Evaluating effectiveness of the application of the new perspective in safety, Safety-II: by Functional Resonance Analysis Method (FRAM) in a manufacturing environment

by

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Abstract

The risk matrix has been used by safety professionals for many years as a significant tool for hazard management, risk assessment and prioritization, and to aid in offering a proactive approach to prevent negative outcomes. However, relative risk matrix assessments do not provide enough required variety to understand the complete picture necessary in complex systems of work; it merely explains definite type of hazards and their counter measures in isolation. Moreover, application of a linear causal relationship to recognize hazards creates an extensive attention to negative outcomes and lower level of controls, limiting stakeholder involvement and cross disciplinary engagement. Question sets inspired by the Functional Resonance Analysis Method (FRAM) have been applied to understand if an alternative approach offers a more effective means of risk assessment, and thus is of greater value to both the stakeholders and the organization. Only one research study has been performed to illustrate if the new methods proposed in recent years (Resilience Engineering, FRAM, etc.) are applicable in industries. Albery et al., (2016) developed a new methodology as part of his dissertation in order to study the application of the new methods in a manufacturing environment. In view of that, this research investigates whether Albery's findings are valid within other industries.

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Contents

Chapter 1

INTRODUCTION

The word "safe" means that an outcome of an action will be as it expected. In other words, safety is an outcome of a system when all the actions which are under taken or will be taken go right and meet success. But paradoxically, we assess and measure safety by counting the tasks and actions which went wrong (Hollnagel, 2014). It is the critical point that the difference of Safety-I and Safety-II emerges. The idea of safety as a "Dynamic non-event" introduced for the first time by Professor Karl Weick (1987) in *California Management Review,* defines it as "Reliability is an ongoing condition in which problems are momentarily under control due to compensating changes in components." This definition can smoothly express the current approach to safety that provides the underlying elements of this research. The distinction between, and definitions of Safety-I and Safety-II are critically important to this research and will be elaborated on in the literature review, but are best summed by Hollnagel, 2014, pg. 134) as follows:

"Just as Safety-I is defined as a condition where as little as possible went wrong, Safety-II is defined as a condition where as much as possible goes right, indeed preferably as a condition where everything goes right. In analogy with resilience, Safety-II can also be defined as the ability to succeed under expected and unexpected conditions alike, so that the number of intended and acceptable outcomes is as high as possible."

A risk matrix as a hazard assessment tool has been used in industries for many years in order to (i) document the hidden hazards, (ii) proactively reduce and prevent negative consequences. The main purpose of a risk assessment is to determine whether the level of the risks that are associated with the work activities are acceptable, or are in a level that needs more controls in order to lower risk to an acceptable level. The process of the risk assessment should be rational, logical and structured while performing a systematic comparison of different risk control options so that the best decision can be made. The risk assessment process can be divided into three stages: (Gadd, Keeley, & Balmforth, 2004)

- Preparing for the assessment;
- Carrying out the assessment;
- Post-assessment activities.

Although the distinctions between the three stages are not simply practicable, it can provide a guiding framework that should be considered through the process. Moreover, the linear causal relationship for describing the hazards emphasizes only the negative consequences and lower order controls that limit stakeholder learning and cross disciplinary engagement (Cox, 2008).

Numerous research studies have been performed in the risk assessment area, and a substantial number of them illustrate the weaknesses and misconceptions about hazard assessment tools. Only one study illustrates the new method of identification and recognition of the hazards within the today’s complicated socio-technical systems. Albery et al. (2016) has demonstrated how to apply the new method of thinking, a Safety-II perspective, in hazard identification and assessment by recently proposed technique called Functional Resonance Analysis Method, or FRAM. The challenge of Safety-I prototype, replacing it with the perspective of Safety-II and essentially foresee the isolated hazard management in order to optimize the greater system have been proposed by Albery et al., (2016). This research aimed to investigate the validity and applicability of this newly proposed risk assessment tool in a different manufacturing environment where hidden hazards are not recognizable by linear risk assessment methods and using a tool with greater requisite variety may mitigate them.

The Functional Resonance Analysis Method (FRAM) provides a new technique to understand if a new approach to safety can provide a more effective risk assessment. In fact, FRAM is a tool with greater requisite variety to mitigate the hazards associated with linear risk assessment methods (Hollnagel, (CRC), & Cedex, 2013). In the FRAM approach, the entire system is considered in addition to the recognized hazards and their counter measures by assessing safety and productivity in one activity. This approach to risk assessment is in contrast with the Safety-I perspective of risk assessment that uses risk matrix assessments with only hazards and their controls in isolation. FRAM perspective delivers a more comprehensive assessment of the system by using sets of questions with identification of higher controls through collaboration with all stakeholders.

The research evaluated four work systems within an electrical equipment manufacturing environment. The systems were selected based on two main characteristics key to both Safety-II and FRAM assessments, these characteristics are as being (Albery, Borys, & Tepe, 2016):

- variability in functions,
- the level of control on the variability,
- the couplings between functions within the systems, as well as couplings to upstream and downstream systems.

The objectives of the research are set in order to create a learning cycle (Aygris, 1999), firstly to understand how work was imagined and performed in each of the systems were selected, and secondly to evaluate and compare learnings from risk matrix and FRAM based approaches (Albery et al., 2016).

Four sets of questions were employed as means of risk assessment in order to obtain required information regarding to the objectives of the research which are as below:

- To understand how the work has been described and how it has been performing in four different work systems in a manufacturing environment.
- To evaluate and compare the learnings from risk matrix and FRAM based approaches of risk assessments.

The construction of the FRAM model is not reflected in this paper as it is another full project and it is not in the scope of this research, however it would be another area of interest to expand.

Chapter 2

REVIEW OF LITERATURE

2.1The Three Concerns with Safety

2.1.1 The Need for Safety

Hollnagel (2014) in his “Safety-I and Safety-II, the Past and the Future of Safety” has explored the roots of word “Safety” and its meanings through history. The word “Safety” is an Old French word *sauf*, which sequentially comes from the Latin word *salvus.* The meaning of *sauf* is ‘uninjured’ or ‘unharmed’, while the meaning of *salvus* is ‘uninjured’, ‘healthy’, or ‘safe’. The current definition of “Safe” with the meaning of “not being exposed to danger” goes back to fourteenth century while it was first recorded in 1580s as an adjective to typify actions. The word “Safety” has being used since then frequently in different contexts and it is instantaneously meaningful to us. The assumption that everyone knows and understands what safety means is so prevalent in many documents, standards and even doctoral theses and because of it, no one bothers him/herself to define the word “Safety”. For instance, commonly used expressions such as ‘have a safe flight’ conveys the meaning that we hope the journey with the airplane will take place without any unwanted or unexpected events (Hollnagel, 2014).

In general, when the outcome of an event is as expected or wanted, the event is called ‘Safe’. In other words, when things go right and the outcomes are successful, the actions are being taken safely. Unfortunately, in many cases we are not aware of successful actions or how often things go right. On the opposite side, we have a proper understanding about the things went wrong or at least we have an idea about the unsuccessful actions (Hollnagel, 2014).

In the field of safety management systems, the focus is commonly on avoiding unsuccessful events instead of studying around the actions go right as are expected every day. Although it would be logical to focus on the positive aspects of events rather than on the absence of them, but in the real world safety is being practice otherwise (Hollnagel, 2014).

The need to be free from hazards is psychologically driven from the desire that humans want to achieve the goals as are planned. Humans need to be free from harm to survive. There are many kinds of doubt and uncertainty that are out of control or unexplainable, while the willing to make some rationales always exists. Ibn Hazm (944-1064), who was one of the leading thinkers of the Islam, mentioned to the fact that the dominant drive of all human actions is the desire to avoid anxiety. Indeed, he declared that the main reason to interpret safety as the absence of harm is a psychological need (Hollnagel, 2014).

2.1.2 Safety as a Dynamic Non-event

Professor Karl Weick (1987) introduced the concept of reliability as a dynamic non-event for the first time in an article in *California Management Review*.

> "*Reliability is dynamic in the sense that it is an ongoing condition in which problems are momentarily under control due to compensating changes in components. Reliability is invisible in at least two ways. First, people often don't know how many mistakes they could have made but didn't, which means they have at best only a crude idea of what produces reliability and how reliable they are. […] Reliability is also invisible in the sense that reliable outcomes are constant, which means there is nothing to pay attention to.*"

The definition of reliability as a dynamic non-event has often been paraphrased to define safety. The phrase “the freedom from unacceptable risk” in fact presents whether a system is safe or not. “Dynamic” means that the outcome (of the non-event) cannot be assured, while the definition of “non-event” is that the event does not happen or has not happened (Hollnagel, 2014). Hollnagel (2014) has mentioned to this issue that although defining safety as a dynamic non-event is clever, but the problem evolves where non-events have to be detected or even be noticed. He explained the issue, being impossible to count non-events, by providing some day-to-day routine instances such as how many times we are not injured at work or did not cause harm at work? How many times we did not do something wrong or make a mistake? How many cyclists or pedestrians – or cats or dogs – we did not hit when we drove home from work?

A more realistic example of it can be found in traffic safety numbers. Every year authorities release statistics in traffic safety. The numbers present how many people have been killed or how many accidents happened from the year before, while none of them states the number of people have not killed in traffic. “Dagen H” is a quiet unique instance of the situation where non-events have been counted. In Sweden driving from left-hand side changed to driving on the right-hand side on September 1967. It was regulated that non-essential traffic is banned from 01:00 to 06:00 and any vehicle has to stop completely at 4:50 and then cautiously move to the other side of the road and remain there till 05:00 when the prohibition is lifted. Since there was no traffic, or at least a very small amount of traffic which could be monitored, it can be ensured that there were no non-events during the transition. And because there were no non-events, there will not be any events either, so no accidents would happen (Hollnagel, 2014).

It might be feasible to consider safety as a dynamic *event*; the event is now should be the things go right. Consequently, the non-event becomes the things go wrong and that would be possible to count as we have done normally (Hollnagel, 2014).

2.1.3 Measurement of Safety

The need to demonstrate the presence of safety quantitatively is demanded by both society and industry. Safety should be demonstrated in a way that different individuals explain or experience it in such a manner that they can confirm each other. Safety statistics are a common practice to demonstrate safety (or "unsafety"). A well-known instance of general safety statistics is a list compiled by Bernard Cohen, Professor Emeritus of Physics at the University of Pittsburgh. The list that is shown in Table 1 below illustrates different activities that are associated with the same level of risk. In other words, activities with the same level of risk are in the same row (Hollnagel, 2014).

Table 1 - Various activities with the same level of risk (Hollnagel, 2014)

Spend three hours in a coal mine (risk of having an accident).	Travel 10 miles by bicycle (risk of having an accident).
Travel 300 miles car (risk of having an accident).	Travel 1,000 miles by jet air-plane (risk of having an accident).
Smoke 1.4 cigarettes. Live two months with a smoker.	Eat 100 charcoal-broiled steaks. Drink 30 cans saccharine soda.
Live 20 years near PVC plant (cancer from vinyl chloride).	Live 150 years at 20 miles from a nuclear power plant.
Live two months in Denver (cancer from high average radiation).	Live five miles from nuclear plant for 50 years (nuclear accident).

When quantifying safety by measuring when things go wrong, a paradoxical situation arises. The irony is that the less things go wrong, the less will be to measure. Consequently, when a system is perfectly safe – assuming that it would be meaningful or possible – there will be nothing to measure. In other words, when a source of information is eliminated, the possibility of regulating or managing is reduced. An example of this paradox would be the Single European Sky ATM Research or SESAR program for building the future European air traffic management system. One of the four targets of the program is to enhance safety by a factor of 10. This enhancement is recognized by a drop in the number of reported accidents or incidents, where the further improvement will be either harder or slower (Hollnagel, 2014).

