all other modeled functions) and is itself controlled by fishermen's personal factors.

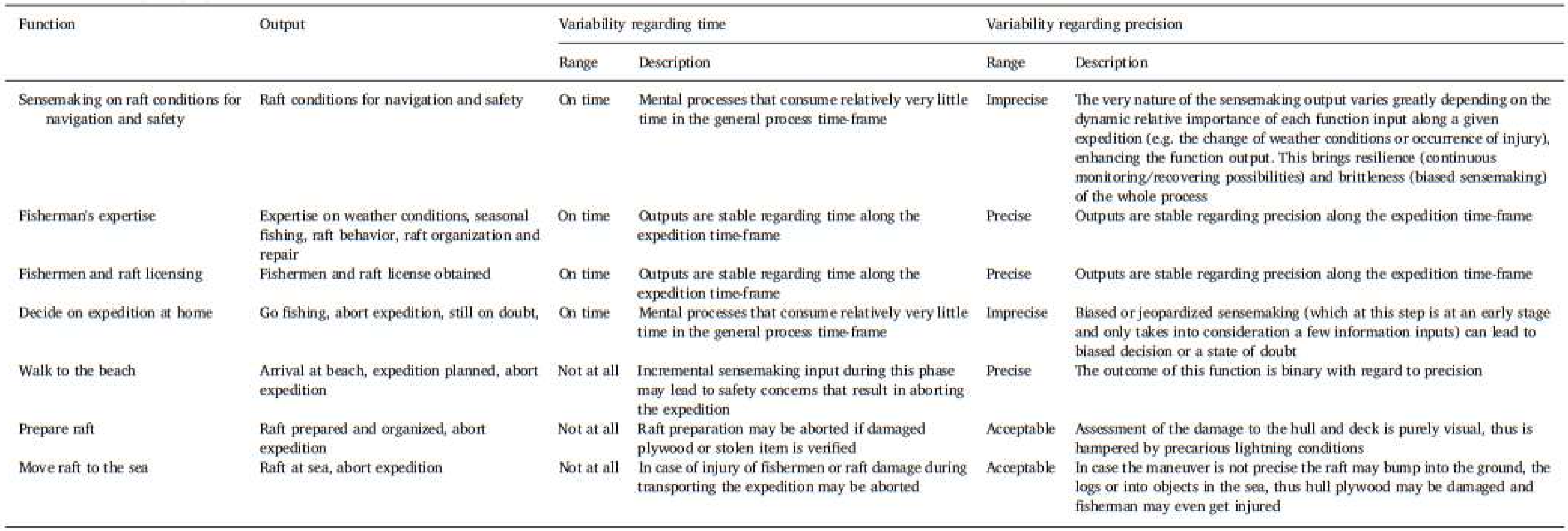
As shown in Figure 4-31, the decision on launching an expedition begins at home, when fishermen observe the weather condition, especially whether there is an indication of heavy rain. At this moment, fishermen have already a basic idea on the raft safety condition, although they will visually check the raft integrity later when they arrive at the beach. Three potential outputs based on that sensemaking process are expected: fishermen may become still in doubt, whether they can go fishing, or they may abort the expedition. Usually, fishermen abort the expedition at this point due to adverse weather or inappropriate physical condition. Sometimes, subsistence conjuncture plays a fundamental role on the sensemaking function output, acting as a variable input that controls the sensemaking function, as evidenced in the following account of one fisherman: "It depends on the needs of the person. I have already gone against the tide under a storm because there was nothing to eat. But it's not good at all." Once fishermen decide to go fishing, the next step is to walk to the beach where they can have better indicators to analyze climate and tide conditions.

At the beach, fishermen refine their expedition plans. At this point, due to a holistic perception of the weather conditions, sea and tide conditions, provided by the affordances of the beach environment – weather indicators are analyzed based on tacit knowledge through the observation of the sky, the wind directions and intensity, the tide level, and the cloud formations – they decide on the convenience of go fishing and make the initial plan for the expedition (where to go).

Having planned the expedition, fishermen start preparing the raft for navigation. At the "prepare raft" function, fishermen evaluate the integrity of the hull, when he looks for holes, cracks, fissures, and flaws in the raft; then they make a mental checklist of all necessary items for a safe navigation. If still in doubt, they may gather more information about the sea, the tides and the best fishery that day from arriving fisherman from earlier expeditions. Bad weather, strong wind, adverse tide, and precarious raft conditions should be reasons to abort the expedition at this stage; still, the necessity of go fishing due to subsistence needs may be the major fisherman driver. Despite the fishermen expertise and experience, a decision based on subsistence needs increase the variability of this function's output, leading to unsafe decisions. At this stage, fishermen define the type of propulsion to be used: sail or motor propulsion. When the raft is prepared and organized, fishermen move the raft to the sea.

Table 4-13 shows the potential variability for preparation and launch of the raft. It indicates that the "Make sense of Conditions for Navigation and Safety" function has high output variability in terms of or imprecise range. This variability is inherent to the macrocognitive processes related to sensemaking, leading to resilience and safety from one side and bad decisions from another.

Table 4-13 – Potential variability for preparation and launch of the raft



Function	Output	Variability regarding time		Variability regarding precision	
		Range	Description	Range	Description
Sensemaking on raft conditions for navigation and safety	Raft conditions for navigation and safety	On time	Mental processes that consume relatively very little time in the general process time-frame	Imprecise	The very nature of the sensemaking output varies greatly depending on the dynamic relative importance of each function input along a given expedition (e.g. the change of weather conditions or occurrence of injury), enhancing the function output. This brings resilience (continuous monitoring/recovering possibilities) and brittleness (biased sensemaking) of the whole process
Fisherman's expertise	Expertise on weather conditions, seasonal fishing, raft behavior, raft organization and repair	On time	Outputs are stable regarding time along the expedition time-frame	Precise	Outputs are stable regarding precision along the expedition time-frame
Fishermen and raft licensing	Fishermen and raft license obtained	On time	Outputs are stable regarding time along the expedition time-frame	Precise	Outputs are stable regarding precision along the expedition time-frame
Decide on expedition at home	Go fishing, abort expedition, still on doubt,	On time	Mental processes that consume relatively very little time in the general process time-frame	Imprecise	Biased or jeopardized sensemaking (which at this step is at an early stage and only takes into consideration a few information inputs) can lead to biased decision or a state of doubt
Walk to the beach	Arrival at beach, expedition planned, abort expedition	Not at all	Incremental sensemaking input during this phase may lead to safety concerns that result in aborting the expedition	Precise	The outcome of this function is binary with regard to precision
Prepare raft	Raft prepared and organized, abort expedition	Not at all	Raft preparation may be aborted if damaged plywood or stolen item is verified	Acceptable	Assessment of the damage to the hull and deck is purely visual, thus is hampered by precarious lightning conditions
Move raft to the sea	Raft at sea, abort expedition	Not at all	In case of injury of fishermen or raft damage during transporting the expedition may be aborted	Acceptable	In case the maneuver is not precise the raft may bump into the ground, the logs or into objects in the sea, thus hull plywood may be damaged and fisherman may even get injured

Information about the sea, tide and fishing grounds conditions are the main source of resilience for fishermeńs decision on quitting or going ahead with the expedition. However, the quality of this information is normally poor. They may get some information at afternoon's expeditions, when fishermen returning from morning expeditions give some advice.

The fishermen do not consult meteorological bulletins on a daily basis, as they rely on their own expertise. They also usually rely on the "bad weather advice", which sometimes is delivered by the port authority. This report is not always issued and comes in the form of a paper bulletin attached to the wall of a precarious support building at the beach by the representative of the Ponta Negra beach raftsmen community. However, this report may not reach the fishermen, either because nobody pasted the paper on the wall, or the shack used by the fishermen at the beach is in bad conditions.

Two control functions are constantly influencing the decision to go fishing or aborting an ongoing expedition. These are the fishermen's physical conditions and the subsistence conjecture. Fishermen's physical (and psychological) conditions are usually related to the subjective perception of each person about their wellbeing and health at the moment they decide to launch an expedition. Another personal function influencing sensemaking process is "Provide subsistence conjuncture". The sensemaking process leads to the formulation of satisficing accounts that control safety decisions in different phases of the expedition.

The only external control on fishermen work comes from the Port Authority. It is based on a License to sail a boat that fishermen must have and the boat license itself, shown as a background function (in grey) in Figure 4-31. However, the theoretical and practical knowledge taught in the professional fisherman's course needed to get the license does not provide an effective contribution for them, mainly due to the gaps between what is taught and the actual fishermen previous knowledge and schooling. Most of the raftsmen declared to have a license; however, only 19 out of 40 took the course. Most of them obtained the document more than 30 years ago when the course did not exist. Low level of schooling is an impediment to the participation and approval of many professional fishermen in the course because many are illiterate or functionally illiterate.

The diagram for FRAM model related to navigation functions is shown in Figure 4-32 and Table 4-14 describes the variability of the functions during navigation and fishing. The sensemaking function during navigation and fishing, despite having the same resource and control aspects of the previous sensemaking function, has a few more inputs. These are the perception of inner compartment water level, objects in the sea, and ships nearby, thus concerning the behavior of the raft in the sea and coming from the function “Provide raft conditions”.

Table 4-14 – Potential variability for navigation and fishing

Function	Output	Variability regarding time		Variability regarding precision	
		Range	Description	Range	Description
Sensemaking on raft conditions for navigation and safety	Sensemaking for navigation and safety	On time	Mental processes that consume relatively very little time in the general process time-frame.	Imprecise	The very nature of the sensemaking output varies greatly depending on the dynamic relative importance of each function input along a given expedition (e.g. the change of weather conditions or occurrence of injury), enhancing the function output. This brings resilience (continuous monitoring/recovering possibilities) and brittleness (biased sensemaking) of the whole process.
Navigate to fishing ground	Arrival at fishing ground, Go back, Repairs needed	Too late, not at all	Time to reach fishing ground may vary greatly due to location of the chosen fishing ground, wind and tide conditions, especially if sail is used. If the motor is used time tends to be more accurate. In days with rough sea and rough winds there is increased risk of raft capsizing, increasing time variability. Sometimes expedition needs to aborted before reach the fishing ground	Imprecise	Capability to reach the fishing ground can be undermined by low visibility (in case of departure during the small hours or during downpour), and difficulties in navigating by triangulation (due to the ever more vertical skyline of the beach). Moreover, repairs on the raft, control of water level in the inner compartment may be needed during navigation or by arrival at the fishing ground
Test on fishing ground	Fishing ground approved or not	On time	This function is consume relatively very little time in the general process time-frame	Acceptable	Several factors influence this function's output, including fish caught, sea depth, presence of seaweed and rocks, and tide behavior
Place nets, wait and haul them up	Quantity of fish caught, Quality of fish caught (size, freshness, type)	Too early/ Too late	Outputs from upstream functions often indicate that waiting time to retrieve nets should be longer or shorter than initially estimated, to optimize quantity and quality of fish caught	Imprecise	In rough sea or during downpours water enters the inner compartment during this phase due to it being open, thus fishermen need to control its water level. Placing and hauling up nets is risky for workers once they need to stay at the edge of the raft and can fall into the sea. The waiting time may vary in a particular fishing ground, and the fish caught may be few of become damaged/ spoiled
Assess expedition results	Go back, Keep fishing, Go to another fishing ground	On timeOn time	This function is consume relatively very little time in the general process time-frame	Imprecise	Function output is influenced by quantity and quality (in terms of freshness and integrity) of fish caught, climatic conditions, physiological conditions of fishermen, and also subsistence conditions. Biased sensemaking due subsistence conditions can result in inadequate or even unsafe decisions
Navigate back to the beach	Go back to the beach, Raft cannot go back	Too late/Not at all	Time to reach the shore may vary due to fishing ground location, wind and tide conditions. Incidents leading to injury of fishermen or damage to the raft may also hamper the capability to return, both temporarily or permanently. Raft capsizing is indeed more prone to happen during this phase, due to fatigue and sleepiness	Imprecise	Fishermen often need to control the water level in the inner compartment due to seepage caused by hull damage. Capability to return to the shore is undermined by low visibility (in case of return during the night or during downpour), difficulties in navigating by triangulation (due to the ever more vertical skyline of the beach) as well as physiological consequences of the expedition workload. Variability can also occur due raft capsizing
Retrieve raft from the sea	Raft on the beach	On time	This function is consume relatively very little time in the general process time-frame	Acceptable	Raft retrieval maneuver may not be precisely executed due to fishermen tiredness, the beach terrain angulation and the greater weight of the raft after returning to shore. Therefore, during the maneuver the raft may bump into the ground, damaging the hull and even injuring fishermen
Diagnose and perform repairs on raft	Repairs are successful or not successful	On time/not at all	Repairs may not be possible due to lack of adequate repair tools or materials of lack of expertise (e.g. motor failure)	Imprecise	Identification of seepage spots is often difficult, and repairs may turn only partly successful of not successful enough to restore navigation capabilities
Wait for rescue	Rescue made or not made	Too late/Not at all	Fishermen may not be found at all or may be found too late to secure a successful rescue	Imprecise	Rescues that are carried out too late may halt the health and physical integrity of fishermen

When the expedition starts, the fishermen have already a robust idea of the chosen fishing ground they are targeting. During motor propulsion navigation experienced fishermen are always looking for drifting objects and jetsam in general (e.g. pieces of wood, trash and plastic bags) that could crack the hull or damage the propeller. If the propulsion mode chosen was the sail, then fishermen must take care to launch the sail only after the rudder is attached to the raft. If this maneuver is not performed they lose control of the raft.

Most fishermen do not know how to fix propulsion motors, and if it fails during the expedition, they should hoist the sail to navigate. However, it was found that the introduction of the propulsion motor as a preferred method to navigate caused some raftsmen to neglect the necessary sail care and proper maintenance, as it is kept stored for long periods, thus causing material deterioration. This scenario can jeopardize the very feasibility to use the sail, as illustrated by the following statement by a fisherman: "*If the engine breaks you have to use the sail. Then you open the cloth, and the cloth is already spoiled, then the entire cloth rips, and you stay there. You may try to paddle, but you cannot go back*."

The redundancy and consequent safety improvement that the 2 propulsion modes could provide are not actually incorporated by the system. Reports on incidents in which the fishermen are adrift in the sea are usually caused by damages in the propulsion. Therefore, it is important that raftsmen get advantage of the 2 redundant propulsion modes available, keeping the sails in a good state, and making the necessary repairs on their return to shore, even when sails are not normally used.

Another factor impacting safety during navigation is navigating during the dark hours. Expeditions usually start at 2 am (returning at the daylight) or at 3 pm (returning after dark). During night navigation, visibility is reduced, increasing the risk of accidents. Collisions, reduced perception about climate and tide changes, and reduced visibility of obstacles at the sea are constant threat fishermen must deal with.

Raftsmen use the triangulation as navigation method based on the position of the stars and on points of reference at the beach. Nowadays, urbanization caused an ever more vertical skyline at Ponta Negra beach, which became an obstacle for fishermen to use the triangulation method. To deal with this situation, eight rafts are using GPS technology to locate the fishing grounds and to navigate during expeditions. The GPS was introduced after safety workshops during this project.

When fishermen arrive at the fishing ground, the motor is turned off (or the sails are collected); then they perform a fishing test to verify if they are at a potentially abundant fishing ground. During the test, fishermen assess sea depth, the presence of water and seaweed, as well as the tide behavior. It reduces the risks of unsuccessful fishing, the physical workload on net retrieval (due to the entangling of seaweed), or the damage or total loss of the net (due to rocks). At this point, sensemaking is used to judge if the fishing ground is a good choice for placing the nets or if it is better to look for another fishing ground. It is important to note that every moment at sea is a potential decision-making the situation, in which fishermen could be confronted with threats or particular occurrences and must decide the best action to dampen the output variability of the system. It occurs when the seas are rough, there are strong winds, or the hull plywood is damaged. In such cases, fishermen must be especially aware to control the water level in the inner compartment (damping variability on the navigation function output). This is also important in the case the raft capsizes, once the righting maneuver is impacted by this variable (not enough water in the inner compartment will make the maneuver too strenuous, and too much water will cause the raft to sink). Raft untap skills is also very important to damp overall system variability. It is a highly risky maneuver that requires special skills that are passed on from masters to apprentices. However, because there is no formal learning process, these skills are put into practice only in real capsizing situations. During safety workshops, experienced fishermen were encouraged to explain how they right a flipped raft for the novices.

Once fishermen establish the fishery, they launch the nets, wait for the fish to be caught and retrieve them. Launching the net requires synchronism among the crew, equilibrium, and a great static effort made by fishermen. Besides that, during the nets launch, the lid that covers the inner compartment is removed to get the net and water may enter, especially in rough sea situations. If the raft turns with the inner compartment without the lid it can be filled with water and the raft cannot be untapped. In this case, the raft will remain turned, and the raftsmen will be holding the raft, because if they try to climb on the raft it tends to sink. It should be noted that, because they do not wear lifejackets during the expedition, they have a hard job to release them from the inner compartment in this situation.

The waiting time before retrieving the nets varies from 30 to 60 min and depends on fisherman estimates regarding quantity and quality of the fish caught. After retrieving the nets, fishermen assess the quantity and quality of fish captured and determine the moment within the waiting time most fish were caught (by analyzing fish freshness), which enable them to deduce if most significant shoals are still present in the fishing ground or have already left the area. This sensemaking process controls the assessment of the expedition results and establishes whether or not they should keep fishing – in the same location or in another place. A decision to navigate back to shore is made if enough fish were already caught, if the weather and sea conditions are becoming not favorable or if, despite a low amount of fish caught, the raftsmen think new attempts to fish in any fishing ground will not be successful enough. The hauling up of nets usually lasts between 30 and 90 min and is generally considered by fishermen to be the most exhausting phase of expeditions. This is mainly due to the effort from pulling the nets with the additional weight from the fish caught and the seaweed that often get entangled, as well as the position on the very edge of the vessel and the required posture. In addition, this stage is held after dawn or dusk when the fishermen are tired.

Afterwards, the fishermen navigate back to the beach. At this moment the raft is considerably heavier due to the plywood being soaked and the fish caught. All the risks related to navigation phases are increased during the return to shore due to the intense fatigue and sleepiness experienced by fishermen. Hence, this phase accounts for most reported accidents and incidents. After reaching the beach, the raft is withdrawn from the sea using the same technique as when it is transported to the water. With the raft secured in the sand, the fishermen retrieve fish caught and the expedition comes to an end.

Improving safety on artisanal fishing from the Safety-II perspective requires measures to facilitate ways in which things can go right. Such measures concern artifacts to inform sensemaking by showing current contextual information, new ways to share and accelerate safety-related knowledge, transformations in the fishing management and commercialization processes, and in ways to improve fishermen subsistence conditions to deal with the issues that create bias on sensemaking. Table 4-15 summarizes projects and actions that are underway in the Ponta Negra community as a result of this research project. All actions and projects follow the action research iterative and participatory approach, from the conception up to test and validation.

Table 4-15 – Projects under development at Ponta Negra

Actions	Description
Artifacts redesign	***New raft project:*** Modifications to the raft design, maintaining the characteristics and specificities existing in the Brazilian artisanal shipbuilding, adapting it to the socio-economic and cultural characteristics of the raft communities, aiming to improve the construction methods and the fishing operations, reduction of the operational costs of the vessel, improving safety and navigability and buoyancy, improving working conditions, reducing accidents and occupational diseases ***Wheelbarrow project:*** A wheelbarrow to transport the rafts to the see
New technologies to inform sensemaking	***Lighting:*** Development and use of handmade artificial lighting system for night navigation ***Navigation technology:*** Use of information and communication technologies (cellphone, GPS). 8 rafts have started to use GPS to find fishing grounds and to guide navigation. ***Search and rescue:*** Development of a collaborative monitoring system for search and rescue of drift rafts in the community
Training program	***Workshops on safe-related expertise:*** a continuous safety program of workshops to discuss safe-related issues regarding navigation (new technologies, cellphone on board, use of engine instead sail), raft conditions, evaluation and share advices on weather and sea conditions; community support in case of accidents (raft adrift in the ocean) ***Maintenance of the vessel:*** Training on the use and make available tools and spare parts to repair faults in the engine or raft components during the expedition (a new knowledge to be acquired) ***Postural Education:*** promotes the understanding of the relationship between the postures adopted in the work and its repercussions. ***Fish handling:*** deals with the storage and handling of fish on board, aiming to improve the quality of the product marketed
Management of fishing processes	***Aspects and recommendations aimed at improving management:*** a) of the fishing activity (organization of work and production); (b) of the fishing-related institutions; c) the interaction of these institutions with the fishing community

4.4.9 Discussion

The research question which motivated this research was how the Safety-II approach can improve the understanding of safety in fishing expeditions enabling the application of useful, practical, and applied safety measures. The first part of the question – understanding safety in artisanal fishing (current context, practices, and functions involved in the safety of fishing expeditions) – was answered by the detailed analysis of fishermen's activities that inform FRAM models, showing that in the fish capture expeditions things go normally well not because people follow prescribed rules or behave as someone thinks they have to do. Things go well because fishermen made continuous assessments and performance adjustments based on their own sensemaking. The Safety II perspective, describing the behavior of the expedition's functions, as modelled by FRAM, shows how performance variability – manifested into functions' dampening mechanisms – is important to build safety while allowing the fishing activity itself to happen. Understanding performance variability enables the inclusion of workers knowledge in safety measures, which Safety I management systems do not normally include (ALMKLOV; ROSNESS; STØRKERSEN, 2014). Therefore, the development of useful, practical and applied safety measures must be done in consonance with the Safety-II perspective (HOLLNAGEL, 2014): safety measures considering the workers safety knowledge to ensure as much as possible that everything goes right, rather than prescriptions to avoid what can go wrong.

The importance to a deeper understanding of current context and practices in fishing domain to develop more effective safety measures has already pointed out in several recent works. After studying the impact of maritime safety regulations to Norwegian coastal transport, Størkersen (2018) disclosed a perception from crewmembers that “procedures do not take variability into account and hamper them in skill and knowledge-based decision making” (STØRKERSEN, 2018, p. 87). She concludes that extensive proceduralization might then disrupt navigation activities (STØRKERSEN, 2018), mainly because extensive proceduralization may constrain people activities (MOREL; AMALBERTI; CHAUVIN, 2008). The study of Thorvaldsen et al. (2018) with commercial fishers from Nordic countries found that guidelines and information from the authorities on safety and accident prevention were not considered to be much influential on the prevention of occupational accidents in fishing, as such guidelines do not match the actual fishermen’s safety behavior. In the same way as observed in this study on artisanal fishing, the Nordic commercial fishermen deal with safety using their sensemaking, carrying out continuous assessments and decisions related to sea and weather conditions, fish, profits and safety (THORVALDSEN et al., 2018). The importance of sensemaking in safety decisions also appeared in commercial fishing expeditions in Denmark. Knudsen and Gron (2010) found that economic factors had a strong influence in the fishers’ perception of risk, stating that “fishermen’s risk perception can be explained by the need to adopt coping strategies, compromises and resilience in an environment marked by uncertainty and unpredictability” (KNUDSEN; GRON, 2010, p. 87), which is almost the same conclusion that McDonald and Kucera (2007) reached when studied commercial fishermen in North Caroline.

The research question on the existing sensemaking behaviors that inform decision-making was answered by FRAM models constructed around sensemaking functions. The sensemaking functions were conceived according to Klein et al. (2007) and Klein (2013) model on how individual sensemaking takes place in dynamic environments. The fishermen’s sensemaking, that guide situation understanding and corresponding actions, are constructed using prior experience combined with tacit knowledge by appropriate cognitive structures called schemas (KLEIN et al., 2007), informed by current data on the situation, leading them to a phase of pattern recognition (BABER; MCMASTER, 2016). Fishermen continuously monitor weather and raft conditions and when confronted with a potentially adverse situation, they search for cues on weather, on information they previously gathered with another fisherman, and on the analysis of the raft behavior, so they can look for the best solution based on their expertise. These findings on fishermen’s sensemaking are very similar to sensemaking behaviors found in other domains (BABER; MCMASTER, 2016; KLEIN et al., 2007; WEICK, 1995). During their routine on fish capture expeditions, fishermen continuously monitor if something goes wrong, exchanging different modes of sensemaking (KEFALIDOU; GOLIGHTLY; SHARPLES, 2018): individual, based on their own assessments and needs; collaborative, based on information coming from other fishermen; and artefact-based, weather bulletins, Lightning, GPS, and Cellphones. It was found that these different sensemaking modes emerge and are combined within the variability of routine (normal) expeditions, when fishermen make sense of an incident situation. For instance, the cellphone on board, enabling the collaboration in cases where the raft became adrift, combining two sensemaking modes, can be very useful to dampen the variability of the overall system in this dangerous situation. Therefore, fishermen should be aware of these strategies and be informed as much as possible by different artefacts, to be able to perform safely their job. The FRAM analysis has shown that the combination of quality of weather and sea information (an artifact-based sensemaking) with a biased individual sensemaking, due to poor subsistence conditions, is the main sources for high variability in the safety decisions on giving up a potentially dangerous expedition.

