# The use of Functional Resonance Analysis Method (FRAM) to model an emergency response plan

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**Abstract:** Accident models, analysis methods and emergency response plans affect what accident investigators and emergency response leaders look for, which contributing factors are found, and which recommendations are issued. This paper contrasts the Functional Resonance Analysis Method (FRAM) for an emergency response plan. FRAM illustrates the dynamic interactions within socio-technical systems and lets the analyst understand the how and why by describing non-linear dependencies, performance conditions, variability, and their resonance across functions. So, it defines a systemic framework to model complex systems from the perspective of function and views accidents and emergency response strategies as emergent phenomenon of function's variability, It is playing an increasingly significant role in the development of systemic emergency response plan .

**Keywords***:* Accident analysis; FRAM; Emergency response plan; Resilience.

## 1. INTRODUCTION

Risk management in our industries has become a major challenge for our society. The new hazards that have accompanied technological advances are needed to be controlled; industrial risk management was formalized with the emergence of reliability and maintainability theory [1]. The designers of safety-critical systems subsequently incorporated this formalism into the standard techniques of systems engineering [2]. Such developments did not, however, explicitly include any reference to human factors [3]. A number of studies aiming to improve working conditions have been successfully conducted and have contributed to reducing risks. However, establishing a direct link between risk management and the social and human sciences remains somewhat elusive. The methodological framework for risk management now includes specific tools for evaluating human reliability, and more recently organizational reliability. The first methods to be developed used the formal framework of reliability, which meant approximating human behavior to machine behavior [4]. This approach was strongly criticized by the scientific community. Dougherty [5] and Hollnagel [6] provide a summary of this criticism.

## 2. ACCIDENT THEORY MODELS

The analytical method used in dependability analysis represents accidents as successions of events in which safety appears as a property of the system. Resilience engineering [7], in a systemic framework, goes beyond this and defines safety as an emergent system phenomenon, rather than as a property.

To facilitate this approach a classification of accidents into three categories has been proposed [8]: sequential, epidemiological and systemic. In the sequential model, an accident is explained as a succession of events linked together by a cause-to-effect relation- ship. In Reason's [9] epidemiological model an accident is the result of passive failures, introduced by latent conditions whose effect is not immediate, but becomes manifest when a particular function or system component is called upon. Finally, the systemic model introduced by Woods [10], Leveson [11] and Hollnagel [8] describes an accident as the result of complex interactions between the different components of the system. An accident is the consequence of a coincidence of events, rather than of a deterministic succession of events [8].

This article introduces the results of an accident analysis to construct a system model that could be used to highlight constraints and contradictions in the system. The model was then analyzed using the

Functional Resonance Analysis Method (FRAM) [12-14]. FRAM is particularly well suited for mapping dynamic dependencies in complex systems. It is used to provide a better understanding about how functional variability in planning, preparedness, execution, resource availability, economic factors, and human factors affect emergency response actions. The results of FRAM analyses can provide information for ways to increase the overall resilience of such systems [15].

The notion of modeling and mapping dynamic dependencies with systemic models and especially FRAM are already used in several contexts (computer science, ecological sciences, medicine), some in relation to industrial safety applications [16-20]. Nevertheless, as indicated by [21] there is a gap between research and practice which could hinder the awareness, adoption and usage of systemic models.

## 3. FUNCTIONAL RESONANCE ANALYSIS METHOD

FRAM was originally developed for accident analysis by Hollnagel [12]. However, it can also be used as an alternative approach to risk assessment [22, 23]. It describes the socio-technical system in terms of its functions and its activities rather than in terms of its structure. The aim of the FRAM method is to represent the system's dynamics by modeling the non-linear interactions that are part of the system, and through a novel representation of the performance of functions and activities [4, 12, 13 and 24]. A FRAM model is developed by determining the activities or functions that make up a process and how they are coupled. The data for developing a FRAM model can be obtained through a number of methods, including ethnography, interviews, documented processes, and so on. Each function is then described in terms of its aspects [24].

## 4. PRINCIPLES OF FRAM

Te following section outlines the theoretical principles that guide the implementation of FRAM.