2.2 History of Safety

2.2.1 Safety Through Ages

The development of safety can be described with development of rationales of the "causes" of accidents and also "mechanisms" of accidents. The "causes" can be explained by socially accepted roots or reasons of *why* accidents happen and the "mechanisms" refer to the ways that *how* an accident happened. Therefore, the thinking about the causes has directly related to the notion of causality and to failure. Although the two, causes and mechanisms, are not completely independent, the development in the thinking about "causes" has not been harmonized with the development of thinking about "mechanisms". The set of probable causes presents the changes in the technologies being used plus the systems being employed. The change in the nature of causes demonstrates the changes in what the components of the systems are. For instance, the changes from entirely technical systems, such as steam engines, towards socio-technical systems like train dispatch centers. Clearly, if no steam engine exists, the mechanical hazards will be at zero; or the chance of the trains' collision would not be a concern if the train transportation system has not been developed (Hollnagel, 2014).

The initial point of safety, for the entire history of it, has been the occurrence of an unexpected event, whether it is an accident, an incident or even been categorized as a risk or hazard. Generally, new types of hazards have been introduced by new types of causes (for instances, metal fatigue, software failure or organizational failure), instead of challenging the basic primary assumption of causality. Since, humans have the partial desire to simplify explanations and single type causality, the development of one major type of cause had been dominated rather than the combination or consideration of all hazards together. The advantage of single type causality is the elimination of the need to consider the dependency or interactions between all the potential causes, which results in the single cause-effect relationship dominant type hazard explanation. Recently, it has been found necessary to change the perception of single cause-effect relationship, not only about the possible causes, but also the way they generate effects. It means that the notion of causality in the traditional way no longer explains events in the format of simple malfunctioning of a component or multiple components. In other words, the reason may be a condition or situation that only occurred momentary, but long enough to disturb some of the future actions or activities. (Hollnagel, 2014)

Safety has advanced and evolved through three ages, the first ''Technical Age", the second "Human Factors Age" and the third "Management Systems Age," (Hale, A. R., & Hovden, J., 1998). Glenden *et al.* (2006) have mentioned that each age is built on the age before and does not leave any one of those ages behind. These ages are important to this research because they enlighten the path where safety should be monitored in order to provide more effective solutions to the protection of current complicated socio-technical systems.

2.2.1.1 The Technical Age:

The first age refers to the period of time when most concerns surrounding the technology itself and also the people that had not learned how to guard against the risks. At this age, technologies were considered particularly unreliable and the main concern was to find technical means to guard machineries, prevent explosion, and structural collapse. Despite the fact that the necessity of reliable equipment in every industry still exists, the need for reliability analysis became widespread after the end of World War-II. One reason was the increasing demand of maintenance and repair of military equipment during the war, and the second reason was the technological and scientific improvements that provided new openings for creating more complicated technical systems. Particularly, improvement in digital computers, control theory, information theory, and the inventions of the transistor and the integrated circuit created the advanced opportunities of productivity in which the systems became more and more difficult to understand. So, it challenged the human ability to both on understanding inside of the systems and also to manage them. Both Civilian and military domains experienced a rapid growth in terms of scope and performance of the technical systems in this age, when it caused the need of methods to address the safety and risk of these systems. Methods such as Fault Tree Analysis (FTA) or Failure Mode and Effects Analyses (FMEA) or Hazard and Operability Analysis (HAZOP) were developed not just to analyze possible causes of hazards, but also to prevent risk and hazards before a system was taken into the operation (Hollnagel, 2014).

2.2.1.2 The Human Factor Age:

On 28 March 1979, at the Three Mile Island (TMI) nuclear power plant, the disaster happened and the notion that the mastery of all the sources of risks can effectively manage safety of the system dissolved. Before it, the consensus had been that the implementation of methods such as FMEA, FTA or HAZOP can guarantee the safety of the nuclear power plants. The second age is based on the concept that the established hazard assessment methods that have been mentioned above would not be sufficient for ensuring the safety of high risk organizations similar to nuclear power plants. After this disaster, it was clearly obvious that there is a missing aspect called "Human Factor". It began to consider human aspect, "human error", in the existing methods (FMEA, FTA, etc.) but shortly these methods were replaced by more developed methods such as Human Reliability Assessment (HRA) that became established as the standard analysis for nuclear power plant safety. The notion that "human error" could be a logical tool to describe the occurrence of failures was willingly adopted by other industries, and the growth of models and methods quickly increased (Hollnagel, 2014).

2.2.1.3 The Management Systems Age:

Although the transition from the second age to the third was less dramatic than the first transition to the second, two main reasons can readily describe it. The first reason was that addressing safety and health concerns could be provided by approached such as human factors engineering and Human–Machine Interaction design. The second reason was that the methods like HRA (Human Reliability Analysis) and many "human error" methods were not satisfactory due to their limitation. Accidents such as the Space Shuttle Challenger Disaster and the explosion of reactor number four at the Chernobyl nuclear power plant, which both occurred in 1986, made it clear that the organization had to be considered over and above the human factor. The third age, which is still in the transition from the second age, attempts to include the organizational factors in the linear causality paradigm. The organizational factors are commonly less straightforward than human factors (humans can be seen in the models as part of machines that work like an artificial mind but for the organizational factors it will not be a case).

“Organizational accidents” or “organizational failures” are seen as equivalent to technical failures, just as human failures were in the aftermath of the TMI (Three Mile Island) disaster. Evidently, it is an extreme simplification to look at organizations and humans as “factors” and adequately address them by methods that follow the principles developed to deal with technical problems (Hollnagel, 2014).

2.2.2 The Current State of Safety – Safety-I

The American National Standards Institute (ANSI) (ANSI Z10, 2012) defines safety as the freedom from unacceptable risk, while unacceptable risk is defined as a risk with a high probability. This definition relates to the traditional definition of safety which refers to the conditions where nothing goes wrong. Although the feasibility of being 100% certain what is going to happen is very low, but being safe means that the likelihood that something can go wrong is acceptably small. In correspond to human activity it makes a good sense to just focus on things go wrong, since such situations are by definition unexpected and they may lead to unwanted harm or loss of property (Hollnagel, 2014).

One of the consequences of associating safety with things that go wrong is an absence of attention to things that go right, which is unintentional and inevitable. The main reason would be practical limitations in terms of time and effort, which means that it is impossible to pay attention to everything. The gradual and involuntary reduction in respond to a frequent incitement is known as habituation. Habituation is very common and normal – William James: “Habitual actions are certain, and being in no danger of going astray from their end, need no extraneous help”. It means that things go well because the system works well as it should. While it is logical to accept few difference between outcomes but it would be totally fatal to paying no attention to all actions of a system since the concept of habituation makes a lot of sense (Hollnagel, 2014).

Hollnagel (2014) described how things work by two new statements, “Work-As-Done” and “Work-As-Imagined”. Work-as-done refers to how work is done in a work place, such as hospital ward, an aircraft cockpit, a production line, a supermarket, etc. It is also called the “Sharp end”, the situation in which work is performed and the consequences of actions show themselves straightly. The other end of work is the “Blunt end”, situations and activities that effect directly or indirectly the conditions where the work at the sharp end takes place. It is called “Work-As-Imagined”. Work-as-imagined is made up by the people who have controls on the constraints and resources - like policy makers, directors, managers, designers, etc. - effecting personnel, equipment and general conditions of work at the sharp end.

Frederick Winslow Taylor, an American engineer, introduced the Scientific Management Theory early in 1900’s. According to Scientific Management Theory, an analysis of tasks and activities could function as the foundation for improving work efficiency. The scientific and engineering developments of twentieth century created a significant reliability on technology leading to established the belief that this degree of reliability can be achieved by human and to a stronger degree by organizational systems. This theory constitutes the notion that the work-as-imagined establishes the necessary and sufficient basis for safe and effective work. In other words, a safe environment, or in general safety, could be ensured by constructing a precise working instruction and comprehensive training. According to this way of thinking, reduction or removal of performance variability by implementing the rules of Scientific Management Theory can help to maintain efficiency and eliminate malfunctions and failures, either by standardizing work or by constraining all types of performance variability (Hollnagel, 2014).

The outcome of a system can be categorized as either failure or success. It can be justifiable for a given person or a group as either acceptable or unacceptable, but cannot be both (Hollnagel, 2014).

The statistics in figure 1 below illustrate the ratio of 1:10,000 that is the number of failures to successes in an organization or a system. It means in an organization or a system one action out of 10,000 actions being performed is failed and the rest, 9999, have been performed as they were expected. The currently perspective in safety illustrates that the number of failures should remain as low as reasonably possible, by providing a system to ensure that the work is being performed as it imagined (prescribed), in order to call an organization safe or not safe. In other words, the only focus is on the left side of ratio and there is no attention to the large success' number. Hollnagel (2014) titled this way of thinking as "Safety-I" or the traditional perspective in safety which is illustrated by Figure 1.

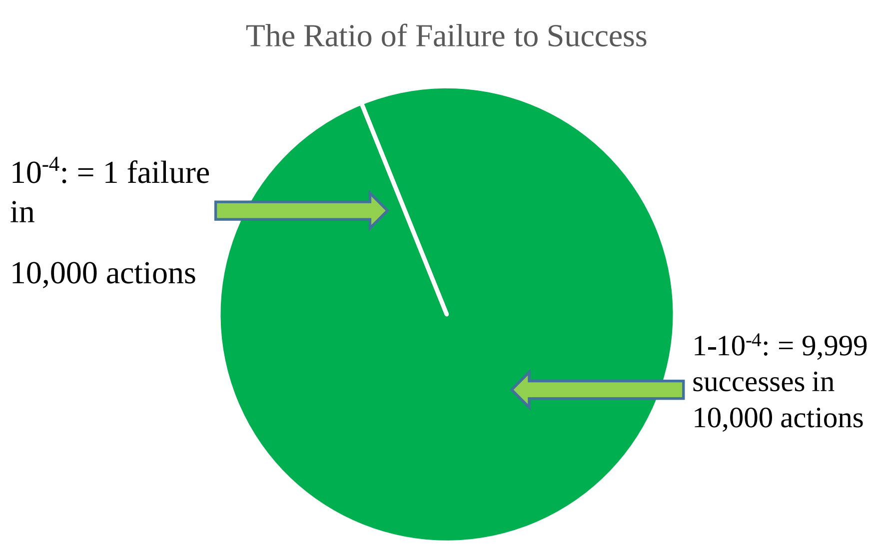

Figure 1- Comparing the number of things go right and things go wrong (Hollnagel, et al., 2014)

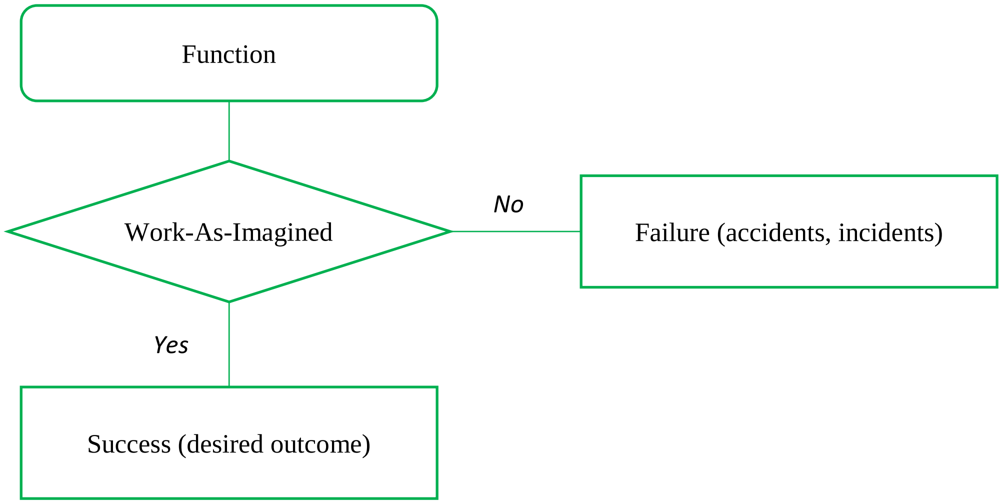

Figure 2 - Philosophy of Safety-I (Hollnagel, 2014)

There are two ways to control operations in the vantage point of Safety-I. These two ways are assumed to be different. The aim of safety management is to maintain systems in the first state, which is desired outcomes, by applying these two approaches. The first one is to "finding errors" when something has gone wrong and then try to fix the error. Hollnagel (2014) has named it "find and fix" approach. The second way for Safety-I to achieve its goals is to preventing the transitions from "normal" "abnormal" states. This way is possible, if it is, merely by controlling the performance variability. In real sense, there should be numerous types of barriers in order to limit the variability happens in every day work, e.g. physical and functional barriers, interlocks and even symbolic barriers. These approaches to safety are clearly reactive since they begin when something has gone wrong or has been identified as a risk (Hollnagel, 2014).