Most of fish capture expeditions in Ponta Negra go well because the expert fishermen are able to constantly adjust their performances to match the conditions of work constructing their everyday safety. Even considering the inherently dangerous working conditions related to the unpredictable maritime environment, rapid weather changes, unstable working platforms, manipulation of heavy equipment, and difficult communication, the records of fatal accidents are rare. According to the reports obtained from the fishermen of Ponta Negra beach, there were 2 fatalities in a period of 15 years of continuous fishing expeditions, with the last one occurring 13 years ago. Considering that in each expedition there are 2 fishermen and each of the 31 Ponta Negra rafts performs an average of 96 fishing expeditions per year, the ratio Fatal accidents/ (Number of fishermen * Number of expeditions) amounts to 2/ 89,280 = or 224 × 10^{-5}. For the traditional Safety approach (Safety-I), a safety figure of 10^{-5} means a very safe work system (AMALBERTI, 2006), thus not demanding immediate safety investments or attention to the development of safety improvements.

However, as revealed by the FRAM analysis, the safety on fishing expeditions, from a Safety-II perspective, is affected by strong potential and actual output variability in the sensemaking functions (in both timing and precision), as well as potential nonlinear couplings (especially those involving uninformed, biased or compromised sensemaking) that can lead to situations where satisficing decisions turn to sacrifice decisions (GOMES et al., 2015) due to the efficiency-thoroughness tradeoff – ETTO (HOLLNAGEL, 2009) between the expedition safety and the need to produce (catch fishes for surviving). In FRAM terms, instantiations of poor individual sensemaking can expose fishermen to out-of-the-ordinary particular circumstances (functional disturbances) that the performance variability mechanisms featured by downstream functions are difficult or even not able to be dampened.

An instantiation in the sensemaking function occurs when scarce financial resources available to the fisherman‘s family (poor subsistence conjuncture) leads to launching an expedition in bad weather conditions such as low visibility at sea, which elevates the risks of turn the raft, being adrift, or slamming the raft into large objects at high seas, characterizing an efficiency – thoroughness tradeoff, ETTO (HOLLNAGEL, 2009). In the last situation, the use of gas lamps (a dampening mechanism embedded in the navigation functions) might be insufficient to prevent damage in the hull. It may create serious seepage, damaging the hull to an extent it is not possible to repair, given fishermen‘s current expertise, as well as, the repairing tools and materials currently at their disposal on board. If there is no means to communicate with land or other vessels then, the situation can become even more dangerous to the fishermen.

Another instantiation occurs when imprecise information on sea conditions is inputted into the sensemaking function – an instantiation of FRAM sensemaking functions shown in Figure 4-31 and Figure 4-32 – leading fishermen to launch an expedition, or continue navigation in rough sea conditions. In such cases, fishermen’s control over the water level at the raft’s inner compartment (a dampening mechanism for the function “place nets, wait and haul them up”) can become too challenging and fail. As too much water enters, in case the raft comes to capsize, righting it could prove to be an arduous task. All these FRAM instantiations and details on things to do ensure an adequate outcome in each instantiations were discussed and reflected during the workshops on safety-related expertise.

In summary, the artisanal fishing with rafts’ work system seems to clearly display that safety should not be perceived by the records of its absence (number of accidents). Instead, this study has shown that safety measures to be applied should be developed according a Safety-II perspective (HOLLNAGEL, 2014) focused in dampening potential output variability without hampering the system‘s adaptive behavior capabilities (MOREL; AMALBERTI; CHAUVIN, 2008), because such fishermen’s adaptive capacities are the source of the system safety and resilience. These findings are according to the previous recommendations coming from ergonomic field studies (JAESCHKE, 2010; JAESCHKE; SALDANHA, 2012), and the Diegues’ (2002) description of fishermen activity.

Table 4-15 summarizes the practical, useful and applied safety measures that guided the projects and actions underway at Ponta Negra community, answering the last research question, on how safety can actually be improved considering the artisanal fishing environment. As a result of being formulated in a participatory way within action research iterative process, the safety measures are able to offer direct support to dampening mechanisms at specific functions from those modelled through FRAM for capture expeditions, depending on how instantiations of the general model unfold. This can be exemplified in the cases of the aforementioned two instantiations, which account for resonance between output variability in poor sensemaking and downstream functions.

For instance, regarding the instantiation on navigating in rough sea conditions, the “fish handling” and “aspects and recommendations aimed at improving management” aim at reducing the occurrence of sacrifice dilemmas due to subsistence needs, thus unbiasing the individual sensemaking, and reducing its potential variability. In addition, the “lightning” project – new lamps charged by electric batteries instead of the old and dangerous gas lamps – increases the illumination capabilities of the raft, affording a better surveillance and the identification of large objects in collision route. The projects “maintenance of the vessel” and “workshops on safe-related expertise” includes ways to reflect and share strategies to respond and make sense on possible incidents during routine navigation, a definition of a spare parts and tools that can support fishermen in case of repairs during navigation, and many other safety-related issues.

Regarding the second example mentioned, the projects, “navigation technology” and “search and rescue” – a collaborative communication system based on cellphones, in which the community can assess situations where rafts are adrift – can improve communication among fishermen to foster more precise information on sea conditions, affording more possibilities to combine sensemaking modes. Additionally, control of the water level in the inner compartment might be supported by modifications in raft design ("new raft" project). Finally, if the raft overturns, changes in its design can also ease the righting process, while the workshops held can improve expertise of novice fishermen concerning this process while still using the actual rafts.

4.4.10 Conclusions

This research, carried out according to the Safety-II perspective, aimed to enhance as much as possible ways in which "the things can go right" at various levels of the artisanal fishing system. FRAM shows that the variability in sensemaking functions is due to the inherent task domain characteristics: dynamic, sometimes difficult to predict decisions influenced by behavioral issues and many different clues. The analysis highlighted that the sensemaking variability is needed to provide a repertoire of adaptive behaviors to create system resilience. However, even being "an activity difficult to learn" as already cited by a fisherman, there are some task characteristics that favor the expertise acquisition, such as the possibility of inadequate decisions (errors) corrections and tolerance on decision errors, the availability of outcome feedbacks, repetitive tasks, understanding and solving problems on-the-fly (small maintenance on the raft). The detailed analysis of fishermen activities showed that captains have rich repertoires of patterns on coping with weather and sea conditions as well as sophisticated mental models on how the raft is functioning and maintaining. Therefore, they are able to make fine discriminations to support safety decisions, and have the resilience to adapt to dangerous situations, such as the relatively common situations of overturned rafts. However, the safe-related decisions – to abort or to go back – are not based only on the external clues or environmental conditions. As shown in the FRAM diagrams, there is a constant trade-offbetween the need to fish to survive and the actual safe conditions to do so.

Since its very beginning, the art of navigating and fishing has relied on cultural and traditional aspects, being passed on through the years from fishermen to apprentices, and from one generation to another. Along with navigating and fishing techniques, fishermen have learned how to identify hazards, how to deal with risky situations, and how to react in case of incidents and accidents. In short, safety in artisanal fishing has always been a condition based mainly on the expertise of fishermen. Such expertise feeds and is fed by a continuous learning process portrayed by practical work. Therefore, it does not look like a good strategy to improve safety in such work activities by adopting safety management systems to change the way people do things. Conversely, it seems to be a good strategy to adopt Safety-II as an effective approach to really improve the work-safety in artisanal workers communities.

4.5 Article E: A Safety-II Analysis on the Effects of COVID-19 on the Access to Urgent care of Amazon's Riverine Populations

4.5.1 Foreword

In this paper we address the problem of predicting the behaviour of complex socio-technical systems when these are put under stressful conditions and crisis. To do this, we explore and test the hypothesis that of trying to predict such behaviour by means of a prospective analysis that is based on comprehensive knowledge regarding the system's normal functioning. We apply this research problem to a riverine mobile emergency care service.

4.5.2 Introduction

The COVID-19 pandemic was declared a public health emergency of national importance in Brazil on February 3rd, 2020 (BRASIL, 2020; GARCIA et al., 2020). It started in Brazilian Southeast region and soon spread throughout the entire country, including remote and less accessible regions like Amazon State where patient transportation through rivers is added to the list of obstacles to overcome. Using Resilience Engineering and Safety-II (HOLLNAGEL, 2014) concepts and methods, this research aims to predict the functioning of the Mobile Emergency Medical Service (SAMU) for riverside and coastal areas during the COVID-19, based on the normal system functioning. The research question was how the Functional Resonance Analysis Model FRAM (HOLLNAGEL, 2012) mapping activities in normal operation can actually be used to predict system functioning under stressful situations, like the ones posed by COVID-19 pandemics.

To do so two studies were performed and presented here. The first one, carried out in the middle of 2019 (before COVID-19), a FRAM model for the Upper Amazon River SAMU was developed using ethnographic methods. In the second study, based on the variabilities already achieved in the normal functioning, a group of experts developed new models on how the system would function during the high demand imposed by COVID-19. Then the accuracy of predictions and the ways sharp end workers cope with them were discussed.

4.5.3 The SAMU in Brazil

In Brazil, the Mobile Emergency Medical Service (SAMU) is a healthcare service that delivers prehospital emergency care to incidents when necessary. SAMU is part of the Brazilian Unified Healthcare System (SUS) and covers about 83% of the country's population (about 170 million people) (FRASÃO, 2018). Inspired by the French model, it is available 24 hours a day, providing on-scene emergency care for patients instead of just transport to healthcare facilities (TIMERMAN et al., 2006).

Launched in 2003 by the Federal Government as part of the National Emergency Care Policy (MACHADO; SALVADOR; O'DWYER, 2011), SAMU provides emergency medical care anywhere: residences, worksites, and public locations. The service is available for dispatch through a standard single-access phone number (192), which is toll-free. The call is answered by a regional dispatch, which determines the appropriate medical resources required by the patient, and mobilizes the ambulance crew closest to the occurrence. The water ambulance crew are stationed throughout strategically-located decentralized bases. Meanwhile, the Dispatch communicates with local health care facilities and keeps track of beds and services' availability.

SAMU services in riverside and coastal areas are carried out through water ambulances. These are boats commonly called "ambulanchas," a neologism from the merging of the words "ambulance" and "speedboats" (in Portuguese, "ambulância" and "lanchas"). Compared to land routes, waterway environments present certain particularities, such as the inconsistency in navigability conditions and the route to be traversed, which is often lengthy and deserted. These features increase the complexity of providing a high-quality and safe emergency care service.

From all Brazilian regions where SAMU operates water ambulance services, the largest and most dependable on it is the Upper Amazon River region, where an Emergency Dispatch Center coordinates the mobile emergency care response to five on-call SAMU water intervention teams (as well as land teams) stationed along the Amazon River cities.

4.5.4 Research Settings

The upper Amazon River region, a part of the Brazilian state of Amazonas, is located at the tripoint between Brazil, Colombia and Peru. It comprises 213,000 km^2 and

9 municipalities as shown in Figure 4-33. Their combined population is estimated at 240,000 inhabitants. The region surrounds a stretch of about 900 km of the Amazon River (along with some of its tributaries) as it enters Brazil from Peru.

Figure 4-33 - The Upper Amazon River region, Northern Brazil, comprising urban areas (black) within respective municipality divisions (shades of green). Six from the nine cities hold SAMU bases, all coordinated by the Dispatch Center at Tabatinga

Due to the local conditions - underdeveloped local infrastructure, sparse population density and local geography consisting of forested and floodable plains - the primary access to cities in the area is through the waterways of its rivers. The hydrography of the area consists of rivers, streams, and boreholes, which enable the flow of people and cargo between urban centers and inland communities.

The Upper Amazon River, during floods, is over one km wide and reaches depths of over 20m. There are no beacons (nautical signaling system), its nautical charts are limited, and mobile phone coverage is almost nonexistent within its area. Additionally, since it has recent geological formation, its format, depth and feasible navigation paths change periodically and require exceptional navigation skills. The various risks for navigation include (QUEIROZ, 2019):

- Underwater sandbanks;
- The collapse of riverbanks, forming waves that sometimes sink boats;
- “Rebojos” - swirls formed at river confluences with different water speeds that can delay trips and sink small boats;

- Shaping of several pathways due to the formation of numerous islands ("paranás"), impeding regular navigation paths (see ahead);
- Large concentration of debris on the surface of its waters, such as tree trunks, which often break boat propellers;
- Dangers and violence posed by illegal activities including illegal mining, drug and arms trafficking, and even river piracy (see Section 4.5.14). The region is one of the main gateways for drugs and illegal arms entering Brazil.

Unlike other regions of Brazil and the world, where water ambulances are complements to land and air emergency care (CALISKAN; ALTINTAS, 2019), in this region that is the only service available to most emergency care provided to the local rural and indigenous population.

Figure 4-34 shows a map of the operation for emergency care service across the municipalities of Benjamin Constant and Tabatinga. This last city is the regional capital and holds the headquarters for the system – the SAMU Dispatch Center for the Upper Amazon River region.

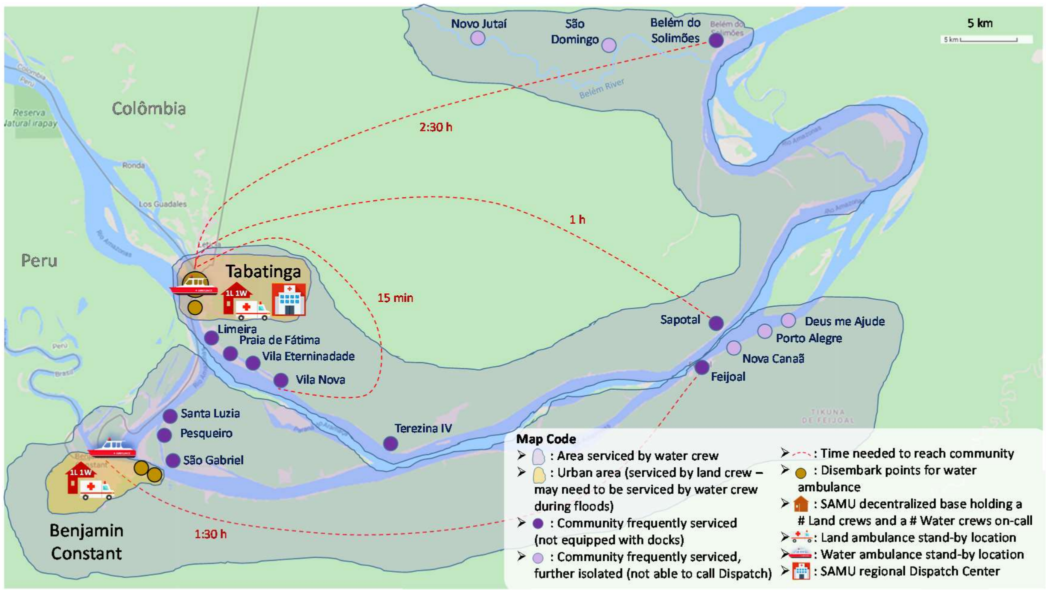


Figure 4-34 - Operation map for mobile emergency care in Tabatinga and Benjamin Constant municipalities

A panoramic view of two of the communities represented at Figure 4-34 can be seen in Figure 4-35, along with nearby "paranás". Although Belém do Solimões is one of the farthest communities to reach from Tabatinga, it is the largest community in all the region – and the largest indigenous village in all of Brazil - with a population of over five thousand people. Therefore, Tabatinga's water crew attends emergency events there frequently. The water ambulances themselves for the Upper Amazon River region are very similar, and one of them is displayed in Figure 4-36 (Tabatinga's own water ambulance is also shown in Section 4.5.19).

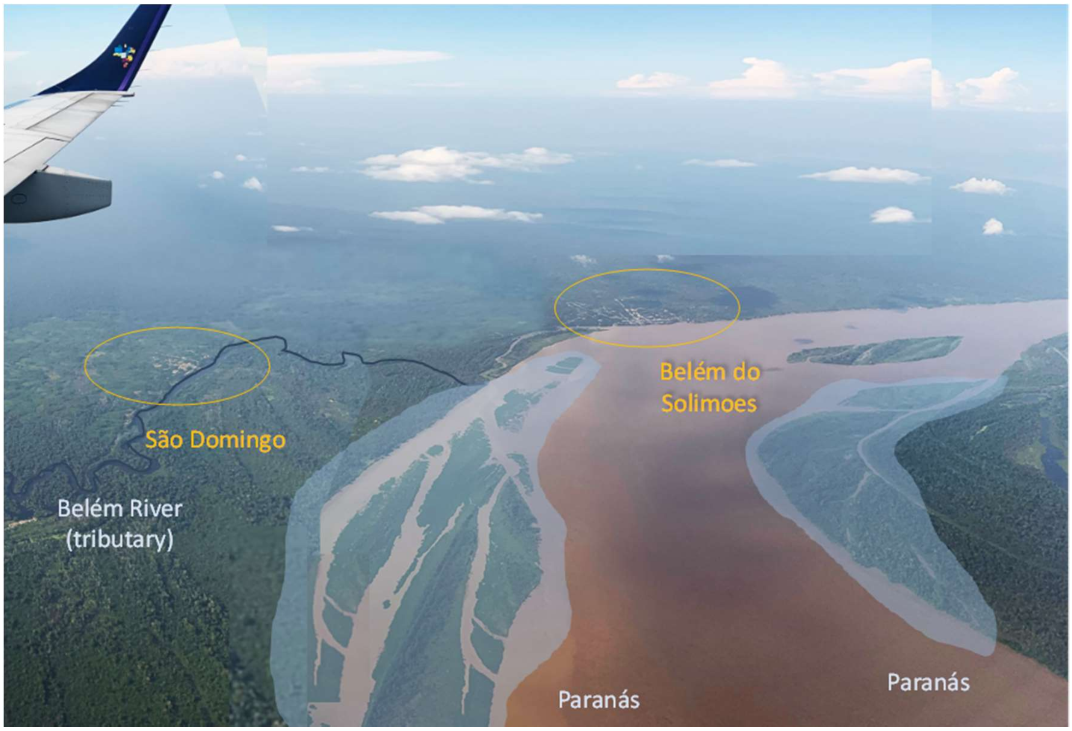


Figure 4-35 - Aerial view of the farthest communities serviced by Tabatinga's water crew and surrounding "paranás". Communities located in the Belém River are only reachable by the water ambulance during the flood season (roughly January – June)

Figure 4-36 - Water ambulance at a disembark point in one of the municipalities. The shoreline of the closest island stretches in the background

4.5.5 Safety-II perspective in healthcare systems

From a Safety-II perspective, the purpose of safety management in healthcare systems, such as SAMU, is to optimize work performance, avoiding possible predicaments (HOLLNAGEL, 2014). Regarding emergency care to riverine populations, the purpose of safety management is to ensure that SAMU teams can safely perform on-site urgent care to injured parties, and transfer patients from the incident to healthcare facilities. Therefore, safety should be improved through constant performance adjustments made by healthcare personnel to meet changing demands and deal with disturbances and surprises (SUJAN; HUANG; BRAITHWAITE, 2017).

Recent studies that applied the Safety-II approach in investigating healthcare systems and patient safety found that, as happens in much less regulated sectors (SALDANHA et al., 2020), safety in healthcare processes is also constructed as needed. Safety management is not only the product of rules and procedures, but it also develops mainly due to adjustments for overcoming constraints in time and resources in everyday clinical work (KROEZE; WIMMER, 2019; MERANDI et al., 2018; SCHUTIJSER et al., 2019).

The motivation for this paper was to show how the Safety-II framework can identify and predict the functioning of an emergency healthcare system in stressful situations, considering its normal functioning. To do so, the study analyzed the pandemic's effects in access of riverine communities to the prehospital emergency healthcare system in Amazon's ultra-peripheral locations, where emergency care is the only gateway for riverine populations into SUS.

4.5.6 FRAM as a method for prospective analysis

FRAM was conceived as a new accident model based on Resilience Engineering concepts and the initial meaning of FRAM acronym was Functional Resonance Accident Model (HOLLNAGEL; GOTEMAN, 2004). It has been widely used in a retrospective way in accident analysis based on resilience engineering principles (CARVALHO, 2011; HOLLNAGEL; FUJITA, 2013; WOLTJER, 2008). However, as described by Patriarca et al. (2020), the Resilience Engineering community soon recognized that FRAM can be used as a method and the acronym's meaning has changed to Functional Resonance Analysis Method that can be used to model system functioning resulting in prospective analysis (PATRIARCA et al., 2020). FRAM prospective analysis has been used to understand the consequences of misalignments of Work-As-Done (WAD) end Work-As-Imagined (WAI) (LI et al., 2019c), to provide reflections on how sharp end adaptations due to system constraints may support or jeopardize system fucntioning (ARCURI et al., 2020; JATOBÁ et al., 2018).

In this work a FRAM model for system functioning in normal conditions was used to predict system behavior in a stressful situation.

The FRAM model for SAMU services in riverside and coastal areas is detailed in the Study I as including the complete system operation: from the call for assistance up to the arrival at the specialized care facility. This FRAM model enabled a deeper understanding and reflection on system variabilities, providing the basis for the prospective analysis of its operation during COVID-19 as described in Study II.

4.5.7 Study I

The goal of Study I was to develop a FRAM model for the mobile emergency care system, operated by the SAMU, in the Upper Amazon River (Alto Rio Solimões, in Portuguese) region. It resulted in a systemic modeling of emergency care situations and their variabilities that can be used by the Brazilian Minister of Health to improve the overall system functioning.

4.5.8 Methods

This study used an exploratory cross-sectional design, based on qualitative data collected in a participatory way through interviews and active observation to map work activities into functions of the FRAM. The participants were workers at Amazons' Municipal Health Departments: managers of the Municipal Health Departments, managers of Mobile Emergency Services, and emergency teams' professionals, such as doctors, nurses, health attendants, and boat drivers.

This research required over 140 hours of fieldwork, in which 47 professionals were interviewed over a 12-day timeframe. The interviews focused on identifying the difficulties that participants encounter while carrying out their activities and the main problems concerning the boats and navigability in rivers in which they operate. Then, participants were approached for data gathering on the teams' performance during the pandemic, and what issues they had been facing under this scenario. Also, published reports were reviewed when pertaining to the COVID-19 pandemic effects on the studied regions.

The data collection comprised the multi-professional emergency care teams, not only those performing directly on water ambulances but also other agents of the system, such as coordinators and managers. During initial contact at the research's location, the participants were recruited through random selection. However, during fieldwork, as per the framework of the local healthcare system, any new interviewees were chosen through recommendation from their colleagues. This configured the probabilistic sampling method called "snowball" for selecting participants (GOODMAN, 1961). Therefore, the number of interviews was determined by observing data saturation during the interviews conducted throughout the research period.

This research received ethical approval from the ethics committee of the Oswaldo Cruz Institute, Rio de Janeiro, Brazil, and was conducted according to recommended procedures and Brazilian regulations concerning scientific research with human participants.

4.5.9 Data Collection, Coding, and Analysis

To map systems functions into FRAM, research's fieldwork sought to grasp the emergency healthcare system's operational aspects to riverine communities in the Upper

Amazon River region. This study took into consideration this system's organizational context, related to its "blunt end" (administrative structure, relationship with municipal and state management, availability of human and material resources, and local protocols). Additionally, other elements of the work environment were considered, such as those related to its "sharp end" (geographic and climatic factors, and populational epidemiological aspects). These factors are experienced by the water ambulance crews and other professionals working in the emergency care service. Thus, the fieldwork was organized into the following steps:

- Visits to the Dispatch Center;
- Semi-structured interviews with a triage team composed of Dispatch managers and with a health manager at the municipal level;
- Guided visit to the decentralized operational bases that host the water ambulance crews in the Upper Amazon River region' municipalities;
- Semi-structured interviews with Dispatch managers and health managers at the municipal and state level;
- Semi-structured interviews with members of the water ambulance crews;
- Inspection, description and technical drawing of the water ambulances and their docking locations,
- Simulation of an emergency operation with the water ambulance crews;
- Semi-structured interviews with managers and professionals from healthcare units in the Upper Amazon River region.