The first principle is that of the equivalence of success and failures [13]. Traditional safety theories emphasized learning from system failures, such as incidents and accidents [13]. However, learning from failures is not enough for keeping current complex socio-technical systems safe. FRAM can be applied to analyze either system incident/accident or the normal operational procedure. According to FRAM, to understand what goes right when the daily work is carried out is as important as understanding what failed in the system.

The second principle is that of approximate adjustments [13]. Human performance can be influenced by many factors, both internal and external, such as fatigue, stress, emotions and mood, vigilance, task demands, and deadlines. Sometimes organizational factors such as the effectiveness of communication or unclear guidelines can make workers tasks more difficult. The complex working context may make the work task more challenging and require workers to make their own decisions. Workers have to adjust their behavior accordingly to meet the system's requirements to produce the desired outcome. They usually need to make some tradeoffs between being efficient and to make sure the work can be completed as precisely as possible. Hollnagel [8] termed these kinds of adjustments as efficiency-thoroughness tradeoffs (ETTOs). These adjustments are necessary and understandable; however, any changed system behavior may raise variabilities.

The third principle is that of emergence [13]. Under each analyzed case, the context and combination of variabilities in the system are unique. As the interactions within a complex system are dynamic and nonlinear, the occurrence of an outcome is emergent. To be more specific, minor variabilities always exist in normal system operations and do not affect system safety. However, the particular external environment may integrate variabilities and magnify their influence to generate an undesired outcome.

The fourth principle is that of functional resonance [13]. From the FRAM perspective, variabilities exist in normal daily operations. These small variabilities may not be able to crash the system alone, but aggregated with other variabilities in the system may cause resonance, which generates a negative outcome. The whole system should be taken into account, instead of focusing on one segment of the system.

## 5. FRAM STEPS

To examine the potentiality of accidents using the FRAM method means examining the operation of a particular system in three separate steps that we outline below [4].

The first step is a formal breakdown of system operation into elementary operational units, each of which has six attributes (Figure 1). These attributes serve as connectors between elementary units:

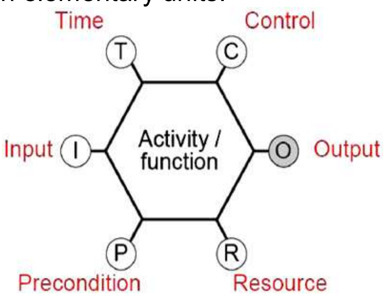



Figure.1. representing a function with six aspects [24]

1. Input (I) is what the function acts on or changes (An input is also used to start the function).
2. Output (O) is what emerges from the function (this can be an outcome or a state change).
3. Precondition (P) is a condition that must be satisfied before the function can be commenced.
4. Resources (R) are materials or people needed to carry out the function.
5. Control (C) is how the function is monitored or controlled.
6. Time (T) refers to any time constraints that might affect completing the function.

In relation to guidelines, the FRAM can be used to describe the written guideline as a set of functions together with the conditions that are necessary for the realization of the functions. The resulting model can be used to analyze the potential variability of conditions and functions and how this may combine to affect the way in which the guideline is implemented [23].

The logic of the FRAM is used to develop questions that are then explored with those who will be using the guideline. Typical questions that might be explored are illustrated in Table 1[23].

Table.1.Guided questions to explore FRAM conditions [23]

| Condition | Guided questions |
|---|---|
| Input | What starts the function?<br>What does the function act on or change? |
| Output | What is the output or results of the function?<br>Do you have to inform anyone?<br>Do you have to collect or record/report anything? If so, where?<br>Who needs the output? Who will use what is produced?<br>Have you agreed with whoever uses this that it is what they need? |
| precondition | What should be in place so that you can complete the function normally?<br>What do you do if the preconditions are not available? |
| Resource | What resources do you need to perform the function, such as people, equipment, IT, power, buildings, etc?<br>What do you do if the resources are not available? |
| Control | Do you have any goals for the function, such as do something within a time frame (this is a control)?<br>What is the purpose of this function?<br>Why do we do this?<br>Do you have formal procedures or instructions controlling the function?<br>Do you have people, such as supervisors, controlling the function?<br>Are there values controlling the function?<br>Do unofficial work practices or culture control the function?<br>Do you have priorities, such as a triage system?<br>Are there constraints such as budget? |
| Time | Is there any time related to the function?<br>Is there a certain time where you have to perform the function?<br>What happens if you are delayed—will you still do the function or not and what is the consequence for the following functions?<br>Time only has four options: too early, too late, on time, or not at all. |