2.3 The Figments of Safety-I

This section discusses a number of very common assumptions in safety. Since they are only assumptions based on some common beliefs and they are not facts, they will not be verifiable. Six major safety figments will be argued based on their occurrence frequency in order to propose an alternative view.

2.3.1 Human Error

In Safety-I perspective the largest single cause of accidents and incidents is “Human error”. Human error is still the fundamental focus of numerous accident investigation models and for sure one of the very basic of human reliability assessments. The concept of human error as part of the safety lore became predominant while technology and equipment improved rapidly in 1900’s. The famous accident investigation model, dominos, proves this assumption by the following statement “fault of person proximate reason for committing unsafe act, or for existence of mechanical or physical hazard, Besnard and Hollnagel (2012).

The ineffectiveness of using human error as the largest cause of accidents can be readily found in the following arguments demonstrated by Besnard and Hollnagel (2012). If a safe system is a system that its failure probability is very low, for instance 10^{-5}, so there will be at least 99,999 cases of successful actions of each case of failure. In other words, if human error is the cause of the adverse events, what is the cause of all other successful actions? In fact, they behave in the same manner everyday regardless of the possible outcome of the actions whether its positive or negative, naturally because they are not aware of the consequences of their actions at the time of acting. A more productive way to see this phenomenon is to instead of calling human as the largest cause of failures, try to recognize how performance varies and study why the behavior that most of the time goes right occasionally makes things go wrong, Besnard and Hollnagel (2012).

In summation, “human error” focuses merely on cognitive aspects and context of the work is in the shadow. This fact narrows cause of adverse outcomes to human malfunction with little attention to how and why people adjust their performance, that bolds the importance of “bridging the gap between what must be done and what can be done” (Runte, 2010, p. 3)

2.3.2 Procedure Compliance

There is an established and strong belief that design of interfaces, work specifications and procedures is always correct and if a failure happens, it is simply going to be found as a “human error”. In another words, the assumption is that humans, as fallible machines, are the source of variability that leads to occurrences of undesirable outcomes; therefore, following the procedures will not only get the job done, but also get it done well. On the other hand, working situations frequently differ from the even precise working instructions and strict compliance may be disadvantageous to both safety and efficiency, Besnard and Hollnagel (2012).

It is not feasible to anticipate all the possible situations that may happen in a workplace and prescribe an adequate instruction for every single activity. A safe outcome will not be ensured by a rigid compliance, while it requires that the operator evaluates the adequacy of, and adopt, procedures to operational conditions (Besnard, 2006). This is why there is always a gap between work-as-imagined and work-as-done and humans are constantly required to adjust their performance to fill this gap, Besnard and Hollnagel (2012).

2.3.3 Layers of Protection and Safety

Safety can be achieved either by eliminating risks or by protecting against their effects. How would it be possible? The traditional perspective in safety proposes improved barriers and protection. At first glance it seems logical to have a safer system by providing more layers of the protection. It is a philosophy behind safety in numerous systems like motor vehicles where multiple passive and active safety systems (Anti Blocking System (ABS), crumple zones, safety belts, airbags, etc.) shield drivers from the injury, Besnard and Hollnagel (2012).

Two main reasons demonstrate that more protection does not necessarily provide a safer system. The first one is psychological and related to habituation where people adopt themselves to the perceived level of risk protection. A study conducted by Aschenbrenner and Biehl (1994) showed that taxi drivers whose cars equipped with ABS drove more aggressively and their accident rates, compared to other drivers, were slightly higher. This study demonstrates that humans naturally respond to increased protection counter-intuitively. The second reason is technical and demonstrates that adding more protection layers increase the complexity of the system. The more a system is complex, the number of combinations that may lead to unwanted outcomes significantly increases, Besnard and Hollnagel (2012).

Obviously, it does not mean that to improve safety less protection is the way or that increased protection never works. It merely means that the effects of implementing additional protections in socio-technical systems should carefully be considered, Besnard and Hollnagel (2012).

2.3.4 Causalities of Adverse Outcomes

The assumption is that root-cause-analysis (RCA) can identify why accidents happen in complex socio-technical systems. Although RCA is deeply involved in the safety-related practices in industry and even there are certificates for people who practice it, but the validity of its methods (such as Fault Tree Analysis, Failure Mode & Effects Analysis, Functional Resonance Analysis, etc.) critically depends on that the outcomes of events are bimodal. It means that outcomes are either correct or incorrect (Hollnagel, 2009). This view is not defendable in numerous technical systems where human performance usually varies noticeably while fail infrequently (Manion, 2007), even when performance fails it can be recovered by humans and maintain the normal situation. Human performance cannot be described as if it is bimodal since things simply go wrong in the same way go right in socio-technical systems. Therefore, variability in human performance is a great contribution that maintains safety while RCA points human as the first reason of unwanted outcomes. In other words, there are many cases where root-cause-analysis cannot—and should not—be used, Besnard and Hollnagel (2012).

Fortunately, there are several alternatives that are more appropriate to prospect human, organizational and technical factors either individually or in combination. One of these newly established approaches is the Functional Resonance Analysis Method (FRAM), introduced by Hollnagel (2004), that describes unexpected events when emerging from low-amplitude variability of everyday performance. Another example is Systems-Theoretic Accident Model and Processes (STAMP) introduced by Leveson (2004) that is based on a systems theory model that view systems structurally and how they are constructed, Besnard and Hollnagel (2012).

2.3.5 Accident Investigation

The primary purpose of accident investigation is to discover the cause or causes of accidents based on the facts logically and rationally. The huge number of accidents and constraints of time and resources lead to reduction of the depth of analysis in accident investigations. Moreover, resources and demands direct what and how it should be done. The management of the investigation then becomes a trade-off between what can be done and what should be done: a trade-off between efficiency and thoroughness (Hollnagel, 2009).

In real word, accident investigations are normally based on some pre-approved implications about how accidents have happened and what measurement can resist the reoccurrence (Lundberg et al., 2009). The need to establish responsibilities is another bias associated with accident investigation. It means that confusion of responsibility and cause of the accident is a crucial obstacle in safety. In other words, the investigation follows the rules that instead of finding proper rationality to explain the real cause of accident takes the way that shortly fails. Lundberg et al. (2009) called this phenomenon as what-you-look-for-is-what-you-find (WYLFIWYF), Besnard and Hollnagel (2012).

2.3.6 Safety First

The phrase "Safety First" is an actual common heard myth in the world of safety management. It means that safety is an absolute priority that can never be compromised. However, in real world, economic considerations may sometimes lead to compromise safety. For instance, aviation is the only industry that always announce to practice such a policy, but even in aviation the intervals of scheduled maintenance for aircrafts has been modified during the economic recessions, Woltjer and Hollnagel (2007). It is understandable that safety has financial implications which influence the feasibility of safety measures. It becomes more understandable when the costs are immediate and real while the benefits of the safety measures are potential and time consuming to be apparent. Furthermore, safety performance is usually measured by the relative decrease in the number of situations where things go wrong instead of an increase in the number of things go right. In summation, safety comes first whenever the organizations can afford it, Besnard and Hollnagel (2012).

2.4 The Need to Change

By comparing a work setting in early 1970s with a recent work setting can obviously illustrate how new technologies and computers have changed workplaces. In early 1970s there were no computers in workplaces or at least the level of automation was very low and computers were at background. Currently, workplaces are occupied with computers that support multiple tasks directly or indirectly and the difference between today and only 40 years ago is significant. (Hollnagel, 2014).

The high rate of inventions and also the constant striving to increase our mastery of the world creates a self-reinforcing cycle of technological innovation. Computing machinery and IT devices have occupied everyday life and changed it beyond recognition. It demonstrates the emergent of the systems that are parallel while we are still thinking in sequential order. In other words, the functionality of systems is constantly developing while the comprehension of consequences of this development is unknown. Hollnagel (2014) has indicated this situation as the *Lost Equilibrium* in which we are producing systems that we are unable to control. So systems become intractable and the ability to understand what will happen, how it will happen and why it will happen becomes faded.

These developments are mostly visible from hindsight. Therefore, our traditional ways of thinking about safety are not sufficient to cope with today's complicated socio-technical environment. Consequently, the need for developing new methods to fill the gap between "work-as-imagined" and "work-as-done" becomes critical (Hollnagel, 2014).

If a system is controllable, it is required to be known in its inside and sufficient data should be available to present a clear description of the system. This kind of systems are tractable. The opposite side is obviously existing. If a system does not have a clear description or it is not possible to know what goes in its inside, the system is intractable. Tractable and intractable systems also have some other characteristics. For instances, tractable systems do not change when being described, while intractable systems change before description is completed. Tractable systems are independent while intractable systems are interdependent. It would be beneficial to mention that the inability to predict intractable systems is due to the human and organizational parts of the system. For the technical parts, complete specification is a necessity for their functioning. Therefore, in order to keep the technology working, human and organizations function as a buffer between subsystems and between the system and its environment to maintain the variability at a level that is not too high or low (Hollnagel, 2014).

In summary, performance variability is unavoidable while is also needed as it mentioned before in order to maintain the systems functionality. In the entire history of safety, the human factor has been always considered as a liability and a source of risk and failure, but by mentioning the role of humans in maintaining the balance between systems and environment, the value of performance variability is recognized and it will be an asset for systems safety. Consequently, the role of humans will be defined as the following when doing a risk assessment or accident analysis:

- Systems always have some flaws and people must be learnt to identify these flaws and maintain functionality of the system.
- People are able to recognize the actual demands and can adjust their performance accordingly.
- People can match procedures to the conditions wherever they should be applied.
- People can detect and correct when something goes wrong or when it is about to go wrong (Hollnagel, 2014).

All in all, the performance variability provided by human is an asset and a tool to get the work done as possible and close as it imagined. They bridge between what is ideal and what is real. Since failure and success both depends on performance variability, failures cannot be prevented by eliminating it. In other words, safety cannot be managed by limiting the performance variability. The solution is instead to identify the situations where the variability of everyday performance may combine to create unwanted effects and constantly monitor how the system functions in order to dampen performance variability when it comes to be out of control (Hollnagel, 2014).

2.5 Moving Towards the New Era - Safety-II

The arguments in the previous section demonstrated that working environments have changed significantly in the last two or three decades and the traditional perspectives in safety, Safety-I, is no longer as effective as the past (Hollnagel, 2014). In this section, the novel perspective in safety, Safety-II, will be presented. In order to precisely explain Safety-II, Safety-I will be firstly deconstructed then the new perspective will be constructed. The deconstruction and construction of each perspective have been performed at three different levels, Phenomenology, Etiology and Ontology. The implication of each level has been stated below. Also the contrasts between Safety-I and Safety-II will be discovered at the end of this section in order to provide a better view of each in one frame.