Field notes and the transcription of interviews underwent content analysis (BARDIN, 1989) through the following phases:

- Arrangement and organization of collected material: defining the recording method – the detailing of the discourse elements – and the general categories with which to work;
- Categorization of discourse elements based on the search for units of meaning;
- Contextualization of the highlighted terms and understanding of the meaning of what was reported by the interviewees, highlighting their consensuses, controversies, and contradictions, expanding the analysis beyond the participants' statements;

- Final analysis of the results looking for trends, characteristics, and interpretation of the data.

Lastly, the operation was modeled based on systemic analysis using FRAM. The analysis focused on the interactions used to coordinate the tasks, the individuals, and the technical systems used. Therefore, work organization is modeled according to the concept of distributed cognition, i.e., a process in which different individuals develop a relationship towards a set of tasks and activities (CRANDALL; KLEIN; HOFFMAN, 2006).

The main steps to develop the FRAM were (HOLLNAGEL, 2012):

- Setting the goal - activities performed in SAMU services - for modeling and describing the situations to be analyzed;
- Identifying the main functions at the several system levels, and characterizing them, according to input, output, preconditions, resources, time, and control, using the FRAM Model Visualizer;
- Characterizing the potential/actual variability of functions, with the participation of SAMU workers;
- Aggregate functions searching for critical instantiations, based on potential/actual couplings among functions.

Functional variability was modeled in terms of endogenous/exogenous disturbances, damping mechanisms, and output variability according to the taxonomy described by Li *et al.* (2019b) and Saldanha et al. (2020). Therefore, from the standpoint of a specific function in the model, exogenous disturbances are modeled as the output variability from upstream functions, while endogenous disturbances are modeled as ones that emerge from within the reference function – given a chosen level of model resolution.

4.5.10 Results

Even under typical operation constraints, transferring patients through remote riverside regions is a fairly complicated task. Water ambulance units are affected by many variables, from operational context, equipment limitations (PPE, boat and docking locations), to availability of complete healthcare teams.

Emergency healthcare to riverine communities in the Upper Amazon River region comprises three key processes:

1. Rescue service for injured individuals (patients) at riverine communities (rural, indigenous, and non-indigenous populations), subdivided into:
    a. Rescue near the coast of the Upper Amazon River, Içá River, and their extensions, streams, and boreholes;
    b. Rescue within riverside communities; or
    c. Rescue of boats or patients adrift in other rivers within the region.
2. Transfer of patients from healthcare facilities in other cities within the region to Tabatinga's hospital or emergency care clinic;
3. Transfer of patients from clinics in Tabatinga and other cities within the Upper Amazon River region to medium and high complexity healthcare facilities in Manaus.

The water ambulance service in Upper Amazon River is responsible for operating processes A and B. In contrast, process C is operated both by land SAMU – coordinated by the Municipal Health Department of the patient's hometown – as well as by the State aeromedical service. The FRAM model, describing how the functions are activated along these three processes, is shown in Figure 4-37.

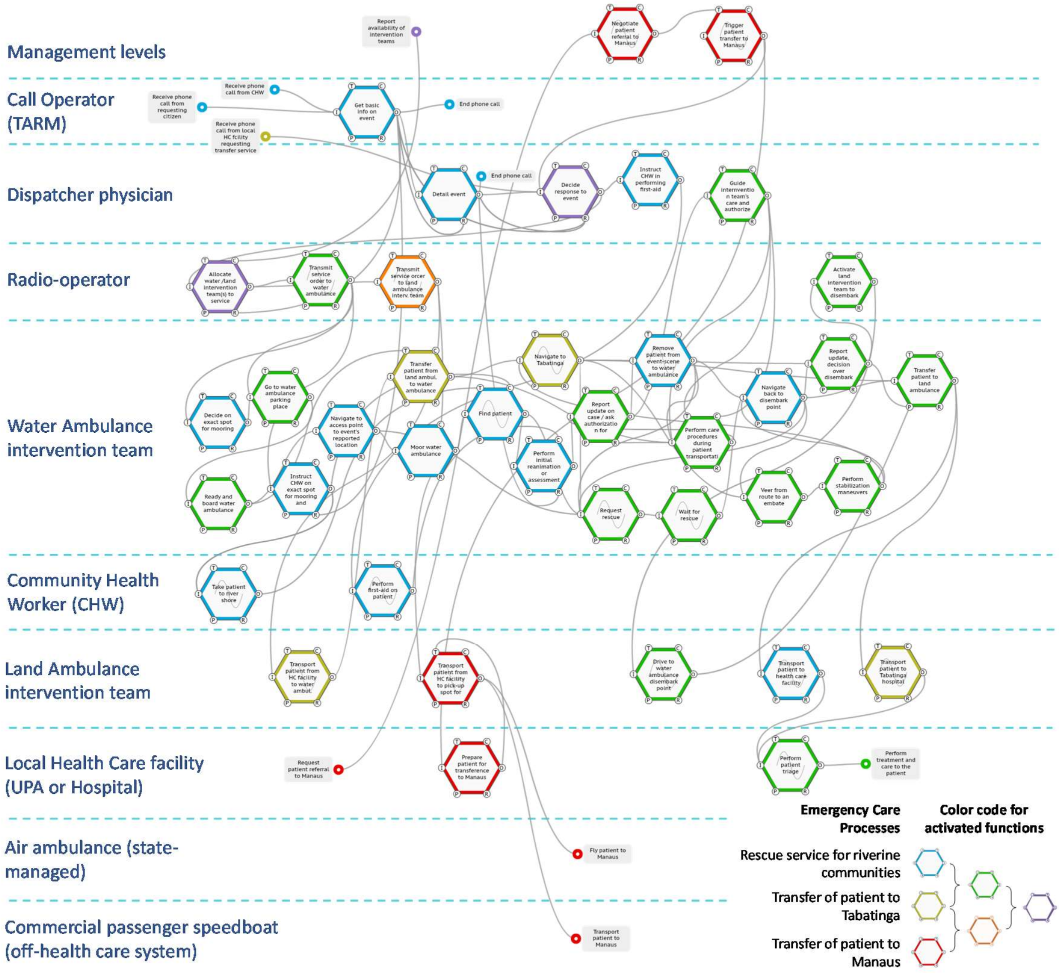


Figure 4-37 - FRAM general model for the mobile emergency care system in the Upper Amazon River region

The model describes how the community healthcare workers (BELLAS et al., 2019; WENNERSTROM; RUSH, 2016) based on the riverine communities – when available – play a fundamental role in addressing the emergencies in this region. They do so in three ways:

1. Mediating communication between the patient/community and the SAMU service, often requesting it themselves;
2. Performing first aid care to patients;
3. Facilitating the patient's location to aid the water ambulance crew, sometimes coordinating the patient's transfer from the occurrence to the water ambulance's docking location for extraction.

The FRAM model shows that the processes carried out for emergency care of the riverine population in Upper Amazon River region occur in coordination between the various SAMU professionals and professionals from other levels of care. Also, the management levels are responsible for background functions whose outputs work as controls and provisions of resources in different operational processes. Some of those background functions are, for instance, “report intervention teams availability” (executed by SAMU Central Dispatch), “supply Personal Protective Equipment (PPEs)” (executed by Municipal Health Departments), and “formulate SAMU protocols” (executed by the Ministry of Health).

It is worth noting that no health agent involved has all the information necessary for effective decision making - they depend on sharing information among themselves. However, despite this scenario of distributed cognition throughout the three processes, they face communication issues due to the poor mobile phone and radio coverage in the region.

4.5.11 Process A - Rescue Service for Patients from Riverine Communities

This process typically begins when the operator receives a call by the patient, patient’s family, local residents or by the local community health worker (CHW) called to the scene. It is usually required that the requester go to a specific location – such as the top of buildings, hills, or trees – in the same community or a neighbour one, to make the call, due to poor mobile phone and radio coverage. Homes that have rural telephones are also places sought after by residents for making the call.

The operator (TARM) then collects critical information about the event, such as the patient’s data, companions, an initial description of the scene, and location – which will be passed on to the water ambulance crew so they can dock the water ambulance as near as possible. If the operator finds it is a hoax, a mistake, or a health event outside the scope of SAMU’s area of expertise, they guide the caller through and end the call. Otherwise, the operator routes the call to the triage /dispatcher physician.

Following the “detail event” and “decide response to the event” functions, the triage physician uses the event / occurrence’s information (which was inserted in the triage software) and SAMU protocols as controls to deepen knowledge about the occurrence. They then determine the appropriate response, including the decision to send a basic or advanced team. Importantly, the output of the functions “get basic info on event” (executed by the operator) and “detail event” (executed by the triage physician) tend to present output variability regarding precision - less accurate data since they are provided by the requester. However, when the caller is the local CHW, the precision of such information is higher, and additional data such as blood pressure can be passed on to the dispatcher physician. In this case, the dispatcher then instructs the CHW on how to provide first aid, according to the nature and circumstances of the event, to keep the patient’s condition stable until the arrival of the water ambulance crew (which may take hours). Thereby, the community health worker can take immediate action such as first measures in assisting childbirth labour, assuring rest and member elevation to victims of venomous wildlife bites, staunch bleeding from work-related injuries etc.

At the Dispatch, the radio operator allocates and activates the water ambulance crew for the event based on the team’s availability, mapped at the beginning of the work shift by the Dispatch’s management. Through the function “transmit service order to water ambulance intervention team,” the radio operator informs the decentralized base about the occurrence – including the requester’s contact information – and dispatches the water ambulance crew. A disturbance related to this function is the impossibility of immediately sending the crew because it may be assisting another event. If so, it is necessary to wait for the water ambulance’s return to the base (or at least the urban perimeter where there is phone and radio coverage) before proceeding with the dispatch. In any case, from the moment the crew is operational, the radio operator and the triage physician are available to be consulted by the water ambulance crew when necessary.

It is essential to highlight that the water ambulance crews are familiar with the geography around the riverside communities and the rivers’ dynamics, which vary according to seasonality (if flooding or drought seasons). Thus, the crew can decide the appropriate location (closest to the occurrence and safest) for docking the water ambulance. There are several specificities regarding this decision. While attempting to access more remote communities, large river branches may have dried out during the season, and contouring it becomes winding and time-consuming. The driver may then decide to land the health attendant and other crew members at an access point closest to this river branch, then bypass it and find the crew already with the patient on the other side.

Once the decentralized base is alerted, the water ambulance crew decides on the best place to dock the water ambulance nearby the occurrence / event scene. Suppose the local community health worker was the requester: in that case, the water ambulance crew attempts to contact them to assess the possibility of the patient being transported to a meeting point to ease extractions/ boarding.

The rescuers then prepare the necessary equipment and materials to handle the occurrence and go to the place where the water ambulance is docked. This step is necessary whenever SAMU does not have a decentralized water base for the water ambulance crew (which is the case for four of the five Upper Amazon River municipalities. Then, the crew prepares the water ambulance, carries out the boarding, and navigates to the occurrence. Upon arriving, they dock at any existing pier, in ravines, or on beaches. Beaches are the least recommended places for docking, as there is a higher chance of stranding the boat, and the subsequent boarding of the patient is hindered. To dock the water ambulance, coordinated action by the driver and the health attendant is usually necessary.

As the crew reaches the patient, the function “perform initial reanimation or assessment maneuvers” is triggered. Medical equipment, PPEs, and information about the occurrence and the patient’s medical history are informed to the team by the requester or people on the scene. The SAMU protocols and the result of the local community health worker’s first aid – before the arrival of the water ambulance crew – act as the control elements for the abovementioned function.

During preparation for extraction, if the patient’s health condition is more severe than imagined, the crew tries to contact the triage physician to update them and ask for guidance. If they can communicate with the Dispatch, the triage physician conducts a briefing with the first responders regarding possible scenarios for the evolution of the patient’s condition, pre-authorizing medical procedures in case communication is not available during the returning trip. The triage physician can later provide further guidance or authorization by reactivating the function “guide intervention team care and authorize procedures”.

Rescuers then maneuver the patient to board the water ambulance. To execute the function “remove patient from event-scene to water ambulance,” the driver must remain in control of the boat during boarding, be it on land or in water. This last scenario can happen when attending the crew of other boats or adrift victims, for instance. The boarding often requires the aid of the local community health worker or others (residents of the community, the patient's relatives, crew of the rescued boats, etc.).

There are still other factors that contribute to the need for assistance from others at this stage. First of all is the water ambulance's design, which does not facilitate the boarding of patients. Secondly, this type of effort is extenuating, especially when transporting and boarding immobilized victims. The distance to be traveled can be long, especially when it occurs during the drought season. At this period, the Upper Amazon River's shoreline recedes greatly from the communities, creating and vast beach areas that take more than 30 minutes to cross on foot. In these circumstances, if the nature of the occurrence does not require the patient to be immobilized during transport, the team may use a net instead of a stretcher. This device allows the physical load to be reduced as others aid the boarding.

Several other disturbances affect the above mentioned function. On occasion, the water ambulance crew must engage in negotiations to convince the patient's family members to allow extraction and care, with reports of hard discussions and violence threats by family members. There is also an early dampening mechanism, triggered when the function "perform initial reanimation or assessment maneuvers" conveys the impression of a severe health condition. In these cases, it is relatively common for the community health worker (or, in larger communities, a health attendant, nurse, or physician) to crew the water ambulance and provide extra support to the intervention team, anticipating possible complications.

With the patient aboard the water ambulance, the health attendant (and a SAMU nurse, who is the head of the decentralized base and joins the crew in the most severe cases) accompanies the patient and performs the tending measures. From that moment on, if rescuers notice the patient's health deteriorating, they will try to contact the triage physician to update them and ask for instructions and authorization to perform procedures. The procedures to be performed by the health attendant are essential, given that the journey may take hours. These measures can be limited, for instance, by the available equipment, the professional's expertise, and the possibility of communication and authorization by the triage physician.

During the transfer journey, there is the possibility that the patient's condition requires specific stabilization measures that can only be done with the water ambulance stopped or with the help of a second person. In both cases, the driver will seek an adequate spot (a sheltered location close to a bank), so that the procedure can be performed.

When approaching the docking location, rescuers call the Dispatch and the decentralized base as soon as within phone and radio coverage to inform coordinates and report updates on the patient's conditions. The disembarking location - decided at this moment by the water ambulance's driver - is also informed so that the radio operator can dispatch a ground crew to pick up the patient.

On arrival, the water ambulance crew briefs the ground crew regarding the rescue. The patient is then taken to the local healthcare facility (usually a hospital or emergency clinic), where the screening and, lastly, assistance will be carried out.

4.5.12 Process B – Transfer of Patients to Tabatinga

This process begins with the local emergency clinic or hospital contacting SAMU's Central Dispatch to transfer the patient to Tabatinga, the largest municipality in the region and home to the most equipped hospital and emergency care clinic. Unlike process A, the Dispatch's operator (TARM), when receiving the request, forwards it directly to the triage physician, who will talk to the health professional of the requesting facility. Together, they decide on how to perform the transfer.

The radio operator then immediately allocates a ground crew and a water ambulance crew, both local, to carry out the transfer. While the water ambulance crew goes to the water ambulance and prepares it for the trip, the ground crew picks up the patient at the health facility and transports them to the boarding point (which is usually not the water ambulance parking spot). Depending on the severity of the case and the availability of personnel at the local healthcare facility, it is common for a health professional from the facility to accompany the patient during their journey to Tabatinga.

The water ambulance crew transports the patient to Tabatinga, a journey that may take from approximately from one hour (when departing from the closest municipality) up to six hours (when departing from more distant ones). During the trip, the green functions (Figure 6) take place as they do in process A. When approaching Tabatinga, the water ambulance crew informs the Dispatch of their proximity and the chosen disembarking point. The radio operator then activates a ground crew to pick up the patient and take them to the local hospital or emergency clinic.

4.5.13 Process C - Transfer of Patients to Manaus

This process is the only one that directly involves municipal management levels for its operation. It starts with the hospital or emergency care clinic from one of the region's municipalities requesting the Municipal Health Department to transfer the patient to a more sophisticated healthcare facility in Manaus, the State capital, which lies about 1,500 kilometers down the Amazon River.

Since the aeromedical service is usually overworked, it is common for the Municipal Health Department to choose alternative transportations, such as express commercial carrier boats. These, however, take approximately 24 hours to reach Manaus and are available only three to four times a week. Also, patient transportation using these boats occurs in an improvised manner - immobilized patients are carried in the boat's floor, besides passengers' seat rows.

Whether by aeromedical transport or commercial boat, the result of the function "negotiate patient's referral to Manaus" determines when the rest of the process will be triggered. When the triggering occurs, the local healthcare facility is advised to prepare the patient for transfer. In contrast, SAMU is called to deploy a ground crew to transport the patient to the location of departure. The patient is then taken to this location and is relocated by aeromedical transport or commercial boat to Manaus.

Except for Tabatinga, the region's SAMU bases hold each only one land ambulance. Therefore, an endogenous disturbance to the function "transport patient from HC (Health Care) facility to pick-up spot for Manaus" is that this vehicle may be in another occurrence when requested. In this case, the compensation mechanism consists of negotiating with the local management the availability of an alternative vehicle to carry out the transportation. This is executed by the decentralized base, after being activated by the Dispatch.

4.5.14 Incidents during operation and the need of rescuing intervention teams

During the execution of processes A and B, incidents can occur while navigating or searching for the patient after docking. Among those, which can happen in correlation, can be cited loss of geo-orientation, motor and other equipment failures, collisions with floating objects (tree trunks, debris etc.) or the riverbed, as well as falls, cuts and wildlife encounters while traveling land routes.

Additionally, SAMU intervention teams in the region are very vulnerable to attacks by riverine pirates. Reports are that the security forces themselves often do not have the resources to face criminals. Therefore, patrolling and surveillance actions during the night are reduced or stopped, despite SAMU's need to operate 24 hours a day (see Figure 4-38).

Figure 4-38 - Floating Military Base named Anzol (Portuguese for "Hook"), constantly moved between locations and used by the Brazilian Federal Police and Armed Forces to intercept vessels and help fighting drug traffickers and pirates in the Upper Amazon River region. It had been deactivated at the time we performed fieldwork.

Source: Department of Federal Police / Tabatinga

All these issues may preclude the crew from proceeding with the operation or escalate into accidents, making arise the need for the rescue of the water ambulance crew itself – sometimes along with the patient on board. There are no formal procedures established to handle such situations.

In our FRAM representation of the system, this dynamic is modelled through disturbances that can affect respective functions and create output variability, ultimately leading to activation of the "request rescue" function.

In this step, the water ambulance crew may resort to three paths of action: (a) calling the local Municipal Health Department to request a boat from the fire department, civil defense, or the military; (b) calling the crew's relatives, friends, or acquaintances who have boats and are available to conduct the rescue; and (c) draw attention to people or boats in sight, alerting them of their need of assistance. Thus, in the event of a rescue, water ambulance crews may depend on boats that were not designed for this purpose, or on informal arrangements based on personal connections from the crew. It is important to note that after a rescue is carried out during process B, the crew will head to the closest harbour instead of continuing the long trip to Tabatinga. This is represented in the model as the output of the function “wait for rescue” serving as input solely for the function “navigate back to disembark point”.

There are two main underlying reasons why the functions “request rescue” and “wait for rescue” occur under such vulnerability conditions. Firstly, there is no SAMU water ambulance redundancy in each municipality. Moreover, there is an overall shortage of other water vehicles for essential public services in the region, such as the police, fire department, and civil defense.

Secondly, riverine emergency care depends on crews traveling long distances over vast territories under no phone or radio coverage. This not only impedes the crew to alert the Dispatch over their need to be rescued, but also creates a “blind time window” that delays in several hours the time needed for the Dispatch to start considering on its own the possibility of an accident as a reason why communication has not been reestablished.

4.5.15 Study II

Study II was aimed at using FRAM as a prospective analysis tool to address the research question. Therefore, from the general FRAM model for the mobile emergency care operation in the Upper Amazon River region, we formulated a predictive model for estimating system behaviour during the COVID-19 pandemic. This formulation was based on the assumption that as the crisis reached the region, it would come to alter general overall system functioning through at first directly impacting variability dynamics in specific functions. Then, by means of their output variability these functions would in turn affect the rest of the system as a whole.

4.5.16 Methods

Research steps were designed in order to calibrate the general FRAM model to accommodate instantiations considering the effect of the COVID-19 pandemic in the region.

In the first step of the proposed formulation, we analyzed each previously modeled system function based on knowledge gathered from their behaviour and considered potential changes in their variability dynamics due to the pandemic. From this, we identified group of directly impacted functions and produced estimations on the influence the pandemic would have over them. Impacts can be summarized as the **increase in likelihood (↑L) or severity (↑S) of some endogenous disturbances**, **the rise of new endogenous disturbances (N)** and the **decrease in maneuverability of some dampening mechanisms (↓M)**.

In a second stage for the development of the predictive model we carried out the analysis of functional resonance. From it, we came to identify how variability couplings might drive three trends that lead to the collapse of the mobile emergency care system in the region. These three scenarios, each conveyed by a group of potential instantiations enabled within the pandemic influence, are detailed in the next subsections.

For each one, a table and a figure are presented. The table details the variability dynamic for the directly impacted functions, while the figure shows a zoomed-in graphical perspective of the predictive model for said scenario, highlighting the output variability produced by directly impacted functions. Conversely, functions and couplings that, due to the pandemic, do not insert additional output variability in the system are not highlighted and detailed in the respective figure and table. With regard to pandemic impacts, those play the sole role of carrying output variability generated by the highlighted functions further downstream along processes A, B and C.

4.5.17 Results

4.5.18 Scenario 1 – Deterioration of Capability to Handle Processes' Demands

The emergency care processes for the Upper Amazon River riverine population has been designed for a regular demand, which is typically low. On the other hand, the COVID-19 crisis had the potential to increase demand for emergency care in the region while simultaneously impacting these process through their functions' behaviour. Therefore, while the usual operation of the ambulance service already presents a considerable misalignment between demand (pressures exerted on the system) and capacity (resources available to deal with such pressures) (ANDERSON; ROSS; JAYE, 2017; DEKKER, 2011, cap. 7), we estimated the COVID-19 pandemic would widen this gap, making the operation less able to cope with the critical conjuncture. The FRAM predictive model for this scenario is shown on Figure 4-39 and detailed on Table 4-16.

Functions and couplings highlighted insert new delays into the system or conditions for delays in following functions. Couplings not highlighted still play a role of transmitting delays downstream.