The second step is determining the potential variability of each operational unit. FRAM classifies operational units into three categories: human (H), technical (T) and organizational (O). The operational unit's potential variability is determined by the respective weights of eleven common performance conditions (CPC), acting as context factors on the operational unit, according to its category. The CPC used in FRAM are based on Hollnagel's CREAM (cognitive reliability and error analysis method) [6]. The CPC are shown in Table 2, according to operational unit category. These context factors can have positive or negative impacts on performance. The quality of each CPC takes one of three possible values: (1) stable or variable but adequate, (2) stable or variable but inadequate, (3) unpredictable. The aim is to determine the set of applicable CPCs for each operational unit and to evaluate their quality. As a general rule, where a CPC is stable or variable but adequate the corresponding variability of performance is low, and where the CPC is stable or variable but inadequate, variability of performance is high. Finally, if a CPC is unpredictable, the corresponding variability of performance is very high.

Table.2. Common performance conditions (CPC).

| CPC | Category |
|---|---|
| Resource availability | H-T |
| Training and experience | H |
| Quality of communications | H-T |
| Quality of human–machine interfaces | T |
| Accessibility and availability of methods and procedures | H |
| Working conditions | H-T |
| Number of simultaneous objectives | H-O |
| Time available | H |
| Circadian rhythm | H |
| Quality of team collaboration | H |
| Quality of organizational support | O |

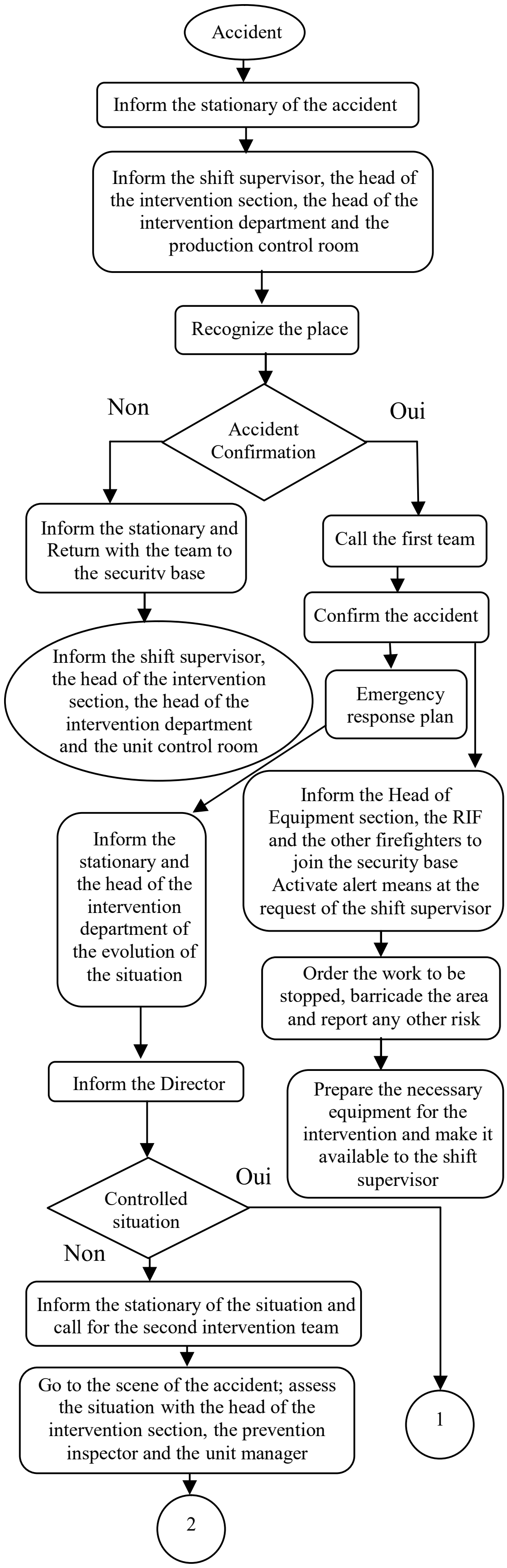
The third step establishes dependencies between operational units. This is easily performed by inserting correspondence attributes assigned in the first step. Graphically, this means connecting the inputs and outputs of each unit, represented by its hexagon, to the outputs and inputs of other units, thus constituting what is termed a FRAM network. This network enables information flows during the normal execution of an operation to be represented formally. The labels H, T and O in the header part of a unit's hexagon indicate the category of entities participating in the operational unit. The network is then used to search for negative functional resonances which may affect the correct sequence of operational units and to detect the propagation of such resonances through the system.