2.6 Deconstruction of Safety-I

The first step is *phenomenology* of safety. Phenomenology refers to the observable characteristics or the indicators of safety. By other words, what makes us declare that something is safe and something is not safe.

The indicators of Safety-I are accidents, incidents, near misses, etc., as are declared by different authorities such as European Technology Platform on Industrial Safety (ETPIS). The irony of Safety-I indicators is that the level of safety is being measured by adverse outcomes of safety. It means, the more adverse outcomes happen, the more indicators are available and the less adverse outcomes (the safer systems) result in less indicators. By other words, the more indicators there are, the less safety there is and vice versa (Hollnagel, 2014).

The second step is the *etiology* of safety. Etiology is the study of causation, of why things occur, or even the study of the reasons or causes behind what happens.

As the phenomenology of Safety-I denotes the indicators of Safety-I which are adverse outcomes or things that go wrong, etiology should be about the possible cause of the failures and the procedure that they happened through them. Thus, the etiology of Safety-I is consisted of assumptions about the causality of accidents, incidents, etc. or in general indicators of Safety-I. These assumptions can be explained either simply or by compound linear developments. The Domino model and Swiss cheese model are examples of composite linear explanation of the assumptions, while recently more complicated, but still linear schemes of explanation, such as Tripod, AcciMap or STAMP, have been released (Hollnagel, 2014).

The third step is the *ontology* of safety. Ontology studies illustrate the true nature and the essential characteristics of safety. As etiology, it describes how failures result in unwanted outcomes, or in other words, description of the true nature of failures. Likewise the etiology addresses that how unwanted outcomes happen and explain the procedure in which adverse outcomes occur; the ontology discusses the nature of failures. The ontology of Safety-I is involved in three major assumptions that have already been mentioned. These assumptions incude that systems are decomposable, the functions of components can be described in bimodal terms, and the order of events can be determined in advance. As is mentioned in the section, “The Need to Change”, it is no longer logical to assume that we can understand the causal relationships between actions and outcomes, or even that they can be described in causal terms. The ontology of Safety-I cannot be sustained (Hollnagel, 2014).

2.7 Construction of Safety-II

The ontology of Safety-II

As it stated before, numerous of today's work situations are becoming intractable and our inadequate ability to comprehend what we do limits our ability to anticipate the consequences of design changes and other means of interventions to enhance safety, quality, productivity, etc. In other words, the less controllable a work situation is, the less ability to know details and the greater need for performance adjustment.

Therefore, the ontology of Safety–II is that human performance, separately or jointly, always is variable. It means that it is neither possible nor meaningful to characterize components of a system bimodal and where they function either successfully or unsuccessfully. Performance adjustment should not be confused by performance deviation and the ability to put the performance adjustment in its effective way is vital for filling the gap between the work-as-done and work-as-imagined (Hollnagel, 2014).

The Etiology of Safety–II

A large number of unsuccessful events can still be explained by breaking down the components of a system and looking at malfunctions. There is a growing number of cases that it is not possible to explain what happens by means decomposing the system or reversing the processes. Providing an explanation is still possible, but in other ways and by other means. In such a case the outcome is "emergent" instead of being "resultant". The meaning of emergent is not that something happens magically, but simply that it happens in such a way that it cannot be explained using the principles of linear causality. Emergent outcomes address the causes as elusive (while resultant comes are as real as their effects). The outcomes may be because of transient phenomena, combinations of conditions, or conditions that only existed at a particular point in time and space. It means, the causes existed at one point in time, but did not leave any permanent trace (Hollnagel, 2014).

Emergent outcomes can be found out as arising from unexpected or unwanted combinations of performance variability where the main source is resonance rather than causality. Considering ontology of Safety-II, it means that all performance adjustments may be in an acceptable level (which in practice they are too small to be noticeable), even though the result may be so large that is noticeable. Emergent outcomes are being considered as non-linear since the relations between the precedents and the consequents is so minor. Because emergence cannot be explained in terms of causality and since there is always the need to explain it, some practical principle is required. A new method developed by Hollnagel (2012) satisfy the need to explain emergent outcomes. The Functional Resonance Analysis Method (FRAM) addresses the dependencies among the functions of a system as they develop within a particular situation. Resonance discusses the phenomenon that a system can oscillate with larger amplitude at some frequencies than at others. At these frequencies even small external forces, that are applied repetitively, can result in large amplitude oscillations which may damage the entire system seriously (Hollnagel, 2014). A further description of the application of FRAM will be discussed in the next section in order to examine the functionality of its main purpose which is to investigate systems by a proactive approach.

The Phenomenology of Safety–II

As Safety-I was defined as conditions where as little as possible went wrong, Safety-II is defined as conditions where as much as possible goes right. The definition of Safety-II has arisen two questions. The first question is how or why things go right? The answer has already been mentioned in the ontology of Safety-II by the argument that the performance variability and performance adjustments are the basis of every day activity. The second question is how we can see what goes right? This question has been pointed out earlier through the discussion of habituation where although it is difficult to notice all the right actions, but it is, indeed, a prerequisite for being proactive to understand when something is going to be wrong. Considering that reliability is a dynamic non-event (Weick, 1987), although non-events are far more important that the events in safety managements, it should be more important to consider the things go right rather than things go wrong. In a nutshell, safety is something that happens rather than something that does not happen. Because it is something that happens, it can be observed, measured and managed. Although Safety–I and Safety–II both lead to a reduction in unwanted outcomes, they use basically different approaches with important consequences for how the process is managed and measured and for productivity and quality. Safety–II management and resilience engineering both assume that everything basically happens in the same way, regardless of the outcome (Hollnagel, 2014).

So far in this section, the traditional approach in safety, Safety-I, has been deconstructed in three different levels and by the outcomes, a new approach to safety, Safety-II, has been proposed. The following paragraphs illustrate a summary of the contrasts between Safety-I and Safety-II.

Phenomenology of Safety;

Accidents, incidents, near misses, etc., are the manifestation of Safety-I. It means that a system is unsafe if such events occur, or the system is safe if no such events occur.

The conflict is when safety is required to be measured by the adverse effects, such as injuries or incidents of safety (Hollnagel, 2014).

Alternatively, the manifestation of Safety-II is defined as a condition where everything goes right. It means that from Safety-II vantage point, safety is something that happens instead of something that does not happen. Since it is something that happens, it can be observed, measured, and managed (Hollnagel, 2014).

Etiology of Safety;

In Safety-I, it includes assumptions about the causality of its manifestation (accidents, incidents, etc.) and also the results that can be explained in order to characterize a malfunction. In other words, in Safety-I the causality of accidents or incidents is based on number of assumptions that lead us towards a single, or sometimes multiple, root causes. These root causes are the result of decompensation of the entire system. There are few models that can describe the casualty of events, such as Swiss Cheese Model (Linear) or STAMP (non-Linear) (Hollnagel, 2014).

Not surprisingly, in Safety-II the outcomes are considered as emergent. It means they may be due to temporary phenomena, combinations of conditions, or conditions that only existed at a certain point in time and place. Since emergence cannot be illuminated in terms of causality, and since we do need to explain it, some new methods such as FRAM (Functional Resonance Analysis Method) have been developed (Hollnagel, 2014).

Ontology of safety;

In Safety-I we are trying to understand completely what we do in order to be able to anticipate the consequences of design changes and implementing new means of interventions, ironically, in Safety-II we have limited ability to recognize what we do. It is purely because of the irony that the most socio-technical systems are intractable and work conditions are totally different from what has been imagined. In the Safety-I way of thinking, human performance has been prescribed by characterizing all components of the system, while in Safety-II human performance is always variable. In other words, in traditional safety, Safety-I, variability is not desirable. However, in Safety-II human performance variability is viewed as an asset (Hollnagel, 2014).

2.8 Functional Resonance Analysis Method (FRAM)

2.8.1 Resilience Engineering

As it was discussed earlier, the third age of safety brought the emergence of socio-technical systems into consideration. The notion of a socio-technical system is that the conditions for performing successfully - oppositely for unsuccessful performances – are generated when social and technical factors are interacting. The consequences of these interactions, which include both linear and non-linear emergent relationships, are:

- System performance cannot be optimized by focusing on only either social or technical aspect lonely.
- Socio-technical systems cannot be safe by analyzing only the system components and their failure probabilities. By other words, the safety assessment of socio-technical systems cannot be achieved by inducing the principles of reliability engineering and Probability Risk Analysis (PRA) (Hollnagel, (CRC), & Cedex, 2013).

A research conducted by Hollnagel & Speziali (2008) studied the developments in accident investigation methods and it illustrated that although the socio-technical systems continue to develop and to be more complex, the accident investigation methods do not change or develop. In other words, the methods we have and apply today may be inappropriate since the world changes consistently. It also means that even the new methods after some time will become less effective, however they were perfectly essential and adequate for the problems of that time. The same issue obviously exists for risk and safety assessment methods. Actually, the predominant models and methods date from the 1970's or earlier (Hollnagel, et al., 2013).

The traditional safety models analyze events as they are chains and sequences of causes and effects, either as simple linear progress or as combinations of it. Accident investigation and risk assessment models both proceed in a sequential manner, gradually follow the links either backward or forward from the chosen starting point. Examples of accident investigation models are the Domino model (simple linear) or the Swiss Cheese model (complex linear) and for risk assessment models, event trees (simple linear) and fault trees (complex linear) (Hollnagel, et al., 2013).

The unwanted or unexpected outcomes or events that lead to them can happen in the absence of malfunctions or failures and be due to performance variability or other temporary phenomena. It is also normal that the relationship between the events and outcomes is not linear and the source and severity of the results may be unpredictable form the preceding events. In this cases, the events are better to be called *emergent* rather than result of casual relations. This phenomenon mostly happens because of the high level of intractability of socio-technical systems. Since, socio-technical systems tend to expand continually and have closer interactions among their subsystems, mostly due to external request for effectiveness and productivity (Hollnagel, et al., 2013).

The current approaches to risk assessment are required to have the entire system described in detail. In a nut shell, the system should be tractable in order to be assessed. The problem is that the socio-technical systems are intractable and it is neither possible nor reasonable to simplify and describe the system in detail. Therefore, it is required to apply new approaches that can be used for intractable systems (Hollnagel, et al., 2013).

Resilience Engineering represents such an approach that has a different view to risk assessment. Instead of decomposing the entire system in order to count errors and calculate the failure probabilities, Resilience Engineering follows other principles. It begins with description of characteristic functions and looks for ways to improve an organization's ability to create processes that are fixed but flexible, to monitor and review risk models, and to use resources in a proactive way in the face of unexpected events. In Resilience Engineering, failures are not being considered as adverse outcomes of a normal system functions, but states the lack of adaptions with the real situations complexity (Hollnagel, et al., 2013).

The safety of socio-technical systems depends on four major facts that the developments of models and methods are required to be based on them (Hollnagel, et al., 2013):

- *Performance conditions are always underspecified.* Working situations are so detailed and it is difficult to specify them. Therefore, people and organizations should adjust their performances to maintain the desired condition. Since resources are limited, these adjustments are approximate. Performance variability is unavoidable, while is a source of success as well as failure.
- *Although many of adverse outcomes are due to malfunctioning of components in a normal situation, many are not.* These intractable adverse events happen as a result of unexpected combinations of variability in normal performances.
- *Safety management cannot be effective if it counts on the calculation of failure probabilities.* Effective controls should be proactive and the responses are prepared and performed ahead of time. It is not reasonable and adequate to count failures then decide to remove or control them.
- *Safety is part of the core process.* Safety is a requirement for productivity, and productivity is achieved by safety. A safe system becomes safer by improvements

instead of constraints (Hollnagel, *et al.*, 2013).