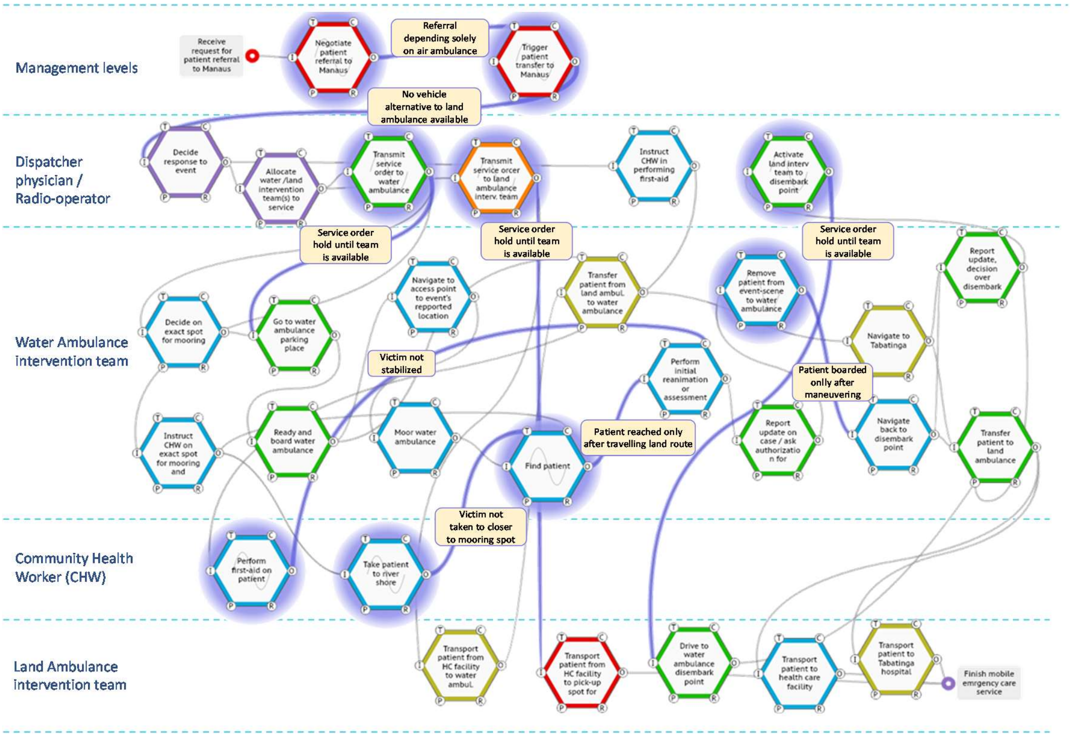


Figure 4-39 - Prospective Analysis - Scenario I – Graphical model

Table 4-16 - Prospective Analysis - Scenario I – Detailing

Function	Output	Exogenous Disturbances (from upstream functions)		Endogenous Disturbances	Dampening Mechanisms	Output Variability Regarding Timing	
		Upstream function	Output variability			Range	Description
Transmit service order to [water / land] ambulance intervention team / Activate land intervention team to disembark point	Service order received by [water / land] ambulance interv team / Land intervention team activated			N: Team members are infected ↑L: Not possible to contact interv team	None available, given limited resources (single water and land ambulance per serviced area)	↑L: Too late	Service order hold until team is available
Perform first-aid on patient	First-aid performed by CHW			N: no means provided to stabilize signs and symptoms from COVID-19	None available	↑L: Omission	Victim not stabilized
Take patient to river shore	Patient's arrival at river shore			N: CHW and residents fearful of approaching infected victim	None available	N: Omission	CHW and residents does not transport victim to closer to mooring point
Find patient	Patient found	Take patient to river shore	N: Victim not brought closer to mooring point		↑L: Follow unknown land route to reach patient further inland	↑L: Too late	Patient reached only after travelling land route. Land routes can take up to 1 hour of walking
Remove patient from event-scene to water ambulance (1st Dynamic)	Patient aboard water ambulance	Take patient to river shore	N: Victim not brought closer to mooring point	N: CHW and residents fearful of approaching infected victim	↑L: Follow unknown land route back to water ambulance	↑L: Too late	Water ambulance reached only after travelling land route without help to transport patient. Land routes can take up to 1 hour of walking
Remove patient from event-scene to water ambulance (2nd Dynamic)	Patient aboard water ambulance			N: CHW and residents fearful of approaching infected victim	↑L: Board patient without help	↑L: Too late	Victim boarded only after maneuvering. More time needed to position patient and water ambulance to enable boarding
Negotiate patient referral to Manaus	Patient referral scheduled			↑L, ↑S: Aeromedics not available in time window safe for patient	↓M: Negotiate transfer via commercial passenger speedboat	↑L, ↑S: Too late	Delayed output and dependence of function on state-managed air ambulance's time schedules
Trigger patient transfer to Manaus	● Local HF facility triggered for the transference ● SAMU triggered for the transference			N: Team members are infected ↑L: Not possible to contact land interv team	↓M: Negotiate with Municipal Health Department the use of another vehicle	↑L: Too late	Delayed output. Function can only be executed when interv team is discharged from previous service order

For processes A and B, our analysis indicated that the impacts of the pandemic in functions' disturbances and dampening mechanisms would make room for potential instantiations where delays resonated and made effective emergency care unfeasible. This would happen through response times incompatible with the severity of the patients' conditions, either due to delays while delivering care or delays at dispatching the water ambulance crews. Moreover, our analysis pointed to a compound effect of these two dynamics, since dispatch of intervention teams could be delayed just through the sole increase in service orders, but also through the delays in previous service orders.

Initially, the large number of service orders during the COVID-19 pandemic leads to an increase in the likelihood in which the function "transmit service order to water ambulance intervention team" delays. This is due to the water ambulance crew being continuously allocated to occurrences. It is worth noting that, given the limited resources and a single ambulance available for each decentralized base, no compensation mechanisms are available to handle such disturbances.

In process A, the community health worker is responsible for providing first aid measures, which are essential for stabilizing the patient before the crew's arrival, as cited earlier. However, for severe COVID-19 cases, which involve symptoms such as respiratory failure, for example, the community health worker does not have the means to handle such a situation from the outset. This, subsequently, affects downstream functions.

Still concerning process A, the function "find patient" is facilitated if it is possible to previously inform the local community health worker regarding the mooring point of the water ambulance (control element). Also, if the community health worker was able to transport the victim (with or without the residents' help) to the berth's vicinity, the function can be performed quickly.

However, during the pandemic, this transport is hindered due to community health workers being afraid of getting infected, as they do not have PPE or training for the safe management of COVID-19 patients. This aspect, originating from the function "take the patient to river shore," impacts the function "find patient" as a new exogenous disturbance. In turn, this disturbance requires, as a dampening mechanism, that rescuers traverse the community area, sometimes at night and through forest trails unknown to them, posing the risk of disorientation, falls, or encounters with dangerous wildlife (see Figure 4-40).

Figure 4-40 - Riverine community in the Upper Amazon River region. Communities' populations range from several dozens to a few thousand residents, and may spread several kilometers inland

With the increased number of occurrences and this fear of contagion by CHWs and residents, the consequences of lack of adequate lighting equipment (flashlights and others) are aggravated. The team then ends up having to use lighting from their personal cell phones. The success of using said damping mechanism will still delay the service, while failure can interrupt the operation and make the need for the water ambulance crew's rescue, as aforementioned.

This fear of community health workers and residents have can also be observed during the function "remove patient from event-scene to water ambulance." Since this function often demands help from others to be adequately performed, this factor can delay its completion.

The functions performed by the land intervention team can also delay – such as transferring the patient from the water ambulance to local health facilities. Regarding process B, there can be a delay for the function "transmit service order to land ambulance intervention team." Once again, this is because a large number of rescues seen during the pandemic lead to increased frequency in which the only land ambulance present in each municipality would be unavailable. There is no dampening mechanism to deal with this disturbance. Moreover, once arrival at the definitive health facility, the patient's screening may also be delayed due to the large number of COVID-19 cases being handled.

Regarding process C, our analysis indicated the COVID-19 pandemic would also impact the delivery of care. This happens as the crisis simultaneously increases the likelihood of disturbances and decreases the maneuverability of the dampening mechanisms for two key functions, executed by the Municipal Health Department management.

Firstly, for the function "negotiate patient referral to Manaus," the Health Department may not be able to provide aeromedical service in time, due to high demand. At the same time, it may be challenging to negotiate patient transportation with those responsible for commercial speedboat services. Thus, the patient may not get a ticket to commercial boats, and, therefore, may rely exclusively on the availability of aeromedical transport to Manaus.

Secondly, the function "transport patient from HC facility to pick-up spot for Manaus" will be delayed if the SAMU ground crew is unavailable to transfer the patient to the aeromedical plane or commercial boat. This may delay the transfer since the compensation mechanism (negotiating with the local Health Department for another vehicle) becomes fragile during the crisis. On the one hand, this happens because vehicles and resources in general made available by the local Health Department have higher demand during a pandemic. On the other hand, these alternative vehicles will only be used to transport COVID-19 patients if they present low-risk of infection to the crew, and if it is possible to sanitize the equipment and surfaces after use.

4.5.19 Scenario 2 – Exposure to Infection and Reduction of Intervention teams Available

From the knowledge we had gathered from the operation as described in the previous section, it was clear that – considering processes A and B - once the pandemic hit the local water ambulance crews and community health workers would be fairly exposed to COVID-19. The provision of PPEs to water ambulance crews is a responsibility of the local Health Departments where the decentralized bases are located. In the pandemic context, the ultra-peripheral character of these municipalities and the expected lack of PPEs to local crews – and to community health workers – would increase risks, reduce the availability of emergency care professionals, and facilitate the COVID-19 outbreak as the teams themselves could unknowingly carry the virus to more isolated communities. The FRAM predictive model for this scenario is shown on Figure 4-41 and detailed on Table 4-17. Functions and couplings highlighted insert into the system an added risk of contamination between people, clothes, objects and surfaces. Couplings not highlighted still play a role of transmitting the risk of infection downstream.

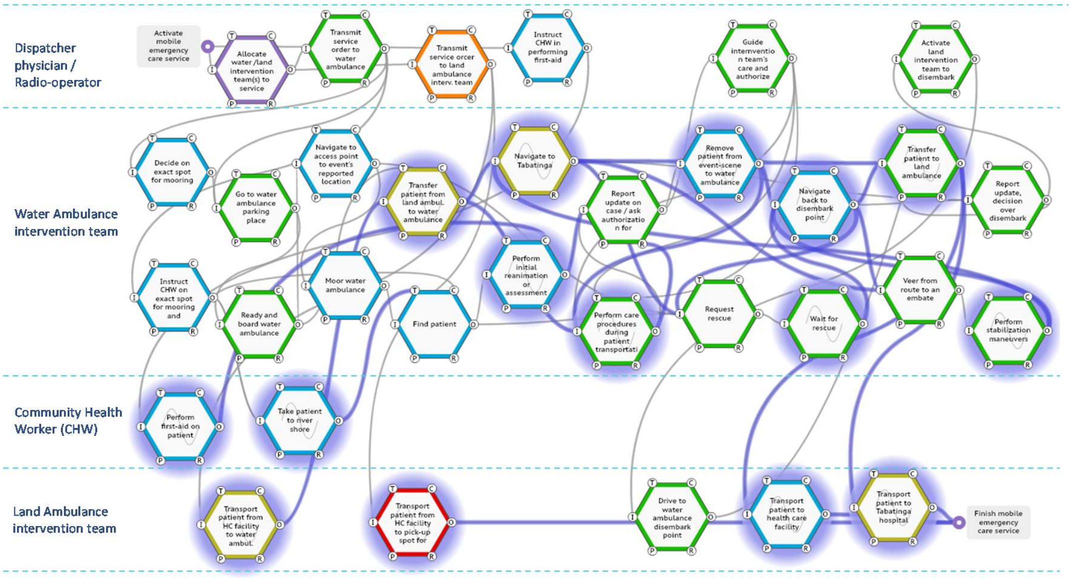


Figure 4-41 - Prospective Analysis - Scenario II – Graphical model

Table 4-17 - Prospective Analysis - Scenario II – Detailing

Function	Output	Exogenous Disturbances (from upstream functions)		Endogenous Disturbances	Dampening Mechanisms	Output Variability Regarding Precision	
		Upstream function	Output variability			Range	Description
Transfer patient from land ambul. to water ambulance	Patient on board water ambulance			N: Risk of infection while manipulating patient	Mostly non available: no sink in vehicles / limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Perform first-aid on patient	First-aid performed by CHW			N: Risk of infection while manipulating patient	Mostly non available: no training / no PPIs	N: Imprecise	CHW becomes infected. Clothes / objects become infected
Take patient to river shore	Patient's arrival at river shore			N: Risk of infection while in physical contact with patient	Mostly non available: no training / no PPIs	N: Imprecise	CHW becomes infected. Clothes / objects become infected
Perform initial reanimation or assessment maneuvers	Initial maneuvers performed			N: Risk of infection while manipulating patient	Mostly non available: limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects become infected
Remove patient from event-scene to water ambulance	Patient aboard water ambulance			N: Risk of infection while manipulating patient for long period	Mostly non available: limited PPIs	N: Imprecise	Intervention team / CHW / community residents become infected. Clothes / objects / surfaces become infected
Navigate back to disembark point	● Arrival at disembark point ● Need to pause trip to stabilize patient ● Incident on trip			● N: Risk of infection when in close proximity with patient for long periods ● ↑L: Multiple victims on board	Mostly non available: tight space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team / second victim / escorts / become infected. Clothes / objects / surfaces become infected
Navigate to Tabatinga	● Arrival at Tabatinga harbour ● Need to pause trip to stabilize patient ● Incident on trip			● N: Risk of infection when in close proximity with patient for long periods ● ↑L: multiple patients on board	Mostly non available: tight space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team / assigned health care facilty proessional / second patient / become infected. Clothes / objects / surfaces become infected
Perform care procedures during patient transportation	Care procedures performed			N: Risk of infection while manipulating patient	Mostly non available: limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Perform stabilization maneuvers	Availability to continue trip			N: Risk of infection while manipulating patient	Mostly non available: limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Wait for rescue	Rescue arrival			● N: Risk of infection when in close proximity with patient for long periods ● ↑L: Multiple victims on board	Mostly non available: tight space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team / assigned health care facilty proessional / second patient / escort / become infected
Transfer patient to land ambulance	Patient transferred to land ambulance	Activate land intervention team to disembark point / Drive to water ambulance disembark point	↑L: Service order hold until land team is available	N: Risk of infection while manipulating patient	Mostly non available: no sink in vehicles / limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Transport patient from HC facility to water ambul. pking spot	Arrival at water ambulance parking spot			N: Risk of infection when in closed space with patient	Mostly non available: tight space / closed space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Transport patient from HC facility to pick-up spot for Manaus	Patient at pick-up spot			N: Risk of infection when in closed space with patient	Mostly non available: tight space / closed space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Transport patient to health care facility	Arrival at health care facility			N: Risk of infection when in closed space with patient	Mostly non available: tight space / closed space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected
Transport patient to Tabatinga hospital	Arrival at Tabatinga hospital or UPA			N: Risk of infection when in closed space with patient	Mostly non available: tight space / closed space / no sink in vehicles / limited PPIs	N: Imprecise	Intervention team becomes infected. Clothes / objects / surfaces become infected

From the moment the water ambulance crew finds a victim infected with COVID-19 and carries out the first stabilization and inspection measures, an extended period of exposure is initiated for mobile emergency care workers. This period may last hours and comprises patient transportation, care procedures, transfer for land ambulance crew, ceasing only with the patient’s arrival at the hospital or emergency health care clinic. There is higher direct contact with the patient during functions “perform initial reanimation or assessment maneuvers," "remove patient from event-scene to water ambulance," "transfer patient to land ambulance," "perform care procedures during patient transportation," and "perform stabilization maneuvers." PPEs such as face shields, masks, gloves and overalls are essential to minimize exposure to the virus, but are scarcely provided as verified during Study I.

During the "navigate back to disembarking point" and "navigate to Tabatinga" functions, there is no physical contact between crew and patient. However, given the small space inside the water ambulance, the proximity to the patient for hours poses the risk of infection (see Figure 4-42). This is increased by the fact that, since the demand for emergency care has increased, the crew may need to transport more than one patient simultaneously.

Figure 4-42 - Cabin interior space in Tabatinga's water ambulance, docked at its stand-by location. The crew stays in close proximity to the victims during the hours-long journey back

For the navigation functions, the dampening mechanisms would be the ones already recommended by health authorities: maintaining the greatest distance possible from the patient, regularly cleaning hands, avoid touching faces, and, at the end of the service, sanitizing the workplace and equipment.

Unfortunately, the availability and structure of water ambulances in the region are not prepared to support these dampening mechanisms. This holds true during the service operation (small space, lack of bathroom, sink and PPEs) and for hygiene actions between occurrences (inadequate cabin design and no time available due to soaring demand for the service during the pandemic). Therefore, risk of infection is increased as process A or B unfolds, due to functional resonance. Land crews also face similar issues with their vehicles.

Regarding community health workers, they are significantly exposed during the execution of the functions "take the patient to river shore" and "perform first-aid on patient," given the lack of PPEs and training to safely handle severe COVID-19 symptoms. There is no effective dampening mechanism that the community health workers can activate in these cases.

4.5.20 Scenario 3 – Complexification of Team Rescue

Another way in which we estimated the COVID-19 pandemic to widen the gap between demand and capacity for mobile emergency care happens whenever the water ambulance crew itself needs to be rescued during the operation. Although already a critical situation under typical conditions as aforementioned, a number of factors makes rescues under the pandemic setting extra challenging. The FRAM predictive model for this scenario is shown on Figure 4-43 and detailed on Table 4-18. For this scenario, the sanitary crisis' impact lies in facilitating conditions for incidents to emerge and, on the other hand, adding obstacles to the rescue functions.

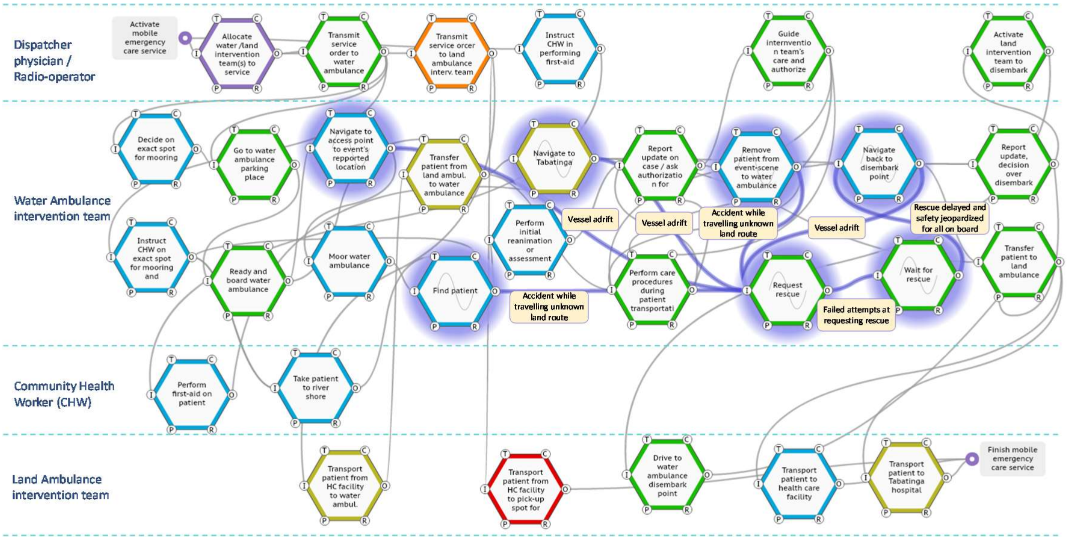


Figure 4-43 - Prospective Analysis - Scenario III – Graphical model

Table 4-18 - Prospective Analysis - Scenario III – Detailing

Function	Output	Exogenous Disturbances (from upstream functions)		Endogenous Disturbances	Dampening Mechanisms	Output Variability Regarding Timing	
		Upstream function	Output variability			Range	Description
Navigate to access point to event's repported location	● Arrival at access point ● Incident on trip			↑L: motor failure (due to extended use in subotimal conditions)	None available	↑L: Omisssion	Not possible to reach event location and need to request rescue
Find patient	● Patient found ● Incident on trip			↑L: need to find way through land route in adverse conditions (unknown / during the night)	Scarcely available (inadequate or incomplete tools and PPI provided)	↑L: Omission	Intervention team unable to reach patient and needs rescue due to getting lost or having accidents (falls / cuts / wildlife encounters)
Remove patient from event-scene to water ambulance	● Patient aboard water ambulance ● Incident on trip	Take patient to river shore	N: Victim not brought closer to mooring point	↑L: need to find way through land route in adverse conditions (unknown / during the night)	Scarcely available (inadequate or incomplete tools and PPI provided)	↑L: Omission	Intervention team unable to reach back water ambulance and needs rescue due to getting lost or having accidents (falls / cuts / wildlife encounters)
Navigate to Tabatinga	● Arrival at disembark point ● Need to pause trip to stabilize patient ● Incident on trip			↑L: motor failure (due to extended use in subotimal conditions)	None available	↑L: Omisssion	Not possible to reach Tabatinga and need to request rescue
Navigate back to disembark point	● Arrival at disembark point ● Need to pause trip to stabilize patient ● Incident on trip			↑L: motor failure (due to extended use in subotimal conditions)	None available	↑L: Omisssion	Not possible to reach disembark point and need to request rescue
Request rescue	Rescue requested	All listed above	↑L: Need to request rescue	● ↑L: Fewer Municipal Health Department vessels are available to rescue due to handling of pandemic ● N: Local known boat owners as well as boats passing by afraid of prolongued contact with potential COVID-19 patient in small boat	None available	↑L: Omisssion	Attempts at requesting rescue fail. Difficulty in requesting rescue
Wait for rescue	Rescue arrival	Request rescue	↑L: Difficulty in requesting rescue		Sustain victim vital signs as well as possible	↑L, ↑S: Too late	Rescue takes longer to happen, potentially threatening victim health condition and exposing all on board to infection and to be intercepted by river pirates

Under the pandemic navigation functions become more likely to produce incidents. As the number of events increases due to the pandemic, so does the use of navigation components and the likelihood of failures in them – notably in the boats' motors. The water ambulances in the region are equipped with four-stroke engines with electronic fuel injection; these are more sophisticated but less resistant, and not quite suitable for operation in the Upper Amazon River region. In this region, the waters have a lot of natural debris, and the fuel available in stations is unreliable, causing constant clogging. Additionally, the drivers do not have training in engine mechanics and boat machinery, which could give them more autonomy in their trips and reduce the need for their rescue. Beyond navigation functions, the sanitary crisis also changes variability dynamics for the function "find patient" - as already observed within Scenario 1 - which may make the crew to need rescue while traversing a land route.

Once the "request rescue" function is activated, the pandemic directly affects it on two fronts:

- Local Health Department's boats - dispatched to the rescue whenever the water ambulance crew in trouble is able to call their decentralized base - become less available during the pandemic, due to the healthcare system being under pressure;
- Local boatmen known to the crew, as well as boats in sight nearby, may be afraid of risking a rescue in which they may need to transport a (or multiple) patient(s) with COVID-19 for long periods on an even smaller boat than SAMU's (see Figure 4-44).

Figure 4-44 - The SAMU pilot's workstation. In cases when the crews faced the need to be rescued, missing radio and phone coverage have forced them to rely on boatmen passing by

As a result, the following function “wait for rescue” may take longer to be completed. This puts the patient at risk (due to their condition worsening), and increases contamination hazard for the intervention team (due to the greater exposure if the transported patient is infected with COVID- 19).

4.5.21 Validation

After the pandemic’s first wave peak in the region, which happened at about July 2020, the three scenarios described in the Results section were validated by supplementary interviews carried out remotely with members of SAMU’s management and teams from the Upper Amazon River region. The variability foreseen in the prospective analysis for the functions activated along the three processes was confirmed.

Specifically, we were able to confirm our estimated output variability from functions as well as its source as changes in variability dynamics regarding:

- Increase in likelihood (↑L) of some endogenous disturbances, such as holding service order until availability of teams for land team in functions “and motor failure during navigation functions in general;
- Severity (↑S) of some endogenous disturbances, such as the length of delays to transport patient through aeromedic plane at function “negotiate patient referral to Manaus”
- Rise of new endogenous disturbances (N), such as the need for CHWs to cope with COVID-19 signs and symptoms in functions without proper equipment at function “perform first-aid on patient”, and fear from residents in approaching the victim and helping the crew at functions “take patient to river shore” and “remove patient from event-scene to water ambulance”;
- Decrease in maneuverability of some dampening mechanisms (↓M), such as compromised negotiation to transfer patient via commercial passenger speedboat at function “negotiate patient referral to Manaus”.

We were also able to confirm that through functional resonance these changes in variability led to: (1) delays on emergency care provided and difficulty in attending to demand (e.g., due to couplings between functions “take the patient to river shore” and “remove patient from event-scene to water ambulance”), (2) COVID-19 outbreak throughout a large part of the SAMU rescuers (e.g., due to couplings between navigation and care performing functions), and (3) difficulty in rescuing (e.g., due to couplings between functions “navigate to Tabatinga” and “request rescue”). As this research was developed, many members of the SAMU teams had already been infected.

Thus, the FRAM modeling of the emergency care system during regular functioning enabled the risk analysis of its abnormal functioning during a crisis, namely the COVID-19 pandemic. However, an additional change in the system’s functioning during the pandemic has been reported. This concerned the operation of the water ambulance crew in coordination with the primary care strategy. In the Upper Amazon River region, each municipality has a mobile riverine primary care clinic (see Figure 4-45) that continuously travels throughout local riverside communities to provide primary care services.

Figure 4-45 - Mobile Riverine Primary Care Clinic

During the pandemic, the primary care teams identified, within communities, severe COVID-19 cases that required extraction to local specialized healthcare facilities. Thus, water ambulance crews started to monitor the mobile health clinic and its itinerary, to speed up the assistance, and sometimes even escort mobile riverine primary care clinics, to attend to patients as soon as possible. This shows the importance of coordination between local health operations at different levels during adverse events. Water ambulance crews have temporarily become, in fact, extensions of, and support to, primary care, in addition to their already established role of primary care in mitigating urgent care cases in riverine populations (LANÇA, 2017).

4.5.22 Discussion

In extreme health events like the ongoing pandemic, healthcare teams encounter even higher demands than usual regarding the provision of care and aspects related to their safety (DOYLE; GRAVES; GRUBER, 2017; SJÖLIN et al., 2015). In addition to the different demographic, social, economic, cultural, and health contexts in Brazil, the ongoing COVID-19 pandemic pressures, even more, the framework of health assistance to riverine populations. Alongside the water ambulances' limitations, this health crisis poses new risks to these communities and compromises the quality of healthcare services. It is important to highlight here that regular emergency healthcare demands continue during pandemics. The historically prevalent events in the region are strokes, diseases, surgeries, childbirths, car accidents, traumas, cuts, and stings, among others.