A FRAM model is built using a software tool called the FRAM Model Visualiser (FMV) [25]. One feature of the FMV is that it identifies conditions that are incompletely described and marks them graphically (Fig. 1). In the case of modeling a guideline, this makes it easy to find the parts of the guideline that are incompletely described or not described at all [23].

## 6. EMERGENCY RESPONSE PLAN

In this section we present an emergency response strategy of Skikda refinery. The purpose of this emergency response plan is to establish a process for the coordination and organization of response operations when an accident occurs [26].

The emergency response plan is initiated by an accident declaration using several means such as (telephone, radio, alarm box, automatic detection …) and finished with a detailed intervention report which is drawn up to describe the intervention operations to be used as feedback. The emergency response plan of Skikda refinery is resumed and represented in the flowchart shown in figure 2.



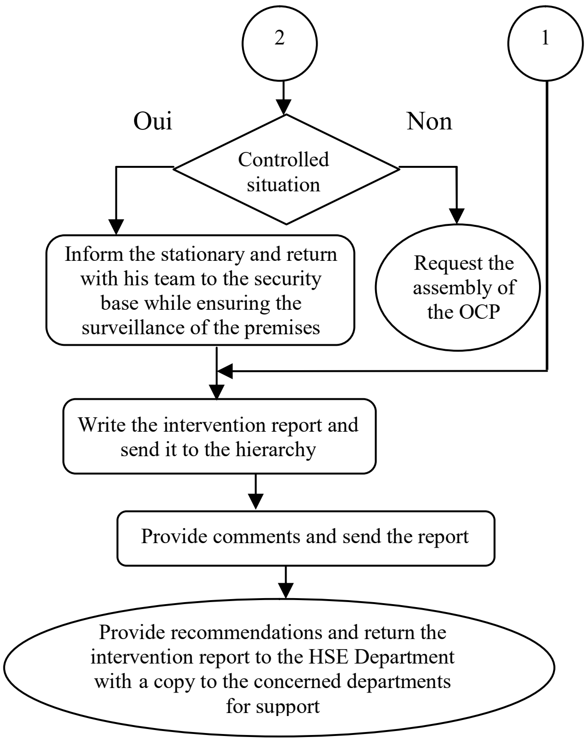



Figure 2. Emergency response flowchart [26]

Emergency response with suitable capabilities to accomplish the request demands. This means that the company selects the appropriate equipment (appropriate setting factors) and the technique (appropriate operational factors and contingency functions or tactics: how, who, where, when) to be deployed in the field to control the accident. Emergency plans with adaptive capacities allow the company to cope with variations in the external environment and in the overall condition of the response system, including the necessary resources. Without a tactical plan that encompasses all contingency functions (and variations) involved in the response activities, the system operates in a complete adhoc (trial and error) basis with little control. Such a situation that may lead to unexpected and, sometimes, unwanted outcomes.

FRAM is therefore used to analyze the essential functions in planning a response strategy. The functions are described in six analytical elements (they are represented in table 3), and coupling linkages are added to denote critical relationships among elements in the normally functioning defense system. These relationships can be specified as dependencies among the functions, as shown in Figure 3 diagram.

Each accident requires a specific resource strategy and tactical plan written in a specific form, and for that strategy/plan to be verified, approved and potentially adapted during implementation.