Therefore, in Resilience Engineering, an organization should have the following four characteristics in order to be safe (Hollnagel, Woods, & Levenson, 2006):

- The ability to respond to systematic and non-systematic threats in a strong but flexible manner.
- The ability to monitor what is going on, counting its own performance.
- The ability to anticipate risks and opportunities in the more extended period.
- The ability to learn from experience.

All of the four characteristics are critically depended on what kind of model the organization is based on. The model is basically the assumptions about the nature of the process that are being taken in the organization. This model is so important for risk assessment and accident investigation since it helps to understand what criteria should be considered and how relations between system components can be described. Figure 3 below shows these four qualities in a schematic way (Hollnagel, *et al.*, 2013).

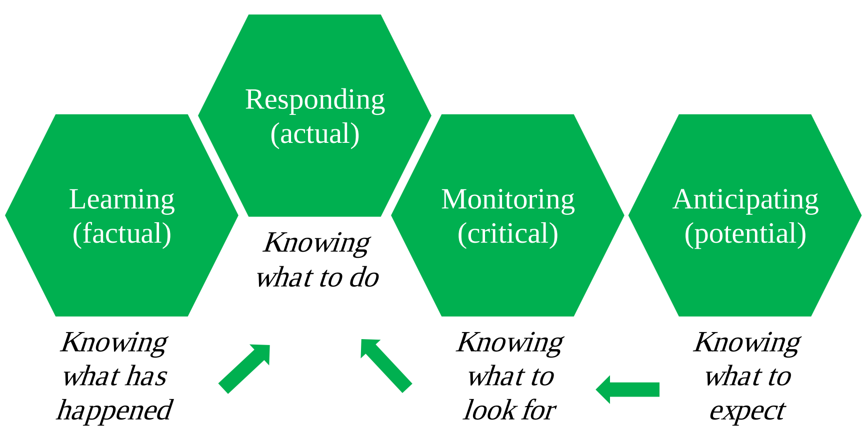

Figure 3 - The four qualities of resilience (Hollnagel, et al., 2013)

2.8.2 Development of The FRAM

The purpose of the development of FRAM is to provide a method that recognizes successes as the opposite side of failures. The method also should be able to recognize past events as well as possible future events, specially what might go wrong (Hollnagel, 2012).

FRAM is built on four principles:

The equivalence of failures and successes

Things go right and go wrong for the same reason, by another words they have the same origin. Failures and successes are equivalent until the outcome is known, though the preceding actions are right or wrong. This argumentation was pointed out by psychologists. Ernst Mach who said that "*knowledge and error flow from the same mental sources, only success can tell one from the other"* (Hollnagel, 2012).

The performance adjustment

Every day performance of socio-technical systems, separately or jointly, maintains the desired conditions (Hollnagel, 2012).

Human performance is variable due to number of factors such as:

- Inherent physiological and/or psychological characteristics, such as fatigue, vigilance and attention.
- Organizational factors, such as external demands and deadlines.
- Social factors, such as being compliance with group working, standards and so on.
- Circumstantial factors, such as working conditions that can be too hot, too noisy, too humid and so on (Hollnagel, 2012).

In large socio-technical systems, work situations are mostly intractable, therefore, people are needed to adjust their performance to match the conditions. These adjustments are critical since the situations are unspecified and resources are not sufficient. Humans are tremendously proficient at discovering ways of overcoming work problems and enhance the efficiency, so this capability is vital for both safety and productivity. In a nut shell, performance variability is a strength rather than a liability (Hollnagel, 2012).

The emergence

Many of the outcomes, either they have been noticed or not, should be described as emergent rather than resultant. There is a growing number of cases in which it is not either possible nor logical to explain the causality of events that are result of known processes. Although it is still possible to explain what happened, but the explanation will be in another way. It has been called "*emergent*" rather than "*resultant"*. The meaning of emergent is not something that happens magically, but it happens in such a way that are not explainable by methods using the principles of decomposition and causality (Hollnagel, 2012).

Resonance

The relations between the functions of a system should be described as they develop in a certain situation rather than as preset cause-effect links. The first reason is that the coupling between the functions cannot be stated in advance precisely. The second reason is that the dependencies can go beyond a simple cause-effect relationship. Actually, the third principle – emergence – represented some events that are not explainable in terms of cause and effect relationship and a more comprehensive method is required to explain it. The fourth principle –

resonance – apply functional resonance approaches in order to explain what can happen in complex socio-technical systems (Hollnagel, 2012).

2.8.3 Development of a FRAM Analysis

The first step in using FRAM is to make it clear whether is going to be used as an accident investigation tool or as a risk assessment. In other words, determine whether it looks at what has happened or looks at what may happen in future. Hollangel (2012) has called this step as "Step 0" where the purpose of the FRAM analysis should be determined. The main goal of Step 0 is to set the prospect for the four steps that should be taken in order to use FRAM as either an accident investigation or risk assessment tool (Hollnagel, 2012).

In this study, FRAM has been used for risk assessment, so the four steps and the scope of the analysis will be described on this basis. When the FRAM is used as a risk assessment tool, the first step defines the scope and the resolution of the descriptions along with the systems' boundaries in which the FRAM being used. The second step narrows the possible outcomes in the purpose of founding the instantiations and actual variability. The third step continue the narrowing but in the ways to find the interactions of performance variability in the forms of functional resonance. The fourth step requires thinking about how a potential not-desired performance variability can be detected and dampened in order to maintain the safety of the system (Hollnagel, 2012).

2.8.3.1 The First Step

The first step of the FRAM is about identifying the functions that are needed to maintain the everyday work successes. The main goal of this step is to describe the work in details in such a way that the work is done as a routine activity, instead of providing a working instruction that just describe how the task should be done (Hollnagel, 2012).

To identify the function, a prospective analysis as in a risk assessment, a timeline is mostly available, like a safety case. If it is not the case, different approaches should be taken in order to identify the functions. Task Analysis is a basic for identifying functions. A task analysis generally includes sub-tasks that are ordered from simplest to the most complex one. In order to develop a Task Analysis, Hierarchical Task Analysis (HTA) provides the required approach. HTA decomposes a task multiple times until it reaches to an elementary level where each sub-is this figure in the right place? task represents a specified goal. An example of a HTA can be seen in Figure 4 below (Hollnagel, 2012).

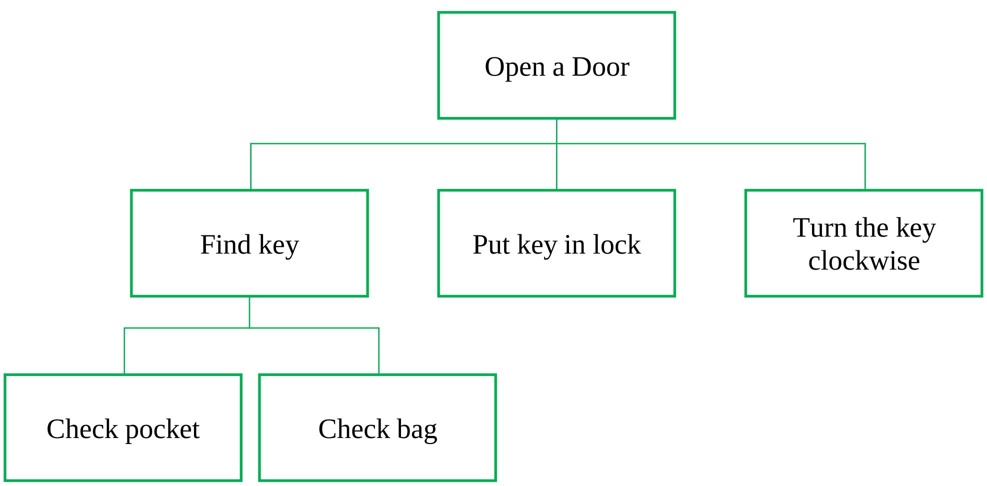

Figure 4 - an example of HTA approach

The Six Aspects of FRAM

In the FRAM, a function can be characterized by the six different aspects or features as explained bellow (Hollnagel, Hounsgaard, & Colligan, 2014):

- Input (I): That which activates the function and/or is used or transformed to produce the output. Constitutes the link to upstream functions.
- Output (O): That which is the result of the function. Constitutes the links to downstream functions.
- Preconditions (P): System conditions that must be fulfilled before a function can be carried out.
- Resources (R): That which the function needs when it is carried out (Execution Condition) or consumes to produce the Output.
- Time (T): Temporal constraints affecting the function (with regard to starting time, finishing time or duration).
- Control (C): How the function is monitored or controlled.

A FRAM function is represented graphically by a hexagon, where each vertex relates to an aspect, as shown in Figure 5 below. In the FRAM, links are clearly defined between the functions. Since a FRAM model is the descriptions of functions, arrows are not used like in diagrams. Therefore, the links do not represent any certain position or direction.

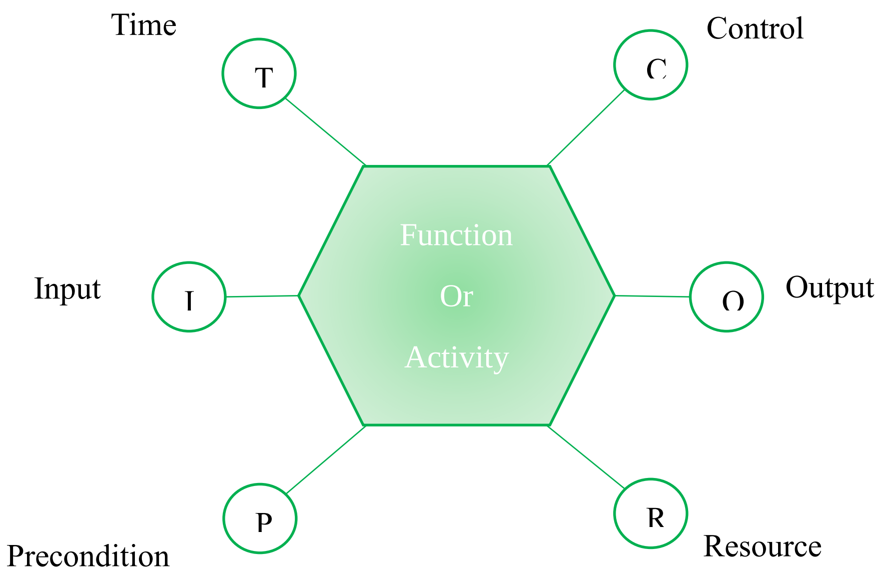

Figure 5 - The six aspects of a function or activity in the FRAM model (Hollnagel, 2012)

2.8.3.2 The Second Step

The second step addresses the potential variability and the actual variability that both establish the FRAM model. The way in which is possible to identify the characterization of performance variability is to understand how functions coupled and how it leads to unexpected outcomes. In FRAM, looking at the variability of the output from the function is more important than at the variability of the function by itself. The potential variability can be also recognized as “Internal” and “External” variability, if it is looked more precisely. The internal variability is about how likely a function varies by itself, while the external variability is about how likely a function varies as a consequence of the working conditions, which in turn may be seen as the outcome of other functions (Hollnagel, 2012).

There are two ways in order to detect performance variability, either internal or external, and how it may affect downstream functions. The simple solution, which indeed is the more practical and not so comprehensive, and the more elaborate solution which is comprehensive but not too efficient (Hollnagel, 2012). Since this research has been conducted in a manufacturing environment and because of the first purpose of this study, which is to examine the feasibility of the FRAM analysis, the simple solution has been used for this study.

The simple solution to discover the consequences of the performance variability is to note that the Output from a function can vary in terms of *timing* and *precision*. In the FRAM, the Output of a function is not being considered by itself but instead the Output as it is used by a downstream function - as Input, Precondition, Resource, Control or Time. In terms of timing, variability happens where an Output occur too early, on time, too late or not at all. In terms of precision, an Output can be precise, acceptable or imprecise. Since the precision depends on the coupling between upstream and downstream functions, it can be so relative. If the Output is precise, the needs of the downstream function is fulfilled and vice versa (Hollnagel, 2012).