The management of cases – suspected or confirmed – of COVID-19 includes support and comfort measures, social distancing and quarantine, and monitoring communities. This management is intended until the number of new cases diminish enough so that these mitigation efforts can be eased. For severe COVID-19 cases, it includes clinical stabilization, referral, and transportation to specialized facilities, emergency services, or hospitals.

Resilience means not only being able to adapt (latent capability) but also changing organizational behavior to focus on adaptation (manifest behavior) when necessary (HUBER; GOMES; DE CARVALHO, 2012). Therefore, it is essential to highlight that the ongoing COVID-19 pandemic emphasized existing problems regarding SAMU's operations. For example, in normal operation conditions, providing PPEs for professionals was already complicated.

The three described scenarios reflect the deterioration of system safety for mobile emergency care in the Upper Amazon River region. Their latent instantiations also point out the essential role of community health workers from riverine communities in attending to emergencies while focusing on providing first aid measures to patients (OZANO et al., 2018).

Due to their experience and the nature of the epidemiological profile of the occurrences, the community health workers are generally able to provide first aid (JATOBÁ et al., 2020). Typical examples are accidents with mowing tools (chainsaw, machetes, and others), heart attacks, snake bites, etc. However, community health workers do not have medical instruments or PPEs for primary care for critically ill COVID-19 patients. Thus, providing training and proper equipment to the community health workers could facilitate their jobs and improve the healthcare provided by them (BALLARD; MONTGOMERY, 2017).

Another relevant aspect concerns the fact that the system has become accustomed to using commercial passenger boats to carry out extractions. However, during outbreaks this transportation method must be avoided from carrying out this activity, because it offers the risk of contamination for other passengers. This is especially relevant since processes B and C, which in typical situations are less representative, during the pandemic became the main processes.

There is one last aspect that should be highlighted. As expected, during the ongoing pandemic, the water ambulance is dispatched to rescue and care for patients in more severe conditions, who need medical monitoring. However, the regular water ambulance crews are composed of health attendants and drivers. During this period, advanced health teams with physicians should be made available by the Ministry of Health and the State Government.

The typical response to the COVID-19 pandemic has been to invest in infrastructure and expand the healthcare capacity to receive and treat patients – with an increase in the availability of beds, respirators, and health professionals (CHOPRA et al., 2020; MEARES; JONES, 2020; WHITE; LO, 2020). However, the Amazon region, and particularly sub-regions furthest from the capital, such as the one studied here, pose a unique challenge to healthcare systems, which is to make sure patients can be brought the systems and guarantee their access to healthcare.

4.5.23 Conclusion

Urgent care and transportation to riverine communities in the Upper Amazon River region are possible not only because SAMU professionals follow prescribed rules rigorously, but because they make performance adjustments based on available resources. The Safety-II perspective, describing the behavior of the system's functions, as modeled by FRAM, shows how performance variability – manifested through functions' dampening mechanisms – is vital to building safety while allowing urgent care to be delivered.

However, the elements that add to the resilient capabilities of this system are extra-organizational. They are essentially exogenous to SAMU (when they depend on an initiative from the local community health worker) and even to the whole public healthcare system (when they rely on an effort from the residents' actions). Therefore, since the intervention operation (and particularly process A) tends to depend on an *ad hoc* help from the population, safety has become jeopardized as informal support networks become more fragile.

This may be because residents' help does not show up as expected or in high enough proportion, due to their fear of infection. Alternatively, the water ambulance crews may end up contributing to spread the coronavirus across riverine communities and rural areas. CHWs and residents transport patients using their hands and arms; they do not possess expertise in urgent care maneuvers, and are generally not equipped with PPEs. When extracting COVID-19 patients for the water ambulance crew, they may become infected and require emergency care themselves.

The use of the FRAM for modelling regular operation enabled a prospective scenario analysis that accurately predicted disruptions in the delivery of emergency care to riverine population. The FRAM analysis, pandemic scenarios and latent instantiations show that the pandemic directly impacts a significant number of functions while regarding the disturbances they face, and the dampening mechanisms they employ to handle them. A Safety-I reasoning, as well as the application of traditional risk assessment, may prove to be ineffective, given that there are plenty of things to prevent. Therefore, a Safety-II approach may be helpful since it describes deviations from the system's normal functioning, focusing on effective practices, and particularly how to avoid disturbances from affecting SAMU professionals.

5 Discussion, Contributions and Further Developments

To investigate and move toward solutions for variability management to reconcile WAI and WAD, the five studies presented in this thesis were conducted under a systems theory approach, both during data collection and analysis. This is evidenced by the very nature of Ergonomics and Resilience Engineering as systems disciplines. Systems theory was created as an alternative to analytic reduction (ACKOFF, 1971; BERTALANFFY, 1984; CHECKLAND, 1981; WIENER, 1948). The systems approach concentrates on the analysis and design of the whole as distinct from the components or parts (LEVESON, 2017), with system properties deriving from the relationships among the parts of systems i.e. how the parts interact and fit together (ACKOFF, 1971).

One important distinction that has been presented in systems theory is the one on closed versus open systems (BERTALANFFY, 1984). Through a series of examples, Bertalanffy poses that closed systems have no communication with their environment and therefore, components tend to settle into a state of simple equilibrium – i.e. maximum enthropy. On the other hand, open systems are subject to information exchanges with their environments, maintaining themselves "in a continuous inflow and outflow", never being in a state of equilibrium but instead "in a so-called steady state which is distinct from the latter" (BERTALANFFY, 1984, p. 39). Their behaviour is therefore characterised by the constant search for a dynamic equilibrium – the steady state - as a response to the information exchanged with their environment. For that purpose, open systems are characterized by catalyzers that aim to bring the system to the steady state asymptotically, even in the face of disturbances (Figure 5-1, cases b and c) (BERTALANFFY, 1984, cap. 6).

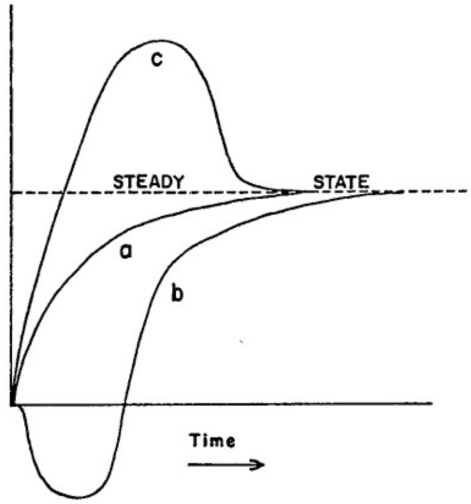


Figure 5-1 – Schematic representation of asymptotic approach to steady state (a), false start (b) and overshoot (c) in open systems

(BERTALANFFY, 1984, cap. 6)

As open systems develop adapting mechanisms to their environment, they tend to acquire traits of complexity. Heylighen (2008) poses that self-organization and adaptivity occur in complex systems as they are maintained at the edge between order and disorder. Euerby and Burns (2010) add that it is the former that give rise to the latter - a variety of self-organized structures or processes enable the possibility of adaptability. Complex systems are subject to high degrees of unexpected variability (SAURIN; WERLE, 2017). As a consequence for the design and management of organizational and technological aspects, if a complex sociotechnical system is to support adaptability, degrees of freedom for self- organization must be left open (EUERBY; BURNS, 2010).

Resilient systems are those that are capable of adjusting before, during, or after changes and disruptions so that the system can keep the necessary operations running in expected and unexpected conditions (HOLLNAGEL, 2011). Thus, it is essential to acknowledge that a portion of the variability encountered is inevitable and sometimes good (DEKKER, 2011; HOLLNAGEL, 2012). Therefore, how different system functions are coupled and how well they are prepared to manage variability (mitigating disturbances and restoring degraded paths back to a steady state) can determine system outcomes and safety (Figure 5-2) (VIDAL et al., 2016).

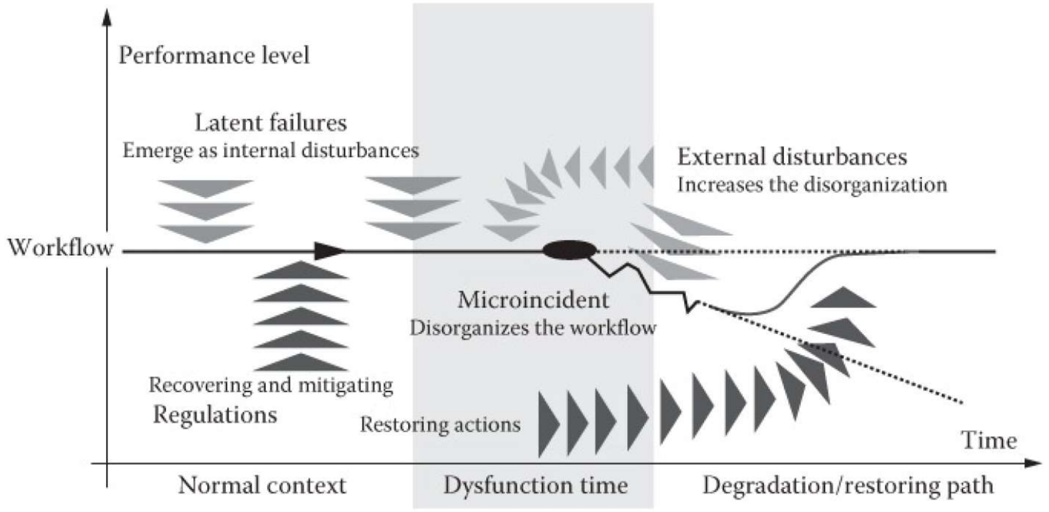


Figure 5-2 – Core of variability management

(VIDAL et al., 2016)

The discussion of this thesis structures itself from contributions of the four papers that are comprised in it. The synthesis of the papers' contributions as well as an overview of how they answer the research questions posed at Section 1.1 are shown in Table 5-1. In the next subsections we discuss each article's findings, contributions and report on follow-up developments being currently carried out.

Table 5-1 - Overview of how Articles A-E answer research questions and summary of key contributions

	Article A Patient visits in poorly developed territories: a case study with community health workers	**Article B** Gatekeeper family doctors operating a decentralized referral prioritization system: Uncovering improvements in system resilience through a grounded-based approach	**Article C** Information Technology Systems at the sharp end of medication therapy management	**Article D** Understanding and improving safety in artisanal fishing: A safety-II approach in raft fishing	**Article E** A Safety-II Analysis on the Effects of COVID-19 on the Access to Urgent care of Amazon's Riverine Populations
Methodological contributions	How different intances from the system's environment may activate certain couplings and set the system in different resonance paths	How different adjustment maneuvers at the sharp end couple between themselves to tackle big-order issues of demand-capacity misalignments in the system	How functional resonance can escalate trade-offs between precision and timing into a sacrifice dilemma where operators cannot choose thoroughness over efficiency	How operators construct their everyday safety in an environment lacking safety proceduralization by constantly adjust their performances to match the conditions of work	How to identify and predict the behaviour of a complex system put under stressful conditions, based on previous understanding of its normal functioning
RQ1: How are system outcomes and safety impacted by variability in complex systems?	Problems from territory conditions can hamper or halt patient visits despite CHWs efforts to cope with them	Gatekeeper doctors and primary care teams coordinate through a number of adjustment maneuvers so patients can receive specialized care in adequate time	Resonance between altered outputs from dispensing pharmacist's functions can create a sacrifice dilemma when dispensing medication	Fishermen make continuous assessment and performance adjustments to guarantee their subsistance while building their safety on the go	Changes in variability dynamic brought by the pandemic ressonate to increase response times and exposure to infection while hampering rescue of teams
RQ2: How can we manage variability to reconcile WAI and WAD in complex systems through supporting dynamic adaptations in the sharp end?	By supporting CHWs' sensemaking through making available precise and updated information so they can can adapt their chosen residences and routes daily	By redesigning the IT referral system to allow for referral forms exchange and communication between gatekeeper, primary care team and specialized care provider	By redesigning the Pharmacy Management System as to support dispensing pharmacist's complex decision-making under time pressure	By redesigning rafts to facilitate righting in case it overturns, and by providing training program on emergency repair of rafts	By redesigning water ambulance to allow for prow, stern and lateral boarding and by distributing specific PPEs to CHWs from riverine communities
RQ3: How can we manage variability to reconcile WAI and WAD in complex systems through realigning planned capacity and demand?	By adjusting public policies and primary care clinics' management goals that stem from them to account for unstable territory conditions	By redesigning the IT referral system redesign of workflow in managing queues: implementing dashboard and queue for schedule-pending requests	By redesigning the Pharmacy Management System to display lab data and past dispensing from the provicial Electronic Health Record	By redesigning rafts' hull to better sustain collisions and by enhancing fish handling processes to improve subsistence conjuncture and lower pressure on the need for expeditions	By redesigning water ambulance to allow for isolation of victim during hours-long transportation, by adding one professional to water crew and by building docks in communities

5.1 Article A and Scaling up findings from in-depth qualitative research

Making decisions about the best route on the territory takes advantage of community health workers' experience. However, as these decisions happen each morning while the community health worker prepares to leave the clinic, sensemaking on current territory conditions is crucial to avoid security and health risks while crossing the territory and remaining inside residences. Article A's findings show that workers make sense on territory conditions in an adaptive and tacit way, using instant messages from personal contacts from people who live in the area on local safety, informal reports from colleagues, and general weather forecasting of the city. As it was disclosed in the analysis, this configuration can lead to higher variability throughout the patient visiting process.

The importance of CHWs' community skills as conceptualized and thoroughly described by Bellas (2017) becomes evident once it is hard to predict or expect how the work of community health workers will occur, given that different workers perform it, at different times, and in different places and conditions. Moreover, if the higher levels of the organization are not fully aware on what really happens, this can translate into slim feedback, correction, or learning. In this sense, strengthening CHWs' community skills becomes vital for managing variability in this system.

Although the findings and reflections presented in Article A are bound to the limitation of a relatively small sample of participants and observations, two follow-up works after Article A (BELLAS et al., 2019; JATOBÁ et al., 2020) have confirmed many of our results by performing large-scale studies with CHWs across all primary care clinics in Rio de Janeiro. Data collection for these studies was carried out through computer-assisted telephone interviews, conducted with a systematic sample of 759 CHWs based in the city of Rio de Janeiro.

The study by Jatobá et al. (2020) found that exposure to territorial violence and environmental or health-related diseases significantly affects members of the general population of a given territory and the CHWs within that territory, interfering with CHWs work performance. The study disclosed that exposition to violence in the territory is common and that, in the absence of more structured means of making sense of territory conditions, CHWs check with other professionals based on the clinic and patients through WhatsApp® groups if there are police operations in the territories. If police are identified as operating in the territory, workers offer strategies to cope, such as looking for shelter (as detailed in Article A). Half of the interviewees in Jatobá et al. (2020) study related exposure to contagious diseases, waste and garbage in the territory, while another half related the issue of exposure to patients' illnesses. Moreover, interviewees reported that the lack of equipment as a factor that increases the risk (JATOBÁ et al., 2020).

In the study by Bellas et al. (2019), which explored the effect of urban violence in CHWs' work conditions in Rio de Janeiro, 64% of interviewees agreed that urban violence prevents them from performing their daily activities in their assigned territory. Almost 70% of CHWs reported that urban violence is a major cause of emotional distress, 28% reported experiencing "excessive interference" from urban violence in their mental health, while 17% of them expressed "strong interference". In addition, approximately 40% of CHWs interviewed (296 in total) stated that they faced difficulties in maintaining patient data (modelled in Article A as the function "register health data" as shown in Figure 4-3), which amounts to registering new patients and keeping patient data updated. The study found that approximately 34% of CHWs claimed "Excessive interference" of urban violence in maintaining patient data (BELLAS et al., 2019).

As for methodological contributions from Article A, three can be argued to have potentially been made. The first one regards the discussion over the application of Resilience Engineering and Ergonomics methods to generate insights to public health policies.

The second one concerns the embedded formulation and application of a procedure to track how problems stemming from complex systems' environment can impact functional variability and ultimately system outcomes. In this sense, Figure 4-15 presents a way to systematize the analysis of actual variability in a FRAM model so we can track how different intances from the system's environment may activate certain couplings and set the system in different resonance paths.

The third arguable methodological contribution regards how a variability-based approach to research design can generate contributions to a control-based approach in modelling. In this context, Figure 4-16 discloses proposed changes for the system's modelled control structure based on the findings from applying FRAM.

5.2 Article B and Strenghtening resilience abilities through Information Technology Design

In decentralized referral prioritization, resilience abilities are manifested to cope with complexity through highly coupled adjustment maneuvers, managing variability and work settings' underspecification. In some particular instantiations, a so-called support cycle between the abilities was observed. Such an example is illustrated in Figure 5-3 and explained here. On several occasions, gatekeepers have had to perform prioritization for critical referral request cases outside working hours (Responding). As they do that throughout their weekly schedules, gatekeepers are continuously mapping and calibrating their predictions for most likely times during the day for vancancies to open (Learning), which allows them to dedicate some critical hours during each day (usually in the morning) solely for the task of prioritizing referrals (Anticipation). In turn, this maneuver enables them – at least several days a week - to systematically check for vacancies at each type of specialized procedure on queue (Monitoring), a maneuver that is particularly time-consuming. Finally, doing this prepares them to manage referral prioritization as unexpected turns of events unfold in clinical practice (Responding).

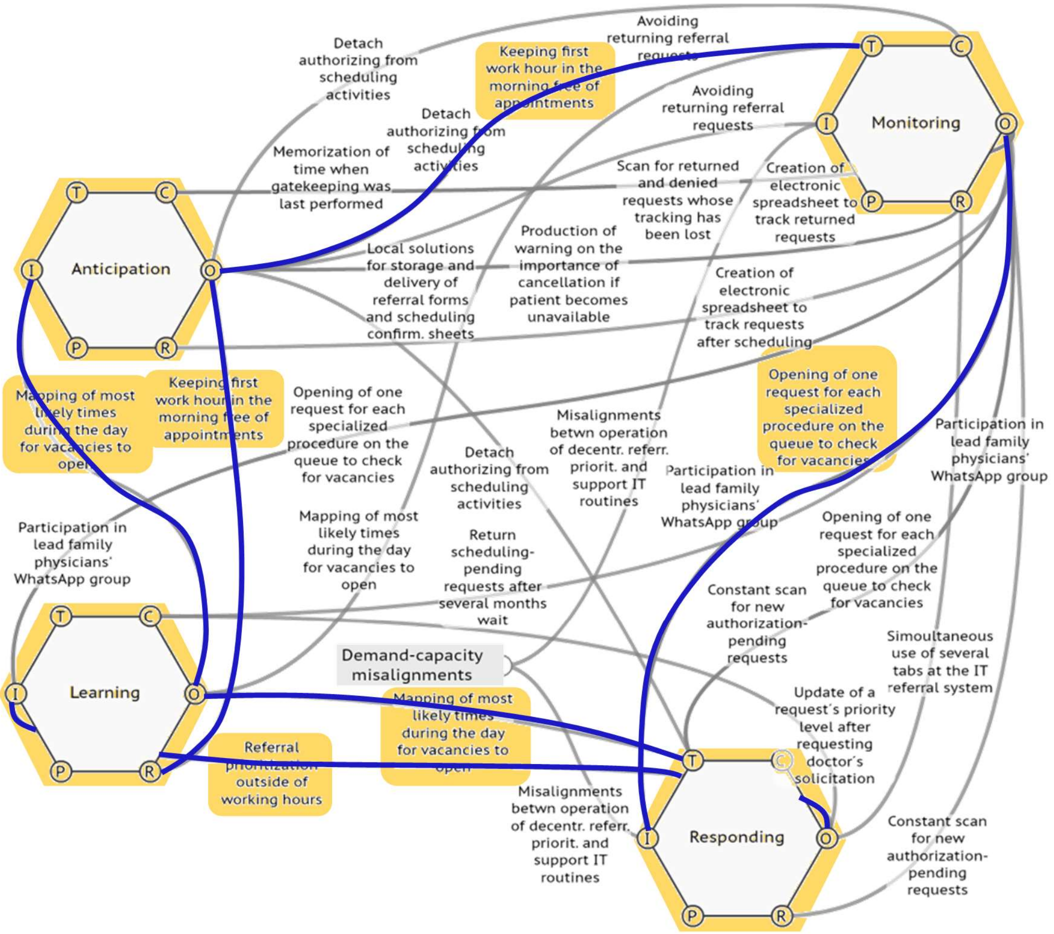


Figure 5-3 – Instantiation of the model for "coping with misalignments between operation of decentralized referral and IT routines" showing a support cycle between resilience abilities

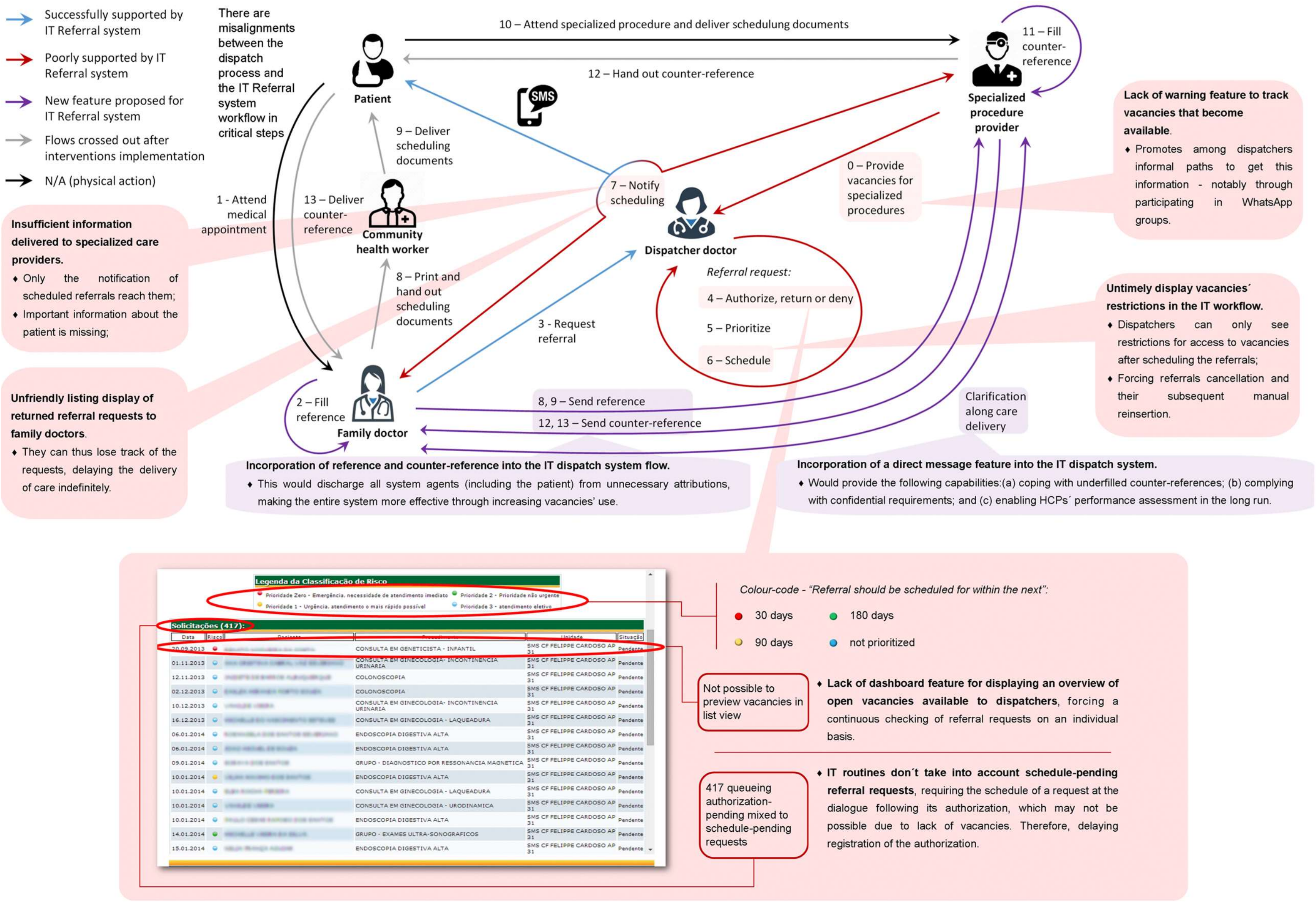
Article B's findings also showed how the need for teamwork emerged to reconcile WAI and WAD in decentralized referral prioritization. As resilience abilities couple through adjustment maneuvers, coordinated actions from a number of system agents are employed to manage critical situations when the system safety is at stake (i.e. elevated risk of permanent damage to a patient health).