Table.2. Common performance conditions (CPC).

| Function | Input | Output | Precondition | Resource | Control | Time |
|---|---|---|---|---|---|---|
| Accident | | Occurrence | | | | |
| Inform the stationary of the incident occurrence | Occurrence | Stationary informed | Workers trained | Competent workers Equipments provided | Procedure used | Decision taken |
| Inform the shift supervisor, the head of the intervention section, the head of the intervention service and the control room | Stationary informed | Shift supervisor informed | Workers trained | Competent workers Equipments provided | Procedure used | Decision taken |
| Recognize the place | Shift supervisor informed | Place recognized | Workers trained | Competent workers | Procedure used | Decision taken |
| Confirm the accident | Place recognized | Accident confirmed accident not confirmed | Workers trained | Competent workers equipments provided | Procedure used | Decision taken |
| Prepare the necessary equipment for the intervention and make it available to the shift supervisor | Accident confirmed | Equipment prepared | Workers trained | Competent workers | Procedure used | |
| Order the work to be stopped, barricade the area and report any other risk | Accident confirmed | | Workers trained | Competent workers Equipments provided | Procedure used equipment prepared | Decision taken |

| | | | | | | |
|---|---|---|---|---|---|---|
| Call the first team | Accident confirmed | Team called | Workers trained | Competent workers Equipment provided | Procedure used Equipment prepared | Decision taken |
| Inform the Director | Stationary informed of the situation | Situation controlled or not | Workers trained | Competent workers Equipments provided | Procedure used | |
| Set up an emergency plan | Accident confirmed | Emergency plan set up | Workers trained document used | Competent workers | Procedure used | |
| Situation controlled or not | Situation controlled or not | Situation controlled Situation not controlled | | | | |
| Inform the stationary and the head of the intervention service of the situation evolution | Emergency plan set up | Stationary informed of the situation | Workers trained | Competent workers Equipments provided | Procedure used | Decision taken |
| Inform the stationary of the situation and call for the second intervention team | Situation not controlled | Team called | Workers trained | Competent workers Equipments provided | Procedure used Equipment prepared | |
| Inform the Head of Equipment section as well as the FIR and remind the other intervention technicians to join the security base Activates alert means at the request of the shift supervisor | Accident confirmed | | Workers trained | Competent workers Equipments provided | Procedure used | |
| Go to the scene of the accident, assess the situation with the head of the intervention section, the prevention inspector and the unit manager | Team called | Situation controlled or not | Workers trained | Competent workers Equipments provided | Procedure used | |
| Inform the stationary and return with the team to the security base while ensuring the surveillance of the premises | Situation controlled accident not confirmed | Security base return | Workers trained | Competent workers Equipments provided | Procedure used | |
| Request the assembly of the OCP | Situation not controlled | | | Competent workers | Procedure used | Decision taken |
| Inform the head of the intervention section, the head of the intervention service, and the control room | Security base return | | | Competent workers Equipments provided | Procedure used | |
| Write the intervention report and send it to the hierarchy | Security base return | Report written | Document used | Competent workers | Procedure used | |
| Provide comments and send the report | Report written | Comments provided | Document used | Competent workers | Procedure used | |
| Provide recommendations and return the intervention report to the HSE Department with a copy to the concerned departments for support | Comments provided | | Document used | Competent workers | Procedure used | |
| Procedures/ plans | | Procedure used | | | | |
| Take decision in time | | Decision taken | | | | |
| Tools/ equipments (radio, telephone, ambulance, car, truck …) | | Equipments provided | | | | |
| Training | | Workers trained | | | | |
| Competence | | Competent workers | | | | |
| Documents | | Document used | | | | |