2.8.3.4 The Third Step

Hence a FRAM model is not being used for a certain situation, it can merely represent the potential variability. Scientific knowledge and practical experience play a crucial role in order to estimate a range of performance variability. An instantiation represents a solid example of the model for specified circumstances and conditions, and the details provided by the instantiation makes it possible to be more precise about whether and how the potential variability can become actual variability. However, it still is not enough to determine if the actual variability is for individual functions. The functional upstream-downstream coupling, which is the whole purpose of Step 3, is to provide an adequate description of how differences in the quality of upstream Outputs can affect the variability of downstream functions, and thereby the variability of their Output. It certainly depends on the function whether it is technological, human or organizational. This step can be executed by the HTA approach that has been described earlier in this chapter (Hollnagel, 2012).

2.8.3.5 The Fourth Step

The last and obviously not the least step is to propose ways to manage the possible occurrences of uncontrolled performance variability or in other words, the possible conditions of functional resonance. Since the primary purpose of the FRAM is to identify the performance variability within in a system, the problem areas in the system's functioning is being identified in addition to the more traditional analysis such as failure modes and malfunctions. Once the problems have been found, the hierarchical controls like below should be taken (Hollnagel, 2012):

- The *elimination* of the hazards, which is possible by removing the affected components of the system.
- The *prevention* of the hazards, which is possible through placing barriers or defense before undesired outcomes happen.
- The *facilitation* of the hazards, which is more along with resilience engineering goals, provides safety by redesigning the system in such a way that is not possible to do things wrong.
- The protection of the hazards, which provides safety via barriers where undesired outcomes happen.

In socio-technical, control of safety and quality are required to be managed by setting appropriate goals and targets, so the ongoing processes and developments can be monitored and that activity can be trackable. In order to select proper indicators to monitor, compromising between effectiveness and thoroughness is always involved. A FRAM model can be used as a tool to anticipate the potential unwanted events that may happen due to the developments, for example by recognizing couplings that lead to increase in performance variability. Therefore, a FRAM model can be proposed as a proper indicator (Hollnagel, 2012).

2.8.4 How to Collect Data for the FRAM

All things considered, the illustrated steps should be taken in order to do a risk assessment, unlike the traditional risk assessment which only looks at probability and severity of undesired results. It is worth mentioning again that the first purpose of the FRAM is to identify the sources of variability and how they may be managed. By other words and from the risk assessment perspective, the main goal is to identify and reduce variability to stop the occurrence of resonance that would create problems within the system (Albery, Borys, & Tepe, 2016).

The FRAM is to describe how an activity is performed and the selected activity should be described in terms of functions needed for performing it. If Figure 6 below shows the normal distribution of the result of an activity, the purpose of the FRAM is not to described the lower tail, 0.6%, which represents accidents and errors and the upper tail, 0.6%, which represents obvious successes. Instead, the FRAM aims to describe the 98.8% that falls in between. The 98.8% represents the activities that being performed as they should (Hollnagel, Hounsgaard, & Colligan, 2014)

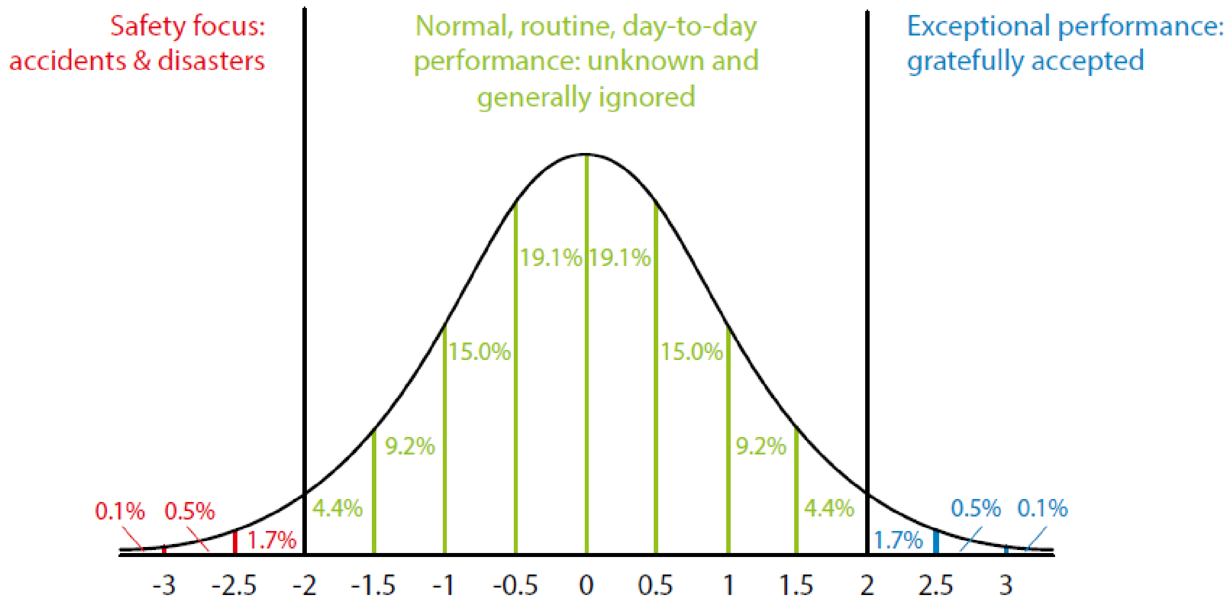

Figure 6 - Source: From Safety I to Safety II: A White Paper. European Organization for the Safety of Air Navigation. (Hollnagel et al., 2013)

Accordingly, the question arises where to obtain this information. The best source of information about the activities of interest is the people who actually carry out the work. Interviews are the primary tool to obtain this information along with field observation and document reviews (Hollnagel et al., 2014).

For interviews, it is very fundamental to comprehend the purpose of the study. It means that the interviewees should know how much information is needed and how will that information be helpful? Necessary sources of information such as rules, regulations, protocols, job descriptions, etc. should be prepared before going into the field. In order to form the basis of the set of questions, data on turnover of personnel, equipment, procedure and organization and major events or changes shall be collected (Hollnagel et al., 2014).

2.8.5 How to Synthesize Collected Data

The collected data from the interviews and information during the preparation phase need to be synthesized by the FRAM principles. The analysis team needs to identify the important functions and sort the material based on them. The foreground and background functions can be recognized at this stage if it is possible. For the foreground function, the six aspects (Input; Output; Preconditions; Resources; Control; Time) should be recognized. Information on Input and Output represents the basic minimum required. The Output should be described in detail with respect to time and precision. Regarding the time, it should be determined whether the Output varies by coming too early, on time or too late. For precision, the Output should be determined if it is imprecise, acceptable, or precise. It should be noted that each function is required to be documented by firstly its name then a detailed description of it (Hollnagel et al., 2014).

2.8.6 Risk Assessment by Risk Matrix vs. FRAM

The risk matrix has not been designed to identify the risks associated with performance variability and it focuses only on the hazards within a system, not the entire system within its environment (Albery, Borys, & Tepe, 2016). Dissimilar to risk matrix assessments that merely explore probability and severity of hazards within a system, a FRAM assessment requires a more comprehensive approach that includes four steps. The first two steps are mainly concentrated on understanding and defining work-as-done, the third step look at the emergent system situations that result from system variability and the fourth managing the undesirable system states (Hollnagel, 2012).

Chapter 3

METHODOLOGY

This research aimed to investigate the validity and applicability of the newly proposed risk assessment tool, FRAM, in a different manufacturing environment where hidden hazards are not recognizable by linear risk assessment methods and using a tool with greater requisite variety may mitigate them. Albery *et.al* (2016) established a research method in order to investigate if the question sets inspired by the concept of FRAM and Safety-II can mitigate the hazards that are not identified by linear risk assessment methods. He developed a research method that investigates the entire system in addition to the hazards and their controls in isolation by using question sets inspired by the FRAM/Safety-II and risk matrix/Safety-I. Hence the Safety-I perspective is included in Safety-II, it has been proposed that the FRAM embraces risk matrix. Albery developed the research grounded on the following logic and designed a methodology that pursues four objectives: "1- understanding work-as-imagined; 2- understanding work-as-done; 3- evaluating learnings from a Risk Matrix/Safety-I assessment; 4- evaluating learnings from a FRAM/Safety-II assessment" (Albery, *et al.*, 2016). The limited number of research studies that have been performed in order to encourage stakeholders to look for resources of variability in their working systems and also the need for investigating the application of the Safety-II approach, motivate the researcher to replicate the methodology of Albery's study in order to explore a greater sample size and also a different type of manufacturing environment to understand if similar relationships exist in other industries.

The objectives of the research are set in order to create a learning cycle (Argyris, 1999) that benefits both researcher and the organization on two certain phases: the work-as-imagined that provides a background for work-as-done (reflects understanding how the work is performed and how it is planned to be performed), and the risk assessment based on Safety-I perspective that provides data for the FRAM-based risk assessment (reflects comparison and evaluation of risk matrix/Safety-I and FRAM/Safety-II in hazards identification and management).

Learning is defined to happen under two criteria. The first is when an organization achieves what is intended (a small gap between the design of action and what in reality happens), the second is when a mismatch between the intention and outcome is recognized and afterwards its correction happens, the mismatch turns into a match (Argyris, 1999).

Organizations do not provide learning; in fact, the individuals who are acting as agents in organizations behave in a way that results in learning. Organizations can create a setting that substantially effect the scope of the problem recognition and designing a solution. Whenever a failure is recognized and solved with no question or changing in the fundamental of the system, the learning is a single-loop. On the other hand, when a system asks why the changes are occurring and why the system is programmed in this order, the learning is double-loop. Single-loop learning occurs when matches between the designed and actual actions happen, or the mismatches are corrected by changing actions. Double-loop learning occurs when mismatches are corrected by first investigating and changing the leading variables and then by the actions (Argyris, 1999). Consequently, in order to create a cycle of learnings, the objectives of the research are set in a double-loop learning as shown in Figure 7 below.

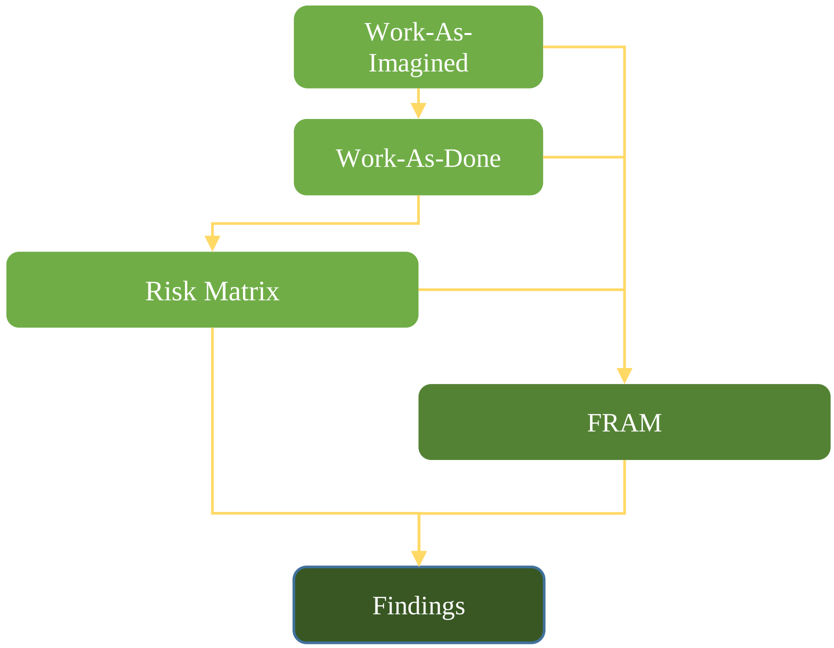

Figure 7 - Double-Loop learning flowchart (Albery, 2016)

In an attempt to achieve the objectives of the research through the methodology, a range of environments with different complexity, process control, and therefore variability was selected. In other words, systems have been selected based on the objectives of the research which are essentially looking for the variabilities in the systems; i.e. the systems that have high variability and low control, and the systems that have high control and low variability.