In these situations, direct and real-time communication is crucial to account for the synchronization of several operative strategies. Among these, can be listed:

- Gathering specific additional information on the clinical condition of patients;
- Managing to allow exceptional pre-booking of vacancies available at a time window in the health information system;
- Negotiating with providers of specialized medical services – from both public and private health care networks - to create new vacancies.

This coordination of activities involve gatekeeper doctors from different hierarchical levels in the system (PHFs, local referral centers and the municipal referral center), medical teams at PHFs and medical services' providers. As a way forward to improve system capability for resilient performance, much potential lies in redesigning information systems – as the one used to operate referral decentralization – so as to facilitate multiple actors engaging along disclosed strategies, ultimately strengthening resilience abilities.

In this context, to further answer research questions 2 and 3, Figure 5-4 builds on Figure 1-2 by showing two kinds of interventions proposed for the IT Referral system (SISREG). The firs group, shown in red, could create a more stable environment by reducing the requirement for some adaptations *in situ* originally created to cope with misalignments between process and IT workflow – in this case, a part of the adjustment maneuvers shown in Figure 4-23. The second group, shown in purple, strengthens adaptations that are crucial for communication and supporting the system's distributed cognition – in this case, adjustment maneuvers shown in Figure 4-24.



Insufficient information delivered to specialized care providers.

- ♦ Only the notification of scheduled referrals reach them;
- ♦ Important information about the patient is missing;

Unfriendly listing display of returned referral requests to family doctors.

- ♦ They can thus lose track of the requests, delaying the delivery of care indefinitely.

Incorporation of reference and counter-reference into the IT dispatch system flow.

- ♦ This would discharge all system agents (including the patient) from unnecessary attributions, making the entire system more effective through increasing vacancies' use.

Lack of warning feature to track vacancies that become available.

- ♦ Promotes among dispatchers informal paths to get this information - notably through participating in WhatsApp groups.

Untimely display vacancies´ restrictions in the IT workflow.

- ♦ Dispatchers can only see restrictions for access to vacancies after scheduling the referrals;
- ♦ Forcing referrals cancellation and their subsequent manual reinsertion.

Incorporation of a direct message feature into the IT dispatch system.

- ♦ Would provide the following capabilities:(a) coping with underfilled counter-references; (b) complying with confidential requirements; and (c) enabling HCPs´ performance assessment in the long run.

Legenda da Classificação de Risco

● Prioridade Zero - Emergência, necessidade de atendimento imediato
● Prioridade 1 - Urgência, atendimento o mais rápido possível
● Prioridade 2 - Prioridade não urgente
● Prioridade 3 - atendimento eletivo

Solicitações (417):

Data	Risco	Paciente	Procedimento	Unidade	Situação
20.09.2013	●	[redacted]	CONSULTA EM GENETICISTA - INFANTIL	SMS CF FELIPPE CARDOSO AP 31	Pendente
01.11.2013	●	[redacted]	CONSULTA EM GINECOLOGIA- INCONTINENCIA URINARIA	SMS CF FELIPPE CARDOSO AP 31	Pendente
12.11.2013	●	[redacted]	COLONOSCOPIA	SMS CF FELIPPE CARDOSO AP 31	Pendente
02.12.2013	●	[redacted]	COLONOSCOPIA	SMS CF FELIPPE CARDOSO AP 31	Pendente
10.12.2013	●	[redacted]	CONSULTA EM GINECOLOGIA- INCONTINENCIA URINARIA	SMS CF FELIPPE CARDOSO AP 31	Pendente
16.12.2013	●	[redacted]	CONSULTA EM GINECOLOGIA - LAQUEADURA	SMS CF FELIPPE CARDOSO AP 31	Pendente
06.01.2014	●	[redacted]	ENDOSCOPIA DIGESTIVA ALTA	SMS CF FELIPPE CARDOSO AP 31	Pendente
06.01.2014	●	[redacted]	ENDOSCOPIA DIGESTIVA ALTA	SMS CF FELIPPE CARDOSO AP 31	Pendente
09.01.2014	●	[redacted]	GRUPO - DIAGNOSTICO POR RESSONANCIA MAGNETICA	SMS CF FELIPPE CARDOSO AP 31	Pendente
10.01.2014	●	[redacted]	ENDOSCOPIA DIGESTIVA ALTA	SMS CF FELIPPE CARDOSO AP 31	Pendente
10.01.2014	●	[redacted]	CONSULTA EM GINECOLOGIA - LAQUEADURA	SMS CF FELIPPE CARDOSO AP 31	Pendente
10.01.2014	●	[redacted]	CONSULTA EM GINECOLOGIA - URODINAMICA	SMS CF FELIPPE CARDOSO AP 31	Pendente
10.01.2014	●	[redacted]	ENDOSCOPIA DIGESTIVA ALTA	SMS CF FELIPPE CARDOSO AP 31	Pendente
14.01.2014	●	[redacted]	GRUPO - EXAMES ULTRA-SONOGRAFICOS	SMS CF FELIPPE CARDOSO AP 31	Pendente
15.01.2014	●	[redacted]	ENDOSCOPIA DIGESTIVA ALTA	SMS CF FELIPPE CARDOSO AP 31	Pendente

Colour-code - "Referral should be scheduled for within the next":

● 30 days	● 180 days
● 90 days	● not prioritized

- ♦ **Lack of dashboard feature for displaying an overview of open vacancies available to dispatchers**, forcing a continuous checking of referral requests on an individual basis.

- ♦ **IT routines don´t take into account schedule-pending referral requests**, requiring the schedule of a request at the dialogue following its authorization, which may not be possible due to lack of vacancies. Therefore, delaying registration of the authorization.

Figure 5-4 – Main information flows, IT shortcomings and intervention proposals for the IT Referral system

5.3 Article C and Mapping the problem space of a specific kind of complex systems

A good IESC assessment of the prescription, an acronym standing for the multiple dimensions taken into account by the dispensing pharmacist at the function “assess prescription’s appropriateness for the patient” – namely Indication, / Effectiveness / Safety / Compliance - is crucial for the quality and safety of the delivered care. And although the FRAM model in Figure 1 shows that this assessment needs various types of data as Resources, dispensers reported the need to take educated guesses often while performing it (LI et al., 2019a; MERCER et al., 2018). Functions that account for direct communication and document forwarding between the prescriber and the dispensing pharmacist could be of support in this context. However, they are not supported by IT (as previously statet in Table 4-11, stage 3), which means that all information is exchanged by phone or - more commonly - fax.

Taking this into account, we propose a new form of coupling to support managing variability in terms of precision, as depicted in Figure 5-5. The dispensing function in the FRAM model accounts for the decision on choosing the medication, route of administration and dosage the patient will take. To accomplish these dispensers considers their expertise, the IESC assessment and the different forms of the medication available in the pharmacy at that moment. To facilitate this critical cognitive task - and in line with an established heuristic of app interface design that advocates aiming for recognition rather than recall of information (NIELSEN, 1993) – an useful feature for PMSs would be a capability of tagging content from registered drug leaflets. This would allow the software to offer to dispensers all the available options of medications at that pharmacy for a context-specific tag.

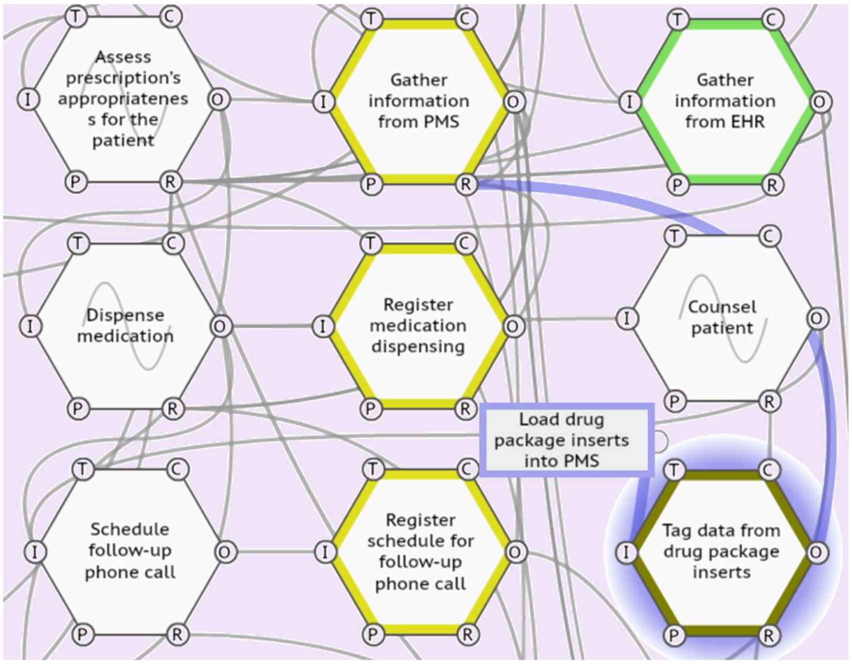


Figure 5-5 - Proposed intervention to improve dispensing. New functions "load drug leaflets to PMS" and "tag data from drug leaflets" as well as new couplings are highlighted

The FRAM model represented in Article C and built on in Figure 5-5 accounts for the prevalent case of MTM across Southwestn Ontario, Canada. However, as we set out to study MTM in the region, we learned that a limited number of clinics and community pharmacies have been piloting new information technology solutions to support the prescription-dispensing process. Two of them have been in the spotlight. The first one allows direct communication between electronic medical records and pharmacy management systems, including sharing prescriptions. The second one allows for dispensing pharmacists to share access to precribers' EMRs.

This scenario accounts for the co-existance of multiple iterations of technology and work organization, two fundamental dimensions of socio-technical systems. This is important because complex systems' behaviour may vary widely due to various restrictions, constraints, and software version iterations. Different iterations of health care processes may display significant differences in terms of what IT and equipment are implemented, how the teams are formed, and how they work and communicate.

The most prevalent process in MTM involve the issuing of a prescription, dispensing of medication, and the counselling and guidance given to the patient. Therefore, as we tried to model with FRAM different iterations of this process that involves the new aforementioned IT initiates, these differences have turned out to be a challenge to frame in a single system model that accounts for information exchange among health care providers. This is seems to be especially noteworthy once our work in Article C indicates that those differences may lead to different functional capabilities and result in diverse manifestations of functional variability across different iterations.

Taking all these into account, we are proposing that, for some systems such as MTM, it would be useful to perform a preliminary phase that charts these different iterations and their functional variations in order to facilitate the analysis of functional variability. For this purpose, we have been developing a new tool, tentatively called the socio-technical matrix, which should be useful when applying a systems-oriented analysis in complex domains where multiple iterations of technology and work organization may co-exist. The aim of this tool is to help better track causal relations in a complex healthcare domain, as it showed impacts brought by specific organizational and technological changes into system behaviour and variability managemement, including potential disruptions in process outcomes.

The socio-technical matrix describes the problem space of a domain as function of a research question or objective. It begins with the development of a 2x2 matrix, where technical dimensions are described on one dimension and social dimensions on the other. Each matrix cell defines a space where the system iterations that take place within a specific technical and social context can be described further. Within each cell, a model or part of one could be explored, along with the functional variability under those conditions of technical stage and social context.

We found useful to define an aggregate variable, C, to track the multiple manifestations of the system studied. C represents the nature of the predominant differences observed in system iterations. We used C to suggest two other variables, Ct (technical) and Cs (social), which were developed during our modelling and reflection on the analysis. Ct and Cs help to define the differences driving the variation in technical and social contexts under exploration.

Finally, for each cell in the matrix, the system is modelled, and the potential functional variability described. In this way, the FRAM approach is built upon by moving it forward to examine differences in functional variability, with the insight of how Ct and Cs may be influencing it.

As aforementioned, the most prevalent process in MTM involve the issuing of a prescription, dispensing of medication, and the counselling and guidance given to the patient. In our modelling of this domain using the socio-technical matrix, we observed that the path the prescription took from the physician's office (origin) to the pharmacy (destination) could be very different depending on the social and technical factors' combination. Hence, the pair origin-destination (the path) of a prescription was labelled as C, given that its expression captures the nature of the predominant difference of the system iterations, and it was used to investigate social and technical factors more deeply. This means that each matrix cell represents one different path that a prescription could take.

Once a prescription path is established, we noticed that the variable shaping the information exchange in substantially different ways at the technical level was the IT settings allowed by the various software systems on the physician or pharmacy end. These IT settings arrangements at the origin-destination thus became Ct. For Cs, we observed that the availability of face-to-face communication influenced the prescription path. Such availability exists when the physician's office and the community pharmacy are physically close. Thus, Cs described how co-location impact the collaborative work among health care providers.

As being shaped by C, Ct, and Cs, all system iterations are represented in the matrix cells Figure 5-6. An example of a cell scope is the space for which MTM unfolds between a physician's office and a community pharmacy that are geographically distant (no option of face-to-face communication) and can only access a provincial web-based electronic health record besides each one's local IT systems (electronic medical record – EHR or pharmacy management system - PMS). This is represented in Figure 5-6 as cell "C".

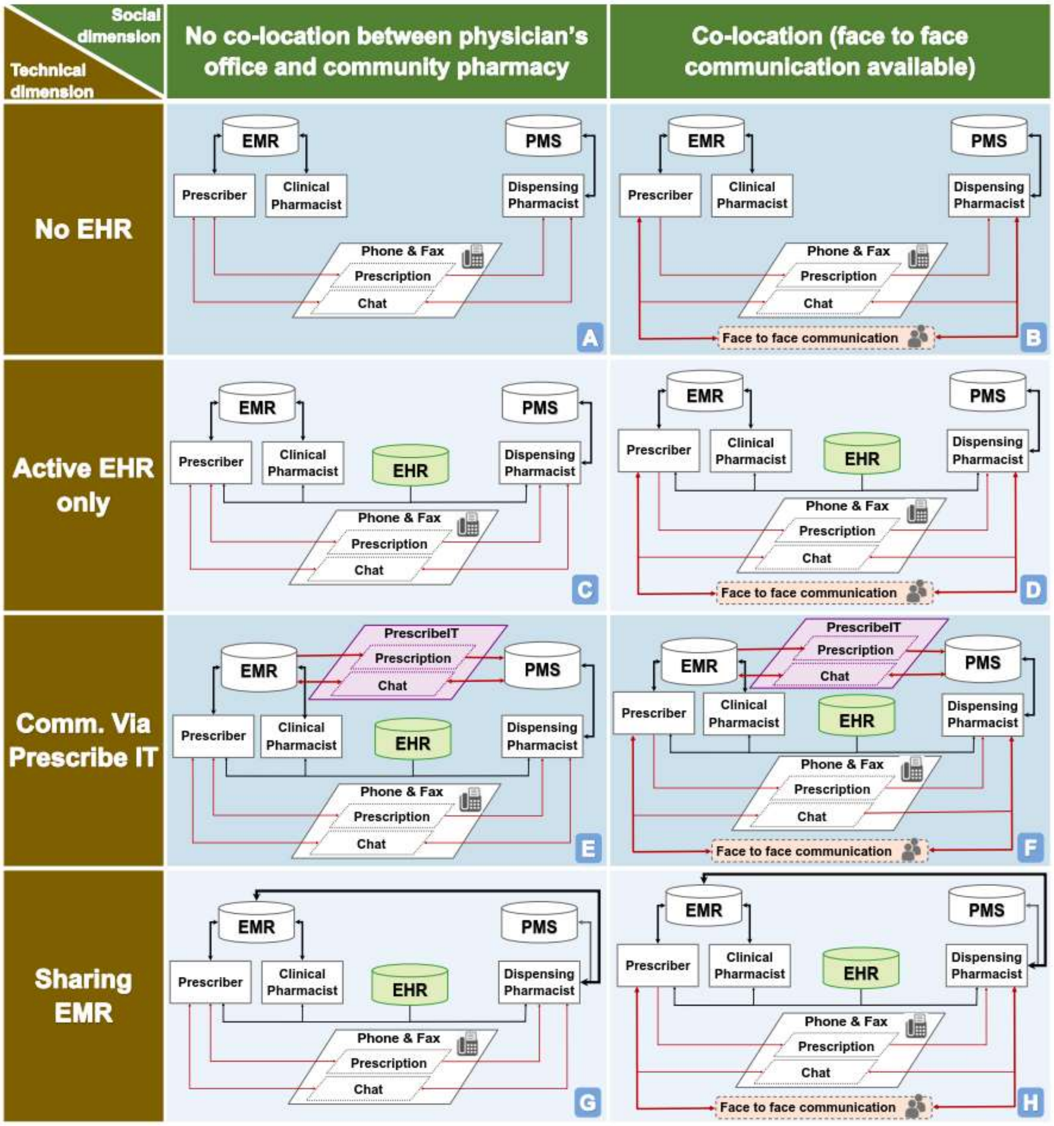


Figure 5-6 – A socio-technical matrix for medication therapy management in Southwestern Ontario

In our preliminary use of the socio-technical matrix to guide the FRAM analysis of MTM and its recent changes in Southern Ontario, we gained insight from what goes right and what goes wrong when prescription paths differ. Also, this revealed that IT configuration and face-to-face availability are highly influential in defining how MTM will unfold. This has influence over the FRAM modelling of the system and variability management, since big changes in work settings change the behaviour of modelled functions (see Figure 5-7).

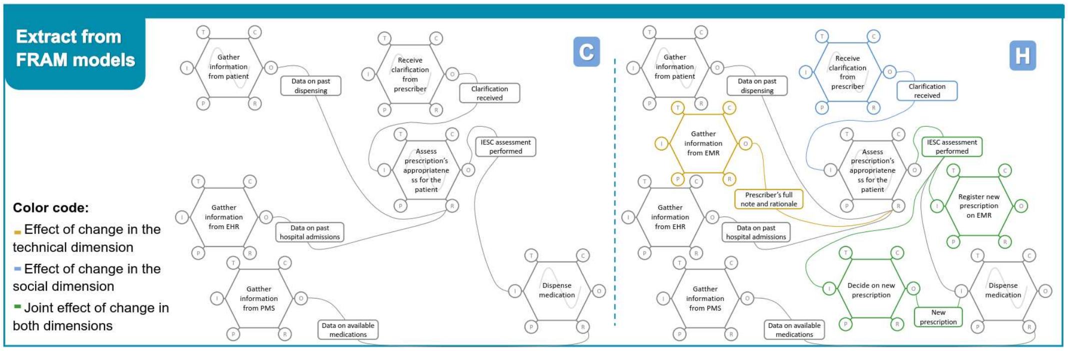


Figure 5-7 – Differences in modelled system behaviour as the joint effect of changes in technical and social dimensions between cells C and H of the socio-technical matrix

A key advantage of using the socio-technical matrix seems to be that, by knowing a prescription's origin-destination, we can locate it at a matrix cell, i.e., we can tell which level of IT support is available and if face-to-face communication is available as MTM unfolds.

For system iterations describing new piloting IT initiatives, a preliminary analysis using the matrix showed that when dispensing pharmacists experienced:

- Shared access to the electronic medical record (EMR) at a physician's office, they found most useful to learn from prescriber's full consultation note (cells G and H in Figure 5-6). This reveals that initiatives toward improving IT support should focus on presenting information like those commonly present at the consultation full note.
- A new piece of software being piloted – aimed at granting speedier and clearer information flow between the prescribers and them –, it has not replaced face-to-face communication cells (E and F in Figure 5-6). This, in turn, might mean that when face-to-face communication is unavailable (most cases) potential issues will remain unresolved.

The current stage of development of this new tool and all related materials produced so far are a follow-up work on Article C and has been submitted by the research team to the 21st Triennal Congress of the International Ergonomics Association (IEA 2021) under the form of an extended abstract bearing the title "**Guiding the modelling of complex systems: the socio-technical matrix**".

5.4 Article D and Guiding design interventions from the analysis of resonance

The application of a Safety-II perspective to describe the behavior of the expedition’s functions, as modelled by FRAM, sheds light into how performance variability – manifested into functions’ dampening mechanisms – is important to build safety while allowing the fishing activity itself to happen. As we carried out prospective analysis of instantiations for the system of artisanal coastal fishing, failures showed up as the flip side of successes.

The instatiation that is shown in Figure 5-8 exemplifies how system outcomes and safety can be impacted when sensemaking function produces output variability. This happens as fishermen expertise (a powerful dampening mechanism that usually balances sensemaking) is overthrown by growing risk of losing subsistence conditions on top of the almost ever-present imprecise information on raft integrity and natural conditions. Hampered sensemaking on conditions for navigation and safety affects almost all downstream functions activated in the fishing process through output-control couplings, reaching these functions as external disturbances.

Once fishermen are at sea despite poor conditions of visibility and navigation, they become more vulnerable to disturbances both endogenous (originating at respective functions) and exogenous (carried downstream through couplings). This menas that dampening mechanisms embedded in navigation and fishing functions may not be sufficient to compensate for the disturbances the functions face. In turn, this can trigger a number of events culminating with the raft overturning while its internal compartiment is full of water, rendering the righting process impossible and thus bringing it to sink.

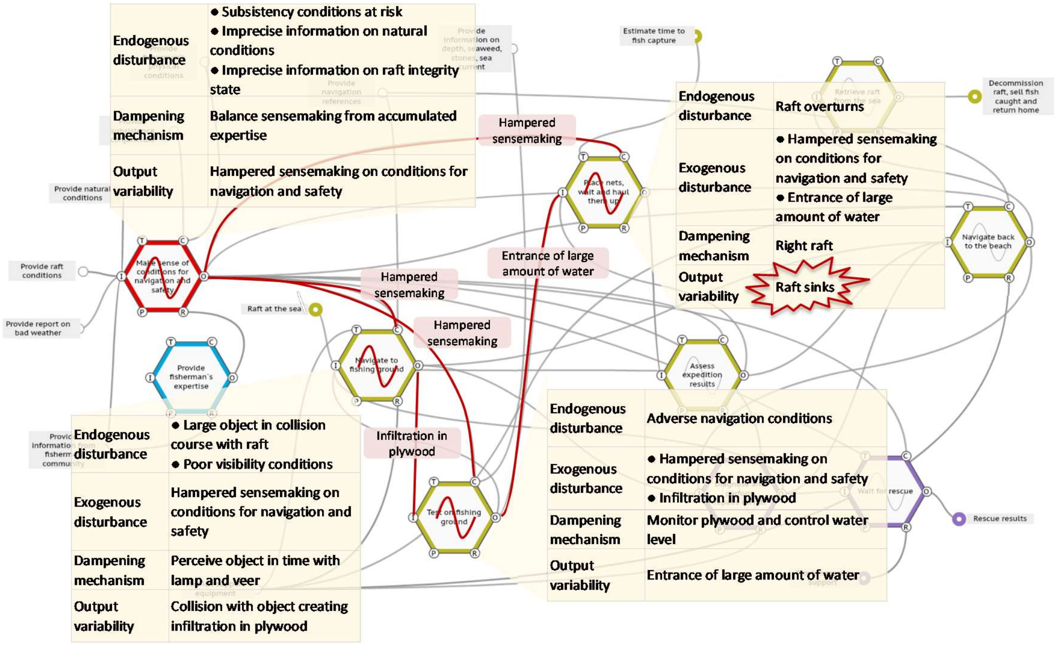


Figure 5-8 – Instantiation of the FRAM model for navigation and fishing – prospective analysis

To what concerns the analysis of resonance presented in Figure 5-8 (as well as others in Articles C and D), however, it is important to note that the classification of disturbances into endogenous or exogenous ones served the sole purpose of tracking variability throughout said analysis. In this sense, it depended solely on the decisions concerning the scope (boundaries) and level of resolution of the system as modeled. This means that a disturbance that is considered endogenous under one level of resolution could be modelled as exogenous if we were to increase the level of resolution and were to add an upstream function that accounted for it. Nevertheless, the result of analysis would remain the same.

Another interesting aspect of modelling variability under this exploratory taxonomy encompassing the classes of endogenous/exogenous disturbances, dampening mechanisms and output variability it has enabled us to understand the ongoing projects for system intervention (Table 4-15) in terms of variability management, as shown in Figure 5-9. Particularly, it allowed us to reflect on and locate system interventions across the analysis of functional resonance, as projects can be understood (and potentially prioritized) given their effect over protecting functions from disturbances (akin to a Safety-I thinking) and strengthening dampening mechanisms (more akin to a Safety-II thinking).