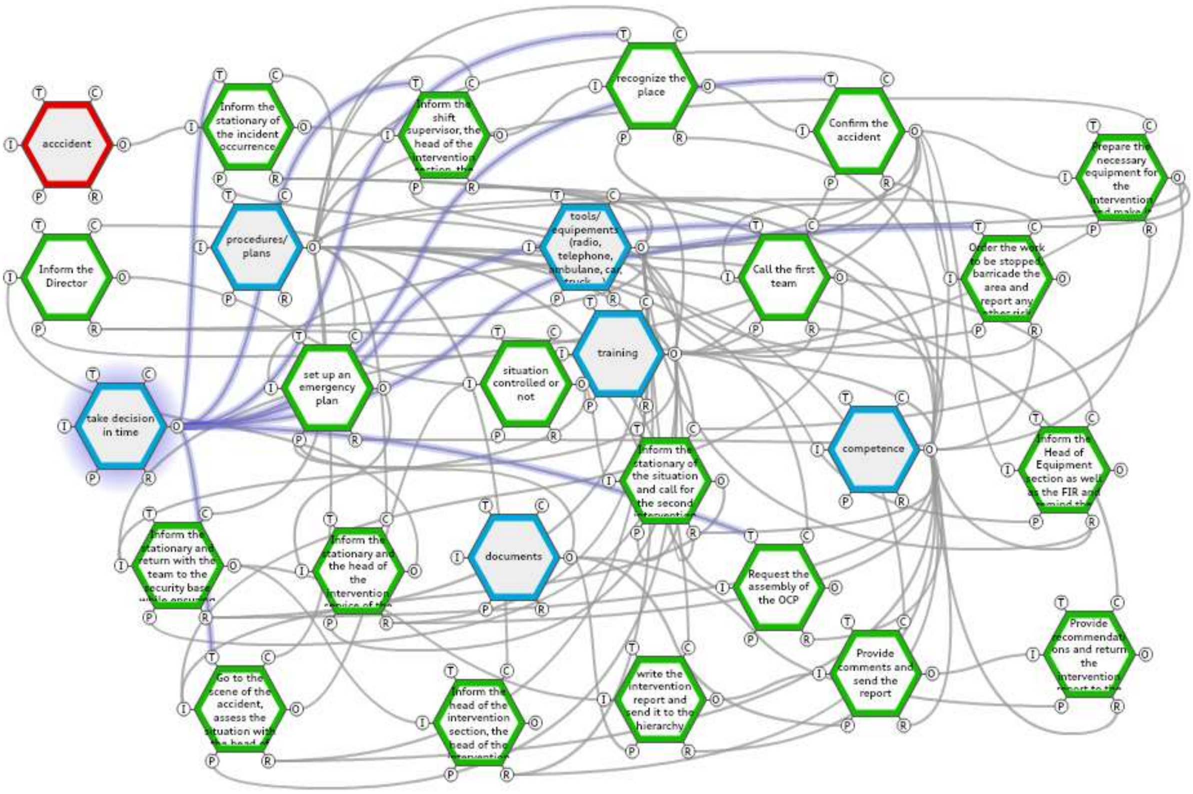



Figure 3. FRAM describing the essential functions of an emergency response plan

The purpose of developing an emergency response strategy/tactics function is to determine deployment procedures, roles clearly defined for all areas, actuation points, teams, types and amounts of resources needed according to everyday demands. Everyday demands at the refinery units include continuously preventing hazards and controlling accidents when they occur.

As indicated above, regular amendments to plans may be required to initialize different actions or adapt existing actions to best support response. It is therefore difficult and also insufficient to define predetermined response strategies regarding methods, procedures, and resources that can cope with emergency response actions. As indicated by resilience engineering, the central issue for an adequate response is the adaptive capabilities of the response team and the resources currently available for alternative response actions.

All required actions that must be provided are described as functions in FRAM model; they are summarized in table 2, and represented in figure 3.

## 7. DISCUSSION

The analysis of a FRAM diagram (Figure 6) indicates that emergency response plan success depends on adequate strategy/tactical development functions, as each function is heavily linked to each other function. An accurate estimation of spill situation is essential to determine an appropriate level of response to be mobilized, and the development of effective strategies/tactics (how, who, where when) are the basis for an adequate response.

The company is structured according to the traditional framework of distributed control systems when developing contingency plans, relying on remote supervisors to provide plans for multiple local actors [27]. FRAM analysis indicated that planning should be viewed with the lens of situated action [28], structuring contingency plans around situation assessments that are done quickly and may be changed on-the-fly.

This compensates for the fact that strategies and tactics are often inadequate to deal with an evolving emergency situation. Local actors have access to the results of actions taken through their own experience and those of their co-workers, and so they should also be empowered to modify or adapt plans, based on their understanding of the plan intention and the range of possible actions.