A medium-voltage electrical equipment manufacturing factory was selected that designs and produces instrument transformers that accurately meter either current or voltage on an electrical circuit in order to protect the metering instrumentation from the power available in the circuit. The plant occupies 110,000 square feet and employs 200 people with considerable cultural and language diversity and also variety of involvement throughout the plant, from Research & Development Engineers to Line Assemblers who are involved in different types of processes, from designing innovative transformers to casting numerous types of molds.

The business has been representing a branch of one of the largest engineering companies as well as one of the largest conglomerates in the world that has tremendous layers of management in its systems. The corporation has operations in around 100 countries, with approximately 135,000 employees in December 2015, and reported global revenue of $35.5 billion for 2015 (ABB Group, 2016).

The plant consists of several departments, receiving, core winding, core fabrication, medium voltage assembly/winding, casting, packing and testing, Thermoplastic Rubber (TPR), Outdoor products (ODP) and shipping. Each department is involved in numerous functions and works within an integrated system. While some of the departments are not part of the main production streamline and manufacture products out of the main production line, similar to fuses and switches in ODP departments, all the departments consistently follow the general safety and quality guidelines.

As it has been mentioned, the systems have been selected based on the objectives of the research and discussions with the safety manager and the supervisors within the manufacturing environment using two main attributes. First, the systems with low process control which are characterized with high variability meaning that the workers are engaged in more physical and mental activities to complete the task. Second, systems with high level of controls require a lower degree of mental and/or physical engagement of workers which result in low variability.

The systems were selected in two coupled pairs, so the variability effects of upstream or downstream can be seen on the overall systems. The process of selecting the systems based on the required criteria conducted through the discussion with quality engineers and production managers who have the better understanding of the systems and the variability that occurs within the systems. Consequently, Medium Voltage Assembly/Winding and Mold Build Up/Casting jobs have been selected to represent the systems with high variability and low control, besides Cutouts Pre and Final Assembly Line that are representing the systems with low variability and high control.

Four sets of questions located in Table 2 were created in order to investigate the systems based on the objectives and criteria of the research. The question sets were created based on the literature, Albery (2016) & Hollnagel (2014), and interviews with professionals and experts within the industry in order to ensure that four major elements of the research, work-as-imagined, work-as-done, Safety-I perspective risk assessment and Safety-II perspective risk assessment have been embraced respectively. The questions were revised a number of times to cope with the criteria of the research and also to encompass the main objective of this research which is to investigate the validation of Albery's (2016) study. Moreover, in order to convey a clear meaning of the questions and also to prevent misunderstanding, the language of the question sets was customized to the manufacturing environment and participants' setting.

For each system, the same question sets were used while the narrative of the questions were constantly being checked to ensure that are aligned with the objectives of the research. Eight workers, two supervisors, two quality engineers and one production engineer (Table 2.1), who were in their respective roles for more than one year and were quite experienced, were selected to be interviewed.

The number of the interviewees were affected by several reasons. The first one was the presence of two pairs of systems with different characteristics, high variability/low control and low variability/high control. The second was the number of quality engineers and supervisors that were working in each system respectively. Since there were four groups of people that were interviewed, the following paragraphs describe the rationales for selections of the number of interviewees in each group.

- Foremost, with the purpose of decreasing the bias in answers to the questions, two workers respectively from each of the four job stations (systems) were selected and it resulted in number of eight. In other words, eight workers who played a crucial role to understand how they performed the job, protected themselves from the hazardous situations and also maintained the positive system performance were interviewed.
- Two quality engineers and two supervisors were selected to answer the questions regarding to the FRAM objective in order to understand how variability take place within the systems and how the performance adjustments would maintain the outcome of the systems at the desired level where all stakeholders could benefit. One quality engineer and one supervisor were selected for MV Winding and Mold Casting job stations (high variability/low control) and one quality engineer and one supervisor were selected for Cutouts Pre and Final Assembly (low validity/high control).
- One production engineer was selected in order to understand how the work was intended to be performed by all the workers at all the job stations. In other words, the production engineer provided a more inclusive perspective in order to achieve the first object which was to understand the work-as-imagined.

The last reason that affected the number of the interviewees was the ultimate aim of this research which is to investigate the validation of Albery's study. It means that it was attempted to maintain the sample size as close as to the original study in order to avoid lurking variables affection (A lurking variable is a variable that is not included as an explanatory or response variable in the analysis but can affect the interpretation of relationships between variables).

The sequence of asking the question sets was based on the objective of the research that are illustrated in the Figure 8. The production engineer was selected for the first iteration in order to understand how the work was imagined to be carried out for each individual activity. Each activity was reviewed in a high level of details and the working instruction that were issued by the respective quality control group were studied precisely. Then the workers were interviewed for the second, third and fourth objectives that are learnings from work-as-done, risk matrix and FRAM findings. In other words, workers were interviewed respectively in order to understand how the work was being performed in their particular activity, how they managed the hazards that they were exposed to day by day and also to understand how they maintained the outcome of the system at the desired level in uncommon conditions. As a final point, the supervisors and quality engineers were interviewed for the fourth objective, FRAM, in order to get additional perspectives regarding to the system performance outcomes and the variability and adjustments that happened within the respective systems.

At the time of the research, the researcher had worked at the plant as a Health, Safety and Environment (HSE) Intern for more than five months. Adequate insight about the systems within the facility and the organization had been attempted to gain during this period of time. Furthermore, the researcher had no line management relationships or influence on any of the participants of the research either directly or indirectly.

The question sets were inquired verbally, no questionnaire survey was used, based on a semi-structured interview process for three major reasons: (i) to avoid the potential poor response (Austin, 1981), (ii) to have the opportunity to evaluate the validity of the respondent's answers by observing non-verbal indicators such as facial expressions, posture, hand gestures and in general body language (Gordon, 1975), (iii) to simulate the real time risk assessment on the job. The interview was centering discussions on the work conditions, job barriers and complexity of the entire process in the workers' own language (Barriball & While, 1994). The answers to the questions were captured manually without using any type of audio-taping equipment for the reason of simulating a real time risk assessment and to avoid any biases that the worker may perceive being audiotaped as being intrusive. The researcher conducted the data collection with assistance of a second coder to ensure that the answers to the questions had been captured and noted properly. The second coder was a graduate student with adequate experience in safety and research projects and also cultural communication skills assisted the researcher to ensure that the questions are properly debriefed and the answers have been appropriately noted. The data assortment was performed at the end of each interview in order to confirm that the collected data was captured and organized appropriately. The University & Medical Center Institutional Review Board Office of East Carolina University had approved the research as an exempt certified study prior to conducting the research. The IRB approval letter has been shown in Appendix B.

Table 2 - Question Sets Inspired by FRAM perspectives (Hollnagel 2014, Albery at al., 2016)

Objective	***Question Set***
1. Work-as-imagined *Inspired by* (Hollnagel, 2014) *and* (Albery, et al., 2016)	1. Are there any controlled documents to describe the job? 2. Are the main factors of the job recognized? 3. Are there any prerequisites before starting the job? 4. Are there any instructions for the changing conditions? 5. Are there any controls applied to limit the deviation/variation?
2. Work-as-done *Inspired by* (Albery, et al., 2016)	1. What is the best possible way to do the job? 2. How close is the best way you do the job to the pre-employment training? 3. Has the team lead or supervisor enforced you to change the way you are doing the job? If so, how often? 4. Has anything unpredicted ever happened? If so, explain it. 5. Do you think that would be something beneficial to improve the work procedure? (By changing the material or the methods) 6. Are the tools a right fit to the job? 7. Is the material being used the best you have ever seen? (According to the previous changes) 8. How do you distinguish if the quality is acceptable? 9. Do you call the team lead whenever you detect a problem in the work or keep working until you they come to you?
3. Risk matrix/ Safety-I *Inspired by* (Albery, at al., 2016)	1. Do you think there are any hazards that would hurt you? Are they recognized by the HSE team? 2. How is the severity of the hazard? a. LOW - ‘‘Band-Aid type injuries” b. MEDIUM - ‘‘A day off” c. HIGH – ‘‘More than day off” 3. How often does it happen? a. Unlikely – “Less than one time in the past 3 years” b. Possible – “One time in the last year” c. Likely – “More than one time in the last year”

	4. What are the controls used to lower the risks?
4.FRAM/ Safety-II *Inspired by* (Hollnagel, 2014) *and* (Albery, et al., 2016)	1. How often does the process change due to the material/process issued? * 2. How do you select the employees? * Tell me about the training and turnover. 3. When and why is a unit rejected? * 4. What is the most common reason to reject a unit? * 5. How would the potential hazards, due to the changes, be identified and controlled? ** 6. Can you stop the running process in order to maintain an adjustment? ** 7. How do you manage an unexpected situation? (in order to save time and material) *** 8. How long does it take to solve a problem? ***
	**To avoid the negative consequences* ***To maintain performance adjustments* ****To compensate performance adjustments*

Table 2.1 Summary of number of interviewees

Objective	***Participant Type***	***Number Interviewed***
1- Work-as-imagined	Production Engineer	1
2- Work-as-done	Workers	8
3- Risk matrix	Workers	8
4- FRAM	Workers Supervisors Quality Engineer	8 2 2

The data that was collected by the both researcher and second coder has been transcribed into a FRAM based template (Hollnagel, 2012). The data were analyzed according to the principles introduced in "The Functional Resonance Analysis Method: Modeling Complex Socio-Technical Systems" (Hollnagel, 2012).

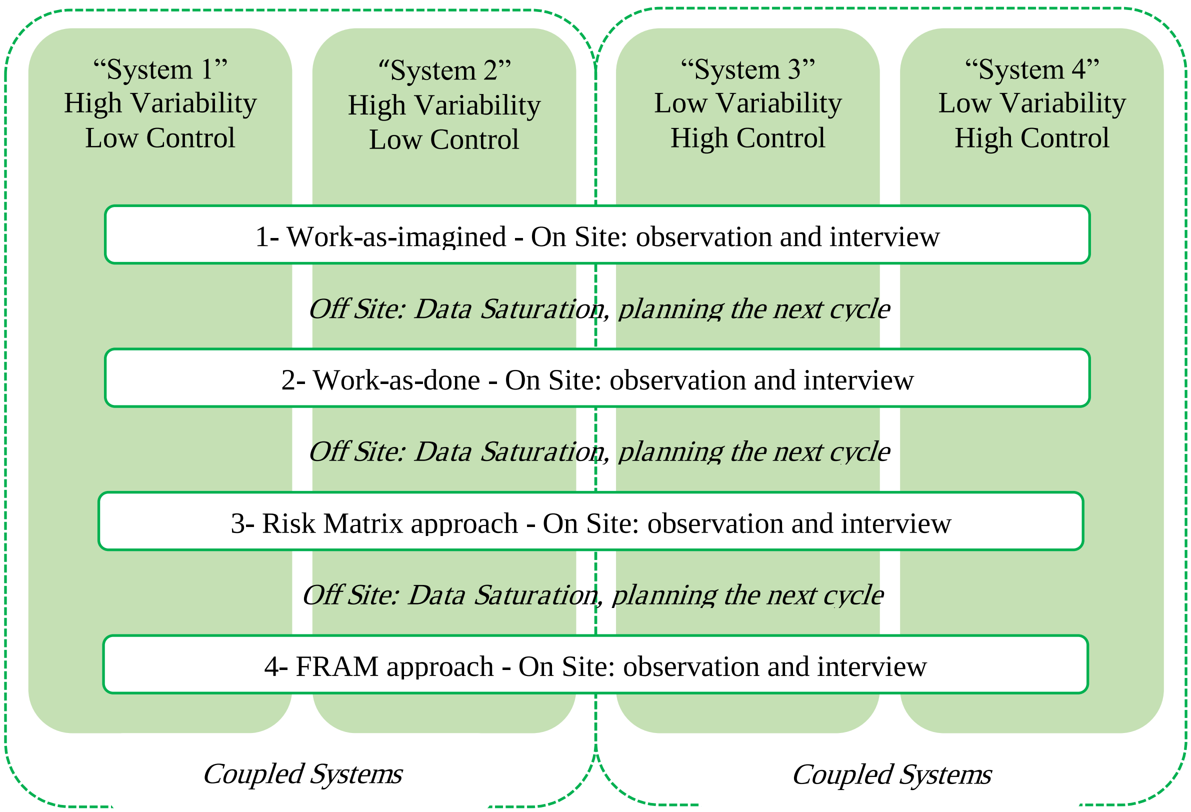

Figure 8- The research methodology in a repetitive research process (Albery, 2016)

Chapter 4

RESULTS

According to several discussions at the beginning phases of the research with the safety manager of the plant and also quality engineers and supervisors in the manufacturing area, it was concluded to select four systems (job stations) with the characteristics described in the methodology section and in Figure 8. Each system has the qualities that are summarized in the Figure 9.