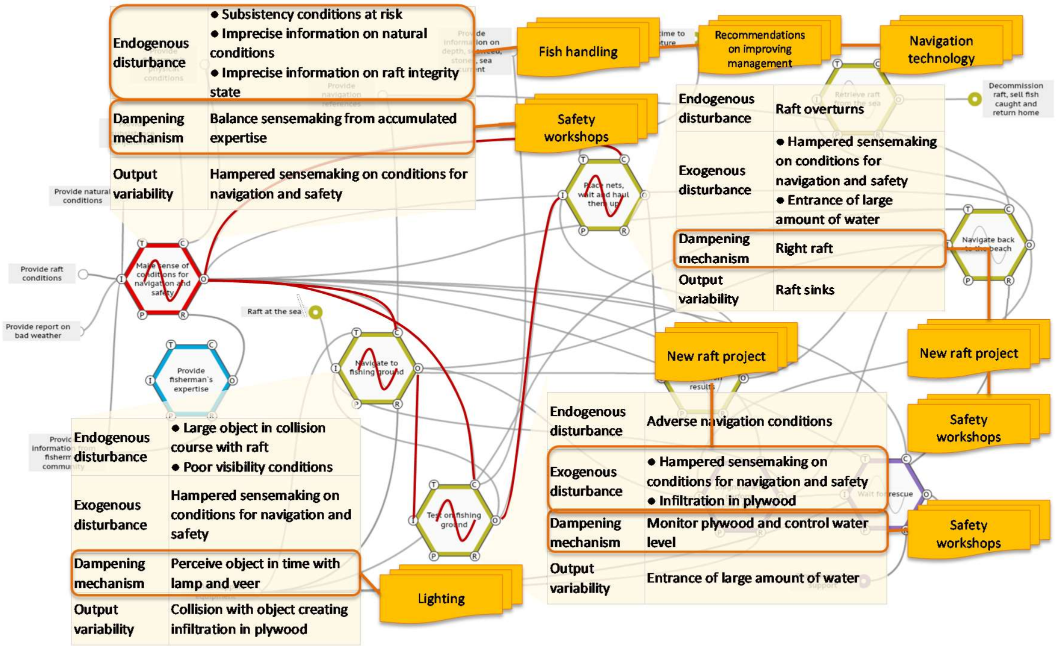


Figure 5-9 – Locating proposed interventions across the analysis of functional resonance

Of course, the conceptual rigour and usefulness of such exploratory approach remains to be more thoroughly assessed. One of its present limitations concerns the fact that recent work has shed more light on how WAI and WAD may differentiate through forms of adaptation not discussed here. These are namely opportunities to improve steps of system processes through reducing workload or increasing efficiency and output quality (ANDERSON et al., 2020; HOLLNAGEL, 2018).

5.5 Article E and Applying Resilience Engineering to complex systems design

Although physically and organizationally well-defined, complex systems in health care may present themselves as functionally ill-defined and open systems. As with other emergency care systems (NEMETH et al., 2008), our findings for the mobile emergency care to riverine communities confirm this characteristic. The support from CHWs and local communities' other health care professionals is fundamental to deliver basic life support, lowered response times lower and safer boarding of water ambulances. In an environment as unpredictable as the one riverine mobile emergency care takes place, it is essential to work toward a system design that can sustain resilient performance.

Taking this into account, as a follow-up study from Article E we are developing a tool (tentatively called demand x capacity matrix) to employ resilience engineering concepts to complex systems design and specifically to requirements specifications, and have conducted a first application of it to the operation of Brazil's national water ambulance service. This work – as is also the case with the research developed in Article E - is part of a research project whose aim was to support the incorporation of the water ambulance service - a part of the Brazilian Mobile Emergency Medical Service (SAMU 192) – into the country's National Emergency Care Policy.

Using the matrix, it was possible to identify how capacity x demand dynamic interplays generated misalignments and consequently shaped adaptations needed from the teams to fill in these gaps, thus framing the focal points for system redesign toward a better fit between the two and an improved support over adaptation. This allowed us to propose system specifications at localized organizational and technical levels, including a new design for water ambulances themselves.

The current stage of development of this work and all related materials produced so far are a follow-up work on Article E and has been submitted by the research team to the 21st Triennal Congress of the International Ergonomics Association (IEA 2021) under the form of an extended abstract bearing the title "**Applying Resilience Engineering to complex systems design: coping with variability in a national water ambulances service**".

6 Conclusion

This thesis has addressed the problem of managing variability in complex sociotechnical systems (Section 1.1). As a research approach to tackle this problem we proposed a methodology – Ergonomic Dynamic Modelling – based on the conceptual framework of Ergonomics and Resilience Engineering. Using this approach, we explored how organizational and technological design can offer support to complex and safety-critical domains in coping with complexity by means of variability management to reconcile WAI and WAD. We did that by conducting a series of detailed studies of system performance, applying a research design combining: (a) fieldwork and data collection using ergonomic ethnographic approach; and (b) data coding, modelling and analysis using concepts and tools from Resilience Engineering.

We believe that this approach was successful in answering the proposed research questions for each of the studied domains, and also in generating useful methodological contributions from each study. Here, it is worth stressing that all models are simplifications of reality to some extent. Variability pervades virtually every part of complex systems at every turn, and it is not possible to include every instance of it in any model, even in one built to account for variability such as a FRAM model. Trying to do so would be detrimental to the model's purpose, depriving it from its contrast and blurring its useful representative character into a kind of impoverished description of reality.

In this context, one major methodological takeaway of this thesis is that FRAM as a method, and with support from an Ergonomics approach at research design and data collection, can be steered towards different purposes within the larger scope of representing functional and variability dynamics. FRAM can greatly benefit from in-depth knowledge of system behaviour, as provided by Ergonomics protocols, to create useful reprentations. On the other hand, studies in Ergonomics can reach extra lengths by applying FRAM notation to systematize and analyze disclosed data to different purposes.

The papers produced from this thesis show examples of purposes that can be addressed in applying the Ergonomic Dynamic Modelling methodology. Particularly:

- Article A applies the methodology to study the influence of environment conditions in a systems' capability of accomplishing major goals. Domain-wise, we addressed this purpose by studying the influence of territory conditions in patient visits' capability of accomplishing public health policies;

- Article B applies the methodology to study the coupling of the four resilience abilities in solving big-order mismatches in the dynamic interplay of a complex system's demands and capacity. Domain-wise, we addressed this purpose by studying the coordinated employment of operative adjustments to compensate for shortcomings in the design of referral prioritization;
- Article C applies the methodology to study ways in which IT can be improved to support resilient performance. Domain-wise, we addressed this purpose by disclosing IT requirements to cope with sacrifice dilemmas in medication therapy management;
- Article D applies the methodolody to strengthen safety practices stemming from workers' knowledge. Domain-wise we addressed this purpose by using a safety-II approach to propose interventions to improve safety in artisanal coastal fishing;
- Article E applies the methodology to predict system behavior under a crisis situation. Domain-wise, we addressed this purpose by conducting a prospective analysis of the impacts of the COVID-19 pandemic into the operation of on-site emergency care within Amazon's ultra-peripheral locations.

Each study has built on the Resilience Engineering framework and produced contributions for managing variability in the addressed domain, both by helping designers to realign planned capacity and system demands and by supporting dynamic adaptations at the sharp-end. In this context, we are hopeful the ideas discussed in this thesis cam provide useful insight and help to structure further discussion. As we move towards engineering ever-more inter-dependable systems we hope we are able to guide the design of specifications to manage variability, cope with complexity and support systems in sustaining graceful extensibility.

7 References

ACKOFF, R. L. Towards a System of Systems Concepts. **Management Science**, v. 17, n. 11, p. 661–671, 1 jul. 1971.

ALBERY, S.; BORYS, D.; TEPE, S. Advantages for risk assessment: Evaluating learnings from question sets inspired by the FRAM and the risk matrix in a manufacturing environment. **Safety Science**, v. 89, p. 180–189, nov. 2016.

ALMEIDA, P. F. DE et al. Strategies for integrating primary health care with specialized care: parallels between Brazil and Spain. **Saúde em Debate**, v. 37, n. 98, p. 400–415, set. 2013.

ALMKLOV, P. G.; ROSNESS, R.; STØRKERSEN, K. When safety science meets the practitioners: Does safety science contribute to marginalization of practical knowledge? **Safety Science**, v. 67, p. 25–36, ago. 2014.

AMALBERTI, R. Optimum system safety and optimum system resilience: agonistic or antagonistic concepts? In: **Resilience Engineering: Concepts and Precepts**. Farnham: Ashgate, 2006. p. 253–271.

ANDERSON, J. E. et al. Implementing resilience engineering for healthcare quality improvement using the CARE model: a feasibility study protocol. **Pilot and Feasibility Studies**, v. 2, n. 1, dez. 2016.

ANDERSON, J. E. et al. Defining adaptive capacity in healthcare: A new framework for researching resilient performance. **Applied Ergonomics**, v. 87, p. 103111, set. 2020.

ANDERSON, J. E.; ROSS, A. J.; JAYE, P. Modelling Resilience and Researching the Gap between Work-as-Imagined and Work-as-Done. In: **Resilient Health Care, Volume 3: Reconciling Work-as-Imagined and Work-as-Done**. Resilient Health Care. Farnham, Surrey ; Burlington, VT: CRC Press, 2017. p. 133–141.

ARCURI, R. et al. Gatekeeper family doctors operating a decentralized referral prioritization system: Uncovering improvements in system resilience through a grounded-based approach. **Safety Science**, v. 121, p. 177–190, 1 jan. 2020.

ARCURI, R.; VIDAL, M. C.; MOREIRA, L. R. **Gestão da variabilidade na manutenção de linhas de transmissão**. Anais do XXXVI ENEGEP. **Anais**... In: XXXVI ENCONTRO NACIONAL DE ENGENHARIA DE PRODUÇÃO. João Pessoa: 2016a

ARCURI, R.; VIDAL, M. C. R.; MOREIRA, L. R. **Instrumentação em Ergonomia: o caso da manutenção de linhas de transmissão**. . In: XVIII CONGRESSO BRASILEIRO DE ERGONOMIA. Belo Horizonte: 2016b

ARGYRIS, C. **Knowledge for action: a guide to overcoming barriers to organizational change**. 1st ed ed. San Francisco: Jossey-Bass, 1993.

ASKILDSEN, J. E.; HOLMÅS, T. H.; KAARBOE, O. Monitoring prioritisation in the public health-care sector by use of medical guidelines. The case of Norway. **Health Economics**, v. 20, n. 8, p. 958–970, 1 ago. 2011.

AUSTIN, P. Z.; GREGORY, P. A. M.; MARTIN, J. C. Negotiation of interprofessional culture shock:The experiences of pharmacists who become physicians. **Journal of Interprofessional Care**, v. 21, n. 1, p. 83–93, 1 jan. 2007.

BABER, C.; MCMASTER, R. **Grasping the Moment: Sensemaking in Response to Routine Incidents and Major Emergencies**. [s.l.] CRC Press, 2016.

BALLARD, M.; MONTGOMERY, P. Systematic review of interventions for improving the performance of community health workers in low-income and middle-income countries. **BMJ Open**, v. 7, n. 10, p. e014216, out. 2017.

BARDIN, L. **L' analyse de contenu**. 5. éd. rev. et augm ed. [s.l.] Presses Univ. de France, 1989.

BAUMEISTER, R. F.; LEARY, M. R. Writing Narrative Literature Reviews. **Review of General Psychology**, v. 1, n. 3, p. 311–320, set. 1997.

BELLAS, H. C. **As contribuições da Ergonomia para a Estratégia Saúde da Família: a atuação do agente comunitário de saúde no território de manguinhos**. Tese de Doutorado—Rio de Janeiro: Universidade Federal do Rio de Janeiro, 2017.

BELLAS, H. C. et al. Effects of Urban Violence on Primary Healthcare: The Challenges of Community Health Workers in Performing House Calls in Dangerous Areas. **Journal of Community Health**, v. 44, n. 3, p. 569–576, 4 abr. 2019.

BERTALANFFY, L. V. **General System Theory: Foundations, Development, Applications**. 9. ed. [s.l.] George Braziller Inc., 1984.

BISANTZ, A. M.; BURNS, C. M.; FAIRBANKS, R. J. (EDS.). **Cognitive Systems Engineering in Health Care**. 1 edition ed. Boca Raton: CRC Press, 2014.

BLANDFORD, A.; FURNISS, D.; VINCENT, C. Patient safety and interactive medical devices: Realigning work as imagined and work as done. **Clinical Risk**, v. 20, n. 5, p. 107–110, 1 set. 2014.

BOOTH, W. C.; COLOMB, G. G.; WILLIAMS, J. M. **The craft of research**. 3. ed ed. Chicago: Univ. of Chicago Press, 2008.

BRAITHWAITE, J. et al. Health Care as a Complex Adaptive System. In: **Resilient Health Care**. Farnham, Surrey ; Burlington, VT: Ashgate, 2013. p. 57–73.

BRAITHWAITE, J.; WEARS, R. L.; HOLLNAGEL, E. Conclusion: pathways towards reconciling WAI and WAD. In: **Resilient Health Care, Volume 3: Reconciling Work-as-Imagined and Work-as-Done**. Resilient Health Care. Boca Ratón ed. Farnham, Surrey ; Burlington, VT: CRC Press, 2017. p. 171–178.

BRASIL. Portaria MS/GM no 188, de 3 de fevereiro de 2020. Declara Emergência em Saúde Pública de importância Nacional (ESPIN) em decorrência da Infecção Humana pelo novo Coronavírus (2019-nCoV). . 2020.

CABRERA AGUILERA, M. V. et al. Modelling performance variabilities in oil spill response to improve system resilience. **Journal of Loss Prevention in the Process Industries**, v. 41, p. 18–30, 1 maio 2016.

CALISKAN, C.; ALTINTAS, K. H. Time, island and ambulance type characteristics of patient transfers from two Turkish islands: Gökçeada and Bozcaada. **International Journal of Emergency Services**, v. 9, n. 1, p. 47–55, 1 jan. 2019.

CALLOU, A. B. F. Povos do mar: herança sociocultural e perspectivas no Brasil. **Ciência e Cultura**, v. 62, n. 3, p. 45–48, 70 2010.

CARAYON, P. Human factors of complex sociotechnical systems. **Applied Ergonomics**, v. 37, n. 4, p. 525–535, jul. 2006.

CARAYON, P. **Handbook of Human Factors and Ergonomics in Health Care and Patient Safety, Second Edition**. [s.l.] CRC Press, 2016.

CARVALHO, P. V. R. DE. Ergonomic field studies in a nuclear power plant control room. **Progress in Nuclear Energy**, v. 48, n. 1, p. 51–69, jan. 2006.

CARVALHO, P. V. R. DE. The use of Functional Resonance Analysis Method (FRAM) in a mid-air collision to understand some characteristics of the air traffic management system resilience. **Reliability Engineering & System Safety**, v. 96, n. 11, p. 1482–1498, nov. 2011.

CARVALHO, P. V. R. DE et al. Reflections on work as done (WAD) and work as imagined (WAI) in an emergency response organization: A study on firefighters training exercises. **Applied Ergonomics**, v. 68, p. 28–41, abr. 2018.

CARVALHO, P. V. R. D.; BENCHEKROUN, T.-H.; GOMES, J. O. Analysis of information exchange activities to actualize and validate situation awareness during shift changeovers in nuclear power plants. **Human Factors and Ergonomics In Manufacturing**, v. 22, n. 2, p. 130–144, 2012.

CASEY, T. W.; KRAUSS, A. D.; TURNER, N. The one that got away: Lessons learned from the evaluation of a safety training intervention in the Australian prawn fishing industry. **Safety Science**, v. 108, p. 218–224, 1 out. 2018.

CASTELLO, J. P. O futuro da pesca da aquicultura marinha no Brasil: a pesca costeira. **Ciência e Cultura**, v. 62, n. 3, p. 32–35, 70 2010.

CELESTINO, J. E. M. et al. Ergonomics and environmental sustainability: a case study of raft fisherman activity at Ponta Negra Beach, Natal-RN. **Work**, v. 41, n. Supplement 1, p. 648–655, 1 jan. 2012.

CHECKLAND, P. **Systems thinking, Systems Practice**. [s.l.] Chichester John Wiley, 1981.

CHIN, J. et al. More Than Information Access: A Cognitive Work Analysis On Physician-Pharmacist Collaboration Through Electronic Medical Records. **Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care**, v. 7, n. 1, p. 8–8, jun. 2018.

CHOPRA, V. et al. How Should U.S. Hospitals Prepare for Coronavirus Disease 2019 (COVID-19)? **Annals of Internal Medicine**, v. 172, n. 9, p. 621–622, 5 maio 2020.

CHUANG, S.; HOLLNAGEL, E. Challenges in implementing resilient health care. In: **Resilient Health Care, Volume 3: Reconciling Work-as-Imagined and Work-as-Done**. Resilient Health Care. Boca Ratón ed. Farnham, Surrey ; Burlington, VT: CRC Press, 2017. p. 47–55.

CLAY-WILLIAMS, R.; HOUNSGAARD, J.; HOLLNAGEL, E. Where the rubber meets the road: using FRAM to align work-as-imagined with work-as-done when implementing clinical guidelines. **Implementation Science**, v. 10, n. 1, p. 125, 29 ago. 2015.

CORBIN, J. M.; STRAUSS, A. L. **Basics of qualitative research: techniques and procedures for developing grounded theory**. Fourth edition ed. Los Angeles: SAGE, 2015.

CRANDALL, B.; KLEIN, G. A.; HOFFMAN, R. R. **Working minds: a practitioner's guide to cognitive task analysis**. Cambridge: MIT Press, 2006.

CRICK, F. **Astonishing Hypothesis: The Scientific Search for the Soul**. Reprint Edição ed. London: Scribner Book Company, 1995.

DAVIS, M. E. Perceptions of occupational risk by US commercial fishermen. **Marine Policy**, v. 36, n. 1, p. 28–33, jan. 2012.

DE CARVALHO, R. J. M. et al. Situated design of line-oriented flight training (LOFT): a case study in a Brazilian airline. **Cognition, Technology & Work**, v. 18, n. 2, p. 403–422, maio 2016.

DEKKER, S. Systems Thinking 1.0 and Systems Thinking 2.0: Complexity science and a new conception of "cause". **Aviation in Focus-Journal of Aeronautical Sciences**, v. 2, n. 2, p. 21–39, 2011.

DIEGUES, A. C. **Sea tenure, traditional knowledge and management among Brazilian artisanal fisherman**. [s.l.] Research Center on Population and Wetlands (NUPAUB) - University of São Paulo (USP), out. 2002.

DOYLE, J. J.; GRAVES, J. A.; GRUBER, J. Uncovering waste in US healthcare. **Journal of Health Economics**, v. 54, p. 25–39, jul. 2017.

ENDSLEY, M. R.; WRIGHT, M. Building shared situation awareness in healthcare settings. In: **Improving healthcare team communication: building on lessons from aviation and aerospace**. Aldershot, England ; Burlington, VT: Ashgate, 2008.

EUERBY, A.; BURNS, C. M. Advancing Complex Sociotechnical Systems Design Using the Community of Practice Concept. **Proceedings of the Human Factors and Ergonomics Society Annual Meeting**, v. 54, n. 4, p. 428–432, 1 set. 2010.

FAO. **Safety at sea as an integral part of fisheries management**. Rome: FAO - Food and Agriculture Organization of the United Nations - Fisheries and Aquaculture Department, 2001. Disponível em: <http://www.fao.org/docrep/003/x9656e/X9656E.htm#P218_9396>.

FAUSTO, M. C. R. et al. The Work of Community Health Workers in Major Cities in Brazil: Mediation, Community Action, and Health Care. **The Journal of Ambulatory Care Management**, v. 34, n. 4, p. 339–353, dez. 2011.

FAVERGE, J.-M.; OMBREDANE, A. **FAVERGE, Jean-Marie; OMBREDANE, André. L'analyse du travail: facteur d'économie humaine et de productivit**. Paris: Éditions PUF, 1955.

FERREIRA, D. et al. Desafios na manutenção do Serviço de Atendimento Móvel de Urgência fluvial no Alto Solimões. **Humanidades & Inovação**, v. 7, n. 16, p. 494–505, 7 out. 2020.

FRANÇA, J. E. M. et al. Analysing human factors and non-technical skills in offshore drilling operations using FRAM (functional resonance analysis method). **Cognition, Technology & Work**, 20 jun. 2020.

FRASÃO, G. **População passa a contar com 476 novas ambulâncias do SAMU 192**. Disponível em: <https://www.saude.gov.br/noticias/agencia-saude/42892-populacao-passa-a-contar-com-476-novas-ambulancias-do-samu-192>. Acesso em: 13 jul. 2020.

FYLAN, B. et al. Gaps, traps, bridges and props: A mixed-methods study of resilience in the medicines management system for patients with heart failure at hospital discharge. **BMJ Open**, v. 9, n. 2, 2019.

GAGNON, M.-P.; SÁNCHEZ, E.; PONS, J. M. Integration of health technology assessment recommendations into organizational and clinical practice: A case study in Catalonia. **International journal of technology assessment in health care**, v. 22, n. 02, p. 169–176, 2006.

GARCIA, L. P. et al. Intervenções não farmacológicas para o enfrentamento à epidemia da COVID-19 no Brasil. **Epidemiologia e Serviços de Saúde**, v. 29, n. 2, 2020.

GARCÍA-DE-LA-FUENTE, L.; FERNÁNDEZ-VÁZQUEZ, E.; RAMOS-CARVAJAL, C. A methodology for analyzing the impact of the artisanal fishing fleets on regional economies: An application for the case of Asturias (Spain). **Marine Policy**, v. 74, p. 165–176, dez. 2016.

GIOVANELLA, L. et al. Family health: limits and possibilities for an integral primary healthcare approach in Brazil. **Cien Saude Colet**, v. 14, n. 3, p. 783–794, 2009.

GLASER, B. G.; STRAUSS, A. L. **The Discovery of Grounded Theory: Strategies for Qualitative Research**. 1. ed. [s.l.] Routledge, 2017.

GOMES, J. O. et al. Resilience and brittleness in the offshore helicopter transportation system: The identification of constraints and sacrifice decisions in pilots' work. **Reliability Engineering & System Safety**, v. 94, n. 2, p. 311–319, fev. 2009.

GOMES, J. O. et al. Ergonomics, safety, and resilience in the helicopter offshore transportation system of Campos Basin. **Work**, v. 51, n. 3, p. 513–535, 1 jan. 2015.

GOODMAN, L. A. Snowball Sampling. **The Annals of Mathematical Statistics**, v. 32, n. 1, p. 148–170, 1961.

GRINDROD, K.; TRAN, P.; BURNS, C. **Medication Reconciliation More than just a check**. Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care. **Anais**...SAGE Publications, 2015

HALL, A. E. et al. To adhere or not to adhere: Rates and reasons of medication adherence in hematological cancer patients. **Critical Reviews in Oncology/Hematology**, v. 97, p. 247–262, 1 jan. 2016.

HALL, R. et al. Modeling Patient Flows Through the Health care System. In: HALL, R. (Ed.). . **Patient Flow**. International Series in Operations Research & Management Science. [s.l.] Springer US, 2013. p. 3–42.

HARRIS, M. et al. Reply letter utilization by secondary level specialists in a municipality in Brazil: a qualitative study. **Revista Panamericana De Salud Publica = Pan American Journal of Public Health**, v. 21, n. 2–3, p. 96–110, mar. 2007.

HEYLIGHEN, F. Complexity and Self-Organization. In: **Encyclopedia of Library and Information Sciences**. [s.l.] Taylor & Francis, 2008. v. Ip. 250–259.

HOLLNAGEL, E. **Barriers and Accident Prevention**. 1ª Edição ed. Aldershot, Hampshire, England ; Burlington, VT: Routledge, 2004.

HOLLNAGEL, E. **The ETTO principle: efficiency-thoroughness trade-off: why things that go right sometimes go wrong**. [s.l.] Ashgate Publishing, Ltd., 2009.

HOLLNAGEL, E. **Resilience engineering in practice: A guidebook**. [s.l.] Ashgate Publishing, Ltd., 2011.

HOLLNAGEL, E. **FRAM: The Functional Resonance Analysis Method: Modelling Complex Socio-technical Systems**. [s.l.] Ashgate, 2012.

HOLLNAGEL, E. **Safety-I and Safety–II: the past and future of safety management**. [s.l.] Ashgate Publishing, Ltd., 2014.

HOLLNAGEL, E. Looking for patterns in everyday clinical work. In: **Resilient Health Care, Volume 2: The Resilience of Everyday Clinical Work**. Farnham, Surrey, UK: Ashgate, 2015. p. 145–162.