The company activities were therefore viewed according to Resilience Engineering framework, which holds adaptive capacity as the key issue for adequate system functioning. Following this perspective, system improvements may be made by adjust procedures or providing resources for faster development and approval of contingency plans, which may be facilitated by establishing a set of common and well-known basic response strategies. Also it is important that operations emphasize supporting adaptation on-the-fly in plans and procedures, and the importance of collaboration and sharing information about the evolution of the accident.

In the company and other highly-complex socio-technical systems, safety should be managed from a proactive, rather than reactive perspective identifying what might go wrong and addressing it rather than reacting to failure events after they occur. Resilience Engineering has consistently argued that safety is more than the absence of accidents, incidents and failures. Everyday work succeeds because people try to make sure that things go right, because they understand how the system works and try to ensure that the system can continue to work effectively.

Using this rationale, we analyzed the company emergency system through the lens of the Safety perspective. The Ergonomic field studies provided an understanding of how response activities are performed under conditions of normal variability in order to support the FRAM modeling. These methods provided critical model data, including the operational modes, basic constraints, the cognitive skills and strategies used by operators to solve problems in everyday operations.

In the company as well as other complex systems, people with different organizational and operational roles (individually, collectively, and the organization) adjust what they do to fit the requirements and resources of work. An example of this is the development of the response strategy that is dependent on available time, information, materials, equipment, people, required procedures, and other factors that may require adjustments. One of these most interesting adjustments is that planning actions are communicated verbally and the contingency plan is not formally documented until after the response, and then mainly as a report about the activities rather than a real action plan with objectives, strategies and tactics. This is also done in an environment with inadequate support for planning actions (write, approval) and suffers under time pressure during the response. The final plan describes only the successful steps and hinders one's ability to see the critical value of adaptations made from the original plan.

Also contributing to overall response performance are the inherent problems of emergency response operations, such as mandated but inefficient activities and common resource limitations. In the face of these problems, human experience can combat them to plan a suitable response strategy. The human ability to adapt, adjust, and find effective ways of overcoming novel problems is the primary reason why the emergency response system works as well as it does.

Performance adjustments and variability are the foundation for everyday successful operation of the emergency response system.

However, there are situations where performance variability may lead to undesirable outcomes. The characterization of performance variability is important because it determines the quality of the function and thus the quality of overall system performance.

## 8. CONCLUSION

This paper presented a systematic framework combining the Functional Resonance Analysis Method and Ergonomic field studies to understand and model the performance variability of a complex system. We believe that the Functional Resonance Analysis Method provides an adequate methodological framework to model a complex socio-technical system that operates to address emergency situations under varying conditions.

The Ergonomic field studies provided a thorough knowledge base concerning the company operator actions and behaviors. It is important to note that the front-line operators are the field experts and the ones that knowhow critical equipment and activities in the defense system can be used effectively. The company responders are not simply performing a set of task procedures and rules, they are trying to get things done with the best possible conditions and this study seeks to shed light on how. Therefore what operators do, how they think, what they know and how they organize and structure information is important to understand as part of the overall study of the system.

Following the FRAM method and with an appreciation for Resilience Engineering principles, this study took into account how functions are carried out in normal working conditions, with equipment functioning normally, in a common response situation of an accident. Knowing how things operate successfully and what is being achieved by the company operations (based on Safety approach) provides insight into ways to increase the overall resilience of the accident emergency response plan.

Performance variability to a large extent is the product of intentional adjustments that operators undertake in order to accomplish their task in the presence of other sources of system variability. People and organizations adjust their activity to the working conditions or context and try to balance efficiency and thoroughness both on the level of specific actions and overall strategies. Performance adjustments are always required but rarely recorded in “work done” documents, which suggests a value for more proactive approaches that can guide the adjustment process.

This would allow the company operators to be better able to develop a suitable response strategy with consideration for common patterns in what responders do, what responders will do, what technology may do and how processes develop during the emergency situation.

The study shows that performance variability is not only normal and necessary to system operations but also indispensable to cope with resource limitations of the system. Variability should therefore not be treated as the consequence of violation or noncompliance, but instead as a beneficial emergent property for managing safety in a complex socio-technical system.

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