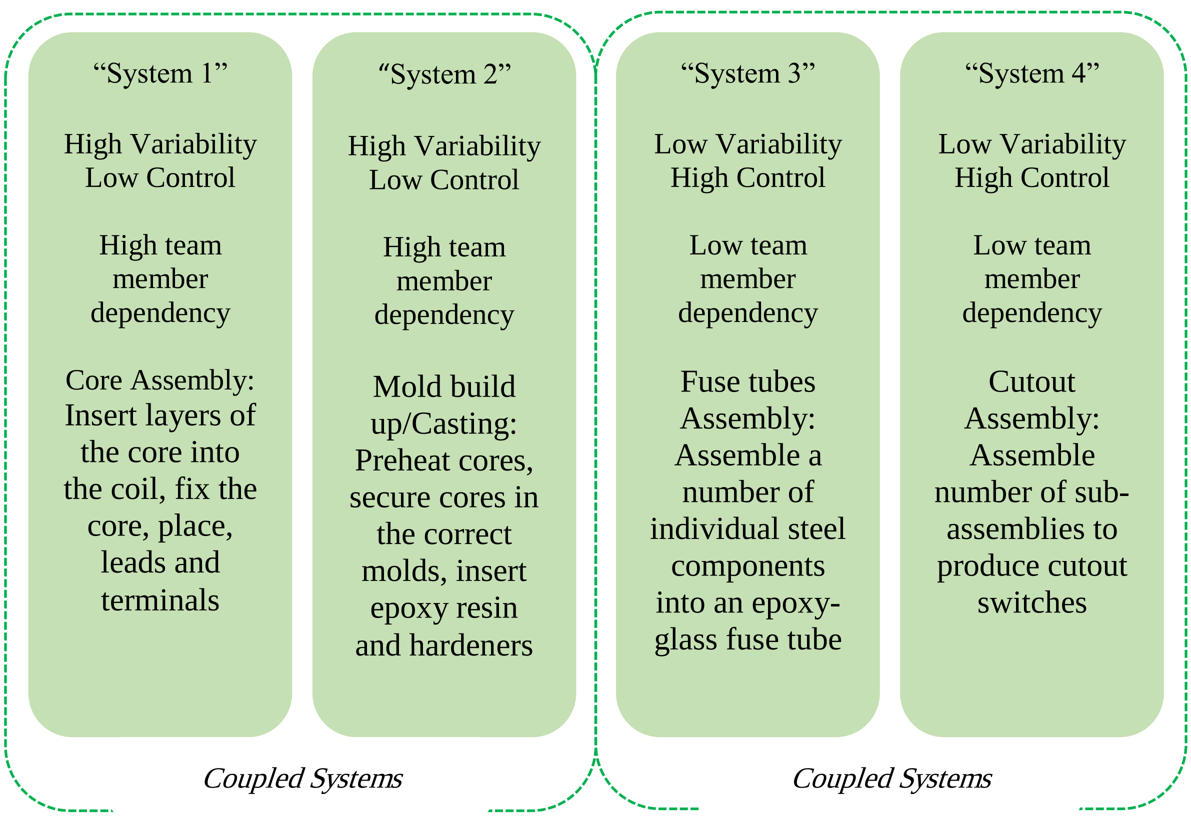

Figure 9 - Summarized qualities of each system (Albery, 2016)

System 1 was selected from the Medium Voltage Assembly area. In this area several workers are assigned to assemble the core parts of Current Transformers and Voltage Transformers. It required workers to perform several actions on the coil before shaping the core and before proceeding to the casting and molding sections which is the system 2. In other words, the system 1 output is the input of system 2. In the System 1, the assembler should set the coil assembly into a fixture that is designed to hold the coil and to prevent any damage to the parts then he/she inserts layers of the core into the coil by sliding them from the smallest one to the largest. Later, the assembler performs some actions to fix the coil on the core by putting straps, bands and wedges. The support bracket, leads and terminals are placed in this section. After some static tests, the finished core goes to the Mold Build up and Casting section which is system 2. In this section, the operators pre-heat (125 +/- 5 degrees of Celsius) the finished cores for minimum of two hours and then load them into molding fixtures based on the type of the unit that is intended to produce. Several molding fixtures are available and the operator has to select the correct one according to his/her trainings and experience. The core coil assembly should be placed on mold baseplate and get attached by the appropriate fasteners. Terminal blocks and high voltage terminals fixtures shall be secured by the correct fasteners as well. Afterwards, the prepared built up mold proceeds to the casting area to be filled up by epoxy resin and hardeners.

System 3 required workers to assemble a number of individual steel components into a fixture (an epoxy-glass fuse tube in cutouts) by using a pneumatic rivet machine and some hand jobs which produce the fuse tube part of cutouts that are receiving the final assembly in system 4. By other words, the system 3 provides the prerequisite part which is needed by the system 4. In system 3, the operator is required to attach the C-blade to the fuse tube using a washer, a stainless steel pin, a spring and a blade stop with the help of a pneumatic rivet machine in order to construct the fuse tube. When the tubes are ready, they proceed to the final assembly station where they are needed alongside the other parts to produce the cutouts. Eight operators in cutout assembly line work constantly to produce three different types of cutouts (ICX, NCX and LBU) according to the Work Order Form they receive at the beginning of the shift. System 4 requires the assemblers to place the poured porcelain assembly in the assembly jig, attach the top and bottom bracket assembly and hook then put the fuse tube into the bottom casting. At the end the assembler needs to center the fuse tube in relation to the top contact and the hooks.

Tables 3 to 7 demonstrate the responds to the questions in Table 2 that were asked in each respective work station (system) in order to investigate potential risks.

4.1 Summaries of responses to the questions for the System 1

System 1 has been selected as it was recognized with high variability and low control characteristics, based on the discussion with quality engineers and the safety manager of the plant, which is confirmed by the responses to the question set 1 that are shown in Table 3. Responses to the question sets 2 and 3 provided data confirming that although it was expected to observe some functions that are introducing uncontrolled hazards, but the system performed as it was projected. The hazards that were documented during the interview had been recognized by the EHS (Environmental, Health and Safety) team.

Question set 4 identified instantiations of the system and the sources of variability leading to resonant states. An example of this was the low training time that was dedicated to new employees and it resulted in numerous deviations and failures in static tests of units which are performed at the final stage of assembly. The most common reason of test failures was partial discharge. Partial Discharges (PD) are small electrical sparks that occur within the insulation of medium and high voltage electrical assets. Partial Discharge occurs due to contamination by particles on the surface of insulating material. The lack of a proper training before performing the job may cause more contamination during the assembly process and result in more PD test failures.

Table 3 - Summaries of responses to the questions for the System 1

Objective	**Question Sets**	**Response**
Work-as imagined	1. Are there any controlled documents to describe the job?	1. General work instructions but no specific one for each type of unit
	2. Are the main factors of the job recognized?	2. All major steps are included in the instructions
	3. Are there any prerequisites before starting the job?	3. Need to be trained on a particular station and they keep training logs
	4. Are there any instructions for the changing conditions?	4. All changes go through the engineer change notice data to be approved in the house
	5. Are there any controls applied to limit the deviation/variation?	5. Try to create gauges and fixtures to limit mechanical deviations in equipment but it is an ongoing process
Work-as-done	1. What is the best possible way to do the job?	1. The best way is the way they were trained
	2. How close is the best way you do the job to the pre-employment training?	2. The training is very close to the best way that the job can be done
	3. Has the team lead or supervisor enforced you to change the way you are doing the job? If so, how often?	3. Never be forced to have changed something
	4. Has anything unpredicted ever happened? If so, explain it.	4. No unpredicted events happened. No surprises
	5. Do you think that would be something beneficial to improve the work procedure? (By changing the material or the methods)	5. Nothing to improve
	6. Are the tools a right fit to the job?	6. Tools are fit but some are worn out

	7. Is the material being used the best you have ever seen? (According to the previous changes)	7. Materials most of the time is good but it has changed slightly
	8. How do you distinguish if the quality is acceptable?	8. Based on the cleanliness of the material and making sure everything has been done based on the instructions
	9. Do you call the team lead whenever you detect a problem in the work or keep working until you they come to you?	9. They ask team leader then ask supervisors
Risk Matrix/Safety-I	1. Do you think there are any hazards that would hurt you? Are they recognized by the HSE team?	1. Cuts, scratches, bumping the head on the hanging equipment. Recognized by the EHS team
	2. How is the severity of the hazard? • LOW - ‘‘Band-Aid type injuries” • MEDIUM - ‘‘A day off” • HIGH – ‘‘More than day off”	2. Low
	3. How often does it happen? • Unlikely – “Less than one time in the past 3 years” • Possible – “One time in the last year” • Likely – “More than one time in the last year”	3. Likely
	4. What are the controls used to lower the risks?	4. House-keeping, work station design, PPE
FRAM/Safety-II	1. How often does the process change due to the material/process issued?	1. No major change within the 5 years
	2. How do you select the employees? Tell me about the training and turnover.	2. Using temp agencies. Look for hands on skills. No set training time. Low turnover
	3. When and why is a unit rejected?	3. Rejected for static issues and test parameters failures
	4. What is the most common reason to reject a unit?	4. Partial discharge
	5. How would the potential hazards, due to the changes, be identified and controlled?	5. EHS review new equipment and it has to be approved by multiple people (change in process
	6. Can you stop the running process in order to maintain an adjustment?	6. All the employees have the power to stop the process

	7. How do you manage an unexpected situation?	7. Usually EHS and engineering handle the situation based on the severity and the area of the job.
	8. How long does it take to solve a problem?	8. Most of the time it takes 4 to 5 hours to fix a problem (same day)

4.2 Summaries of responses to the questions for the System 2

Like System 1, System 2 has been selected as it was recognized with high variability and low control characteristics, based on the discussion with quality engineers and the safety manager of the plant, which is confirmed by the responses to the question set 1 that are shown in Table 4. Responses to the question sets 2 and 3 revealed information regarding to some actions that are not projected in work instructions and may introduce some hidden risks. In view of the fact that System 2 had only employed one universal work instructions with no details in description of the job, numerous actions were observed regarding to identification of variability. One example of this was the selection of the correct type of mold for the casting process. The operators who performed the mold build up job had been working at that position for over 30 years and the selection process was merely based on the vast experience of those individuals.

Again question set 4 identified instantiations of the system and the sources of variability leading to resonant