HOLLNAGEL, E. Prologue: Why do our expectations of how work should be done never correspond exactly to how work is done. In: **Resilient health care III: Reconciling work-as-imagined and work-as-done**. [s.l: s.n.]. p. 7–16.

HOLLNAGEL, E. **Safety-II in Practice: Developing the Resilience Potentials**. [s.l.] Taylor & Francis, 2018.

HOLLNAGEL, E.; FUJITA, Y. The Fukushima disaster – systemic failures as the lack of resilience. **Nuclear Engineering and Technology**, v. 45, n. 1, p. 13–20, fev. 2013.

HOLLNAGEL, E.; GOTEMAN, Ö. The Functional Resonance Accident Model. **Proceedings of Cognitive System Engineering in Process Plant**, 1 jan. 2004.

HOLLNAGEL, E.; WOODS, D. D. Cognitive systems engineering: New wine in new bottles. **International Journal of Man-Machine Studies**, v. 18, n. 6, p. 583–600, 1983.

HOLLNAGEL, E.; WOODS, D. D. **Joint cognitive systems: foundations of cognitive systems engineering**. Boca Raton, FL: Taylor & Francis, 2005a.

HOLLNAGEL, E.; WOODS, D. D. **Joint cognitive systems: an introduction to cognitive systems engineering**. [s.l.] CRC Press, 2005b.

HOLLNAGEL, E.; WOODS, D. D.; LEVESON, N. **Resilience Engineering: Concepts and Precepts**. Aldershot, England; Burlington, VT: Ashgate, 2006.

HUBER, G. J.; GOMES, J. O.; DE CARVALHO, P. V. R. A program to support the construction and evaluation of resilience indicators. **Work**, v. 41, p. 2810–2816, 2012.

HURST, N.; WILLIAMS, D. R.; MARSHALL, P. **Risk Assessment: The Human Dimension**. Cambridge: Royal Society of Chemistry, 1998.

IBAMA. **Estatísticas da Pesca 2007 - Brasil - Grandes Regiões e Unidades da Federação**. Brasília, DF: Instituo Brasileiro ddo Meio Ambiente e dos Recursos Naturais Renováveis, dez. 2007.

JAESCHKE, A. **Oportunidades de melhorias ergonômicas das exigências físicas da atividade jangadeira em Ponta Negra, Natal-RN**. Dissertação de Mestrado—Natal, RN: Universidade Federal do Rio Grande do Norte - UFRN, Dezembro 2010.

JAESCHKE, A.; SALDANHA, M. C. W. Physical demands during the hauling of fishing nets for artisan fishing using rafts in beach of Ponta Negra, Natal-Brasil. **Work**, v. 41, n. Supplement 1, p. 414–421, 1 jan. 2012.

JATOBÁ, A. et al. Designing for patient risk assessment in primary health care: a case study for ergonomic work analysis. **Cognition, Technology & Work**, v. 18, n. 1, p. 215–231, 2016.

JATOBÁ, A. et al. Patient visits in poorly developed territories: a case study with community health workers. **Cognition, Technology & Work**, v. 20, p. 125–152, 6 fev. 2018.

JATOBÁ, A. et al. Assessing community health workers' conditions for delivering care to patients in low-income communities. **Applied Ergonomics**, v. 82, p. 102944, 1 jan. 2020.

JENSEN, O. C.; STAGE, S.; NOER, P. Injury and time studies of working processes in fishing. **Safety Science**, v. 44, n. 4, p. 349–358, abr. 2006.

KEFALIDOU, G.; GOLIGHTLY, D.; SHARPLES, S. Identifying rail asset maintenance processes: a human-centric and sensemaking approach. **Cognition, Technology & Work**, v. 20, n. 1, p. 73–92, fev. 2018.

KERESTECIOGLU, D. **Building Bridges between Pharmacists and Physicians: An Exploratory Investigation via Field, Usability Studies & Control Task Analysis To Enhance Pharmacy Management System Requirements**. Master Thesis—Waterloo, ON: University of Waterloo, 2017.

KERESTECIOGLU, D.; BURNS, C. M.; GRINDROD, K. Building Bridges Between Physicians And Pharmacists: An Interprofessional Approach to Electronic Health Record Requirements. **Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care**, v. 5, n. 1, p. 9–14, jun. 2016.

KLEIN, G. et al. A data-frame theory of sensemaking. In: **Expertise Out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision Making**. New York: Lawrence Erlbaum, 2007. p. 113–155.

KLEIN, G. **Seeing what others don't: The remarkable ways we gain insights**. [s.l.] Public Affairs, 2013.

KLEIN, G.; MOON, B.; HOFFMAN, R. R. Making Sense of Sensemaking 2: A Macrocognitive Model. **IEEE Intelligent Systems**, v. 21, n. 5, p. 88–92, set. 2006.

KNUDSEN, F.; GRON, S. Making sense of fishermen's risk perception. **Policy and Practice in Health and Safety**, v. 8, n. 2, p. 77–94, jan. 2010.

KROEZE, M.; WIMMER, P. **Putting Safety-II into practice by using FRAM in the Dutch hospitals**. In: FRAMILY MEETING 2019. Malaga, Spain, 2019.

KRON, K. et al. Incorporating medication indications into the prescribing process. **American Journal of Health-System Pharmacy**, v. 75, n. 11, p. 774–783, 1 jun. 2018.

LANÇA, E. DE F. C. **Serviço de Atendimento Móvel de Urgência Fluvial de Manaus: perfil dos atendimentos, usuários e fatores relacionados ao agravamento dos atendidos**. text—[s.l.] Universidade de São Paulo, 16 ago. 2017.

LEVESON, N. A new accident model for engineering safer systems. **Safety science**, v. 42, n. 4, p. 237–270, 2004.

LEVESON, N. **Engineering a safer world: systems thinking applied to safety**. Cambridge, Mass: MIT Press, 2011.

LEVESON, N. G. Rasmussen's legacy: A paradigm change in engineering for safety. **Applied Ergonomics**, The Legacy of Jens Rasmussen. v. 59, p. 581–591, 1 mar. 2017.

LI, R. C. et al. Reason for Use: An Opportunity to Improve Patient Safety. In: **Improving Usability, Safety and Patient Outcomes with Health Information Technology: From Research to Practice**. Victoria, BC: IOS Press, 2019a. v. 257p. 47–52.

LI, R. C. et al. Information Technology Systems at the sharp end of medication therapy management. **Proceedings of the Human Factors and Ergonomics Society Annual Meeting**, v. 63, n. 1, p. 698–702, nov. 2019b.

LI, W. et al. A proactive operational risk identification and analysis framework based on the integration of ACAT and FRAM. **Reliability Engineering & System Safety**, v. 186, p. 101–109, 2019c.

LI, Y.; GULDENMUND, F. W. Safety management systems: A broad overview of the literature. **Safety Science**, v. 103, p. 94–123, 1 mar. 2018.

LUO, M.; SHIN, S.-H. Half-century research developments in maritime accidents: Future directions. **Accident Analysis & Prevention**, v. 123, p. 448–460, 1 fev. 2019.

MACCORMICK, A. D.; COLLECUTT, W. G.; PARRY, B. R. Prioritizing patients for elective surgery: a systematic review. **ANZ Journal of Surgery**, v. 73, n. 8, p. 633–642, 1 ago. 2003.

MACHADO, C. V.; SALVADOR, F. G. F.; O'DWYER, G. Mobile Emergency Care Service: analysis of Brazilian policy. **Revista de Saúde Pública**, v. 45, n. 3, 2011.

MACIAZEKI-GOMES, R. DE C. et al. The work of the community health worker from the perspective of popular health education: possibilities and challenges. **Ciência & Saúde Coletiva**, v. 21, p. 1637–1646, maio 2016.

MACINKO, J. et al. Going to scale with community-based primary care: An analysis of the family health program and infant mortality in Brazil, 1999–2004. **Social Science & Medicine**, v. 65, n. 10, p. 2070–2080, 1 nov. 2007.

MARINHO DA SILVA, M. E.; SANTOS, E. R.; BORENSTEIN, D. Implementing Regulation Policy in Brazilian Health Care Regulation Centers. **Medical Decision Making**, v. 30, n. 3, p. 366–379, 1 maio 2010.

MÁSCULO, F. S.; VIDAL, M. C. (EDS.). **Ergonomia: Trabalho Adequado e Eficiente**. [s.l.] Elsevier Brasil, 2011.

MATHESON, C. et al. Resilience of primary healthcare professionals working in challenging environments: a focus group study. **Br J Gen Pract**, v. 66, n. 648, p. e507–e515, 1 jul. 2016.

MCDONALD, M. A.; KUCERA, K. L. Understanding non-industrialized workers' approaches to safety: How do commercial fishermen "stay safe"? **Journal of Safety Research**, v. 38, n. 3, p. 289–297, jan. 2007.

MEARES, H. D.; JONES, M. P. When a system breaks: queueing theory model of intensive care bed needs during the COVID -19 pandemic. **Medical Journal of Australia**, v. 212, n. 10, p. 470–471, jun. 2020.

MERANDI, J. et al. Safety II Behavior in a Pediatric Intensive Care Unit. **Pediatrics**, v. 141, n. 6, p. e20180018, jun. 2018.

MERCER, K. et al. Physician and Pharmacist Medication Decision-Making in the Time of Electronic Health Records: Mixed-Methods Study. **JMIR Human Factors**, v. 5, n. 3, p. e24, 2018.

MINISTRY OF HEALTH OF BRAZIL. **Brazilian Primary Healthcare Policy (Política Nacional de Atenção Básica)**. Brasília, DF, Brazil: [s.n.].

MOREL, G.; AMALBERTI, R.; CHAUVIN, C. Articulating the differences between safety and resilience: The decision-making process of professional sea-fishing skippers. **Human Factors**, v. 50, n. 1, p. 1–16, 2008.

MYERS, M. D. Investigating information systems with ethnographic research. **Communications of the Association for Information Systems**, v. 2, n. 1, p. 23, 1999.

NARDI, B. A. Chapter 15 - The Use of Ethnographic Methods in Design and Evaluation. In: HELANDER, M. G.; LANDAUER, T. K.; PRABHU, P. V. (Eds.). . **Handbook of Human-Computer Interaction (Second Edition)**. Amsterdam: North-Holland, 1997. p. 361–366.

NATIONAL ASSOCIATION OF PHARMACY REGULATORY AUTHORITIES [NAPRA]. **National Statistics**. [s.l: s.n.]. Disponível em: <https://napra.ca/national-statistics>.

NEMETH, C. et al. Minding the Gaps: Creating Resilience in Health Care. In: HENRIKSEN, K. et al. (Eds.). . **Advances in Patient Safety: New Directions and Alternative Approaches (Vol. 3: Performance and Tools)**. Advances in Patient Safety. Rockville (MD): Agency for Healthcare Research and Quality (US), 2008.

NEMETH, C. et al. Resilience is not control: Healthcare, crisis management, and ICT. **Cognition, Technology and Work**, v. 13, n. 3, p. 189–202, 2011.

NIELSEN, J. **Usability Engineering**. 1. ed. [s.l.] Morgan Kaufmann, 1993.

NORMAN-02/DPC. **Normas da Autoridade Marítima para Embarcações Empregadas na Navegação Interior. Marinha do Brasil, Diretoria de Portos e Costas**, 2005.

NOVAK, J. D. **Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations**. [s.l.] Routledge, 2010.

NYSSEN, A. S.; BÉRASTÉGUI, P. Is system resilience maintained at the expense of individual resilience? In: **Resilient Health Care, Volume 3: Reconciling Work-as-Imagined and Work-as-Done**. Resilient Health Care. Boca Ratón ed. Farnham, Surrey ; Burlington, VT: CRC Press, 2017. p. 37–46.

OZANO, K. et al. Improving local health through community health workers in Cambodia: challenges and solutions. **Human Resources for Health**, v. 16, n. 1, p. 2, dez. 2018.

PAIM, J. et al. The Brazilian health system: history, advances, and challenges. **The Lancet**, v. 377, n. 9779, p. 1778–1797, 21 maio 2011.

PATRIARCA, R. et al. Resilience engineering: Current status of the research and future challenges. **Safety Science**, v. 102, p. 79–100, fev. 2018.

PATRIARCA, R. et al. Framing the FRAM: A literature review on the functional resonance analysis method. **Safety Science**, v. 129, p. 104827, set. 2020.

PATRIARCA, R.; BERGSTRÖM, J. Modelling complexity in everyday operations: functional resonance in maritime mooring at quay. **Cognition, Technology & Work**, v. 19, n. 4, p. 711–729, 1 nov. 2017.

PAVARD, B.; DUGDALE, J. **From representational intelligence to contextual intelligence in the simulation of complex social systems**. CASOS conference. Pittsburg. **Anais**...2002. Acesso em: 19 mar. 2016

PAVARD, B.; DUGDALE, J. The contribution of complexity theory to the study of socio-technical cooperative systems. In: **Unifying Themes in Complex Systems**. [s.l.] Springer, 2006. p. 39–48.

PEREZ-LABAJOS, C. Fishing safety policy and research. **Marine Policy**, v. 32, n. 1, p. 40–45, jan. 2008.

PERROW, C. **Normal Accidents: Living with High Risk Technologies**. Princeton, N.J: Princeton University Press, 1984.

PERRY, S. J.; WEARS, R. L.; ANDERSON, B. **Extemporaneous Adaptation to Evolving Complexity: A Case Study of Resilience in Healthcare**. Proceedings of the second resilience engineering symposium. **Anais**...Juan-Les-Pins, France: 2006

PHIPPS, D.; ASHCROFT, D.; PARKER, D. Managing Medicines Management: Organisational Resilience in Community Pharmacies. In: **Resilient Health Care, Volume 2**. [s.l.] CRC Press, 2017. p. 117–128.

PINIELLA, F.; FERNÁNDEZ-ENGO, M. A. Towards system for the management of safety on board artisanal fishing vessels: Proposal for check-lists and their application. **Safety Science**, v. 47, n. 2, p. 265–276, fev. 2009.

QUEIROZ, K. O. Transporte fluvial no Solimões – uma leitura a partir das lanchas Ajato no Amazonas. **GEOUSP Espaço e Tempo (Online)**, v. 23, n. 2, p. 322–341, 18 jul. 2019.

RABEN, D. C. et al. Proposing leading indicators for blood sampling: application of a method based on the principles of resilient healthcare. **Cognition, Technology and Work**, v. 19, n. 4, p. 809–817, 2017.

RAJEEV CHADHA; AMITA SINGH; JAY KALRA. Lean and queuing integration for the transformation of health care processes: A lean health care model. **Clinical Governance: An International Journal**, v. 17, n. 3, p. 191–199, 27 jul. 2012.

RASMUSSEN, J. **The human data processor as a system component. Bits and pieces of a model**. [s.l: s.n.].

RASMUSSEN, J. The human as a systems component. In: **Human interaction with computers**. [s.l.] Academic Press, 1980. p. 67–96.

RASMUSSEN, J.; LIND, M. **Coping with complexity**. . In: EUROPEAN CONFERENCE ON HUMAN DECISION AND MANUAL CONTROL. Delft, The Netherlands: 1981. Acesso em: 16 abr. 2015

RIGHI, A. W.; SAURIN, T. A. Complex socio-technical systems: Characterization and management guidelines. **Applied Ergonomics**, v. 50, p. 19–30, set. 2015.

ROBERTS, S. E. Britain's most hazardous occupation: Commercial fishing. **Accident Analysis & Prevention**, v. 42, n. 1, p. 44–49, jan. 2010.

ROSA, L. V.; HADDAD, A. N.; DE CARVALHO, P. V. R. Assessing risk in sustainable construction using the Functional Resonance Analysis Method (FRAM). **Cognition, Technology & Work**, v. 17, n. 4, p. 559–573, nov. 2015.

SABIK, L. M.; LIE, R. K. Priority setting in health care: Lessons from the experiences of eight countries. **International Journal for Equity in Health**, v. 7, p. 4, 21 jan. 2008.

SALDANHA, M. C. W. et al. The construction of ergonomic demands: application on artisan fishing using jangada fishing rafts in the beach of Ponta Negra. **Work**, n. Supplement 1, p. 628–635, 2012.

SALDANHA, M. C. W. et al. Condições de trabalho e segurança na pesca artesanal com jangadas a partir da análise da atividade. In: **Compendio: V Congreso Latinoamericano y IV Congreso Peruano de Ergonomia**. 1. ed. Lima: SOPERGO, 2017. p. 378–396.

SALDANHA, M. C. W. et al. Understanding and improving safety in artisanal fishing: A safety-II approach in raft fishing. **Safety Science**, v. 122, p. 104522, 1 fev. 2020.

SALTMAN, R. B.; RICO, A.; BOERMA, W. G. W. **Primary care in the driver's seat? Organizational reform in European primary care**. [s.l.] Open University Press, 2006.

SAURIN, T. A.; ROSSO, C. B.; COLLIGAN, L. Towards a Resilient and Lean Health Care. In: **Resilient Health Care Volume 3: Reconciling work-as-imagined and work-as-done**. 1. ed. Boca Ratón: CRC Press, 2017.

SAURIN, T. A.; WERLE, N. J. B. A framework for the analysis of slack in socio-technical systems. **Reliability Engineering & System Safety**, v. 167, p. 439–451, nov. 2017.

SCHUTIJSER, B. C. F. M. **Double checking injectable medication administration: Does the protocol fit clinical practice?** In: FRAMILY MEETING 2019. Malaga, Spain, 2019. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0925753519302000>. Acesso em: 15 jul. 2020

SCHUTIJSER, B. C. F. M. et al. Double checking injectable medication administration: Does the protocol fit clinical practice? **Safety Science**, v. 118, p. 853–860, out. 2019.

SJÖLIN, H. et al. What an ambulance nurse needs to know: A content analysis of curricula in the specialist nursing programme in prehospital emergency care. **International Emergency Nursing**, v. 23, n. 2, p. 127–132, abr. 2015.

SORANZ, D.; PINTO, L. F.; PENNA, G. O. Themes and reform of Primary Health care (RCAPS) in the city of Rio de Janeiro, Brazil. **Ciencia & saude coletiva**, v. 21, n. 5, p. 1327–1338, 2016.

STARFIELD, B.; SHI, L. Policy relevant determinants of health: an international perspective. **Health Policy (Amsterdam, Netherlands)**, v. 60, n. 3, p. 201–218, jun. 2002.

ST-MAURICE, J.; BURNS, C. M. Using Comparative Cognitive Work Analysis to Identify Design Priorities in Complex Socio-Technical Systems. **Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care**, v. 4, n. 1, p. 118–123, jun. 2015.

STØRKERSEN, K. V. **Bureaucracy overload calling for audit implosion: A sociological study of how the International Safety Management Code affects Norwegian coastal transport**. PhD Thesis—Trondheim: NTNU - Norwegian University of Science and Technology, jun. 2018.

SUJAN, M. A.; HUANG, H.; BRAITHWAITE, J. Learning from incidents in health care: Critique from a Safety-II perspective. **Safety Science**, v. 99, p. 115–121, nov. 2017.

THARMALINGAM, S.; HAGENS, S.; ZELMER, J. The value of connected health information: perceptions of electronic health record users in Canada. **BMC Medical Informatics and Decision Making**, v. 16, n. 1, p. 93, 16 jul. 2016.

THORVALDSEN, T. The importance of common sense: How Norwegian coastal fishermen deal with occupational risk. **Marine Policy**, v. 42, p. 85–90, nov. 2013.

THORVALDSEN, T. et al. What works? Results of a Nordic survey on fishers' perceptions of safety measures. **Marine Policy**, v. 95, p. 95–101, set. 2018.

TIMERMAN, S. et al. Emergency medical services: Brazil. **Resuscitation**, v. 70, n. 3, p. 356–359, set. 2006.

UNDERWOOD, P.; WATERSON, P. Systemic accident analysis: Examining the gap between research and practice. **Accident Analysis & Prevention**, v. 55, p. 154–164, jun. 2013.

UTNE, I. B. Systems engineering principles in fisheries management. **Marine Policy**, v. 30, n. 6, p. 624–634, 1 nov. 2006.

VANDERHAEGEN, F. Erik Hollnagel: Safety-I and Safety-II, the past and future of safety management. **Cognition, Technology & Work**, v. 17, n. 3, p. 461–464, ago. 2015.

VARGAS, I. et al. Barriers to healthcare coordination in market-based and decentralized public health systems: a qualitative study in healthcare networks of Colombia and Brazil. **Health Policy and Planning**, v. 31, n. 6, p. 736–748, jul. 2016.

VÁZQUEZ, M.-L. et al. Doctors' experience of coordination across care levels and associated factors. A cross-sectional study in public healthcare networks of six Latin American countries. **Social Science & Medicine**, v. 182, p. 10–19, jun. 2017.

VICENTE, K. J. **Cognitive work analysis: toward safe, productive, and healthy computer-based work**. Mahwah, N.J: Lawrence Erlbaum Associates, 1999.

VIDAL, M. C. **La travail des macons en France et au Brésil: sources et gestion des différences et variations**. Tese de Doutorado—Paris: Conservatoire National des Arts et Metiers, 1985.

VIDAL, M. C.; BONFATTI, R. J. Conversational action: an ergonomic approach to interaction. **Rethinking Communicative Interaction: New Interdisciplinary Horizons**, v. 116, p. 257, 2003.

VIDAL, M. C. R. **Sur l'interaction en Analyse du Travail: La conversation dans une analyse collective en situation**. Proceedings of the 12th triennial congress of the International Ergonomics Association. **Anais**... In: 12TH TRIENNIAL CONGRESS OF THE INTERNATIONAL ERGONOMICS ASSOCIATION. London: International Ergonomics Association - IEA, 1994

VIDAL, M. C. R. et al. Ergonomics point of view of work accidents in safety management perspective. In: **Ergonomics and human factors in safety management**. Industrial systems engineering. 1. ed. Boca Raton, Florida: CRC Press, 2016.

WARHOLAK, T. L. et al. Assessing the effect of providing a pharmacist with patient diagnosis on electronic prescription orders: A pilot study. **Research in Social and Administrative Pharmacy**, v. 10, n. 1, p. 246–251, jan. 2014.

WEICK, K. E. **Sensemaking in organizations**. Thousand Oaks: Sage Publications, 1995.

WEIR, N. M.; NEWHAM, R.; BENNIE, M. A literature review of human factors and ergonomics within the pharmacy dispensing process. **Research in Social and Administrative Pharmacy**, v. 16, n. 5, p. 637–645, maio 2020.

WENNERSTROM, A.; RUSH, C. H. The Terminology of Community Health Workers. **American Journal of Public Health**, v. 106, n. 8, p. e10–e10, ago. 2016.

WHITE, D. B.; LO, B. A Framework for Rationing Ventilators and Critical Care Beds During the COVID-19 Pandemic. **JAMA**, v. 323, n. 18, p. 1773, 12 maio 2020.

WIENER, N. **Cybernetics or Control and Communication in the Animal and the Machine**. 1st. ed. Cambridge, Mass: Mit Press, 1948.

WISNER, A. Understanding problem building: ergonomic work analysis. **Ergonomics**, v. 38, n. 3, p. 595–605, 1995a.

WISNER, A. Situated cognition and action: implications for ergonomic work analysis and anthropotechnology. **Ergonomics**, The Etienne Grandjean Memorial Lecture. v. 38, n. 8, p. 1542–1557, ago. 1995b.

WOLTJER, R. **Aviation Accident Investigation and ATM Automation Risk Assessment using the Functional Resonance Accident Model**. In: FRAMILY 2008. , 2008.

WOODS, D. **Engineering organizational resilience to enhance safety: A progress report on the emerging field of resilience engineering**. Proceedings of the Human Factors and Ergonomics Society. **Anais**...2006Disponível em: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-44349106604&partnerID=40&md5=fb33af27b8f38f699924e41c5becaeca>

WOODS, D. D. Creating foresight: lessons for enhancing resilience from Columbia. In: **Organization at the limit: lessons from the Columbia disaster**. [s.l.] Blackwell, 2005.

WORLD HEALTH ORGANIZATION & UNICEF. **Primary health care: a joint report**: Alma-Ata; USSR. USSR: World Health Organization & Unicef, 1978.

ZHENG, Z.; TIAN, J.; ZHAO, T. Refining operation guidelines with model-checking-aided FRAM to improve manufacturing processes: a case study for aeroengine blade forging. **Cognition, Technology & Work**, v. 18, n. 4, p. 777–791, 1 nov. 2016.

ZYTOON, M. A. Occupational injuries and health problems in the Egyptian Mediterranean fisheries. **Safety Science**, v. 50, n. 1, p. 113–122, jan. 2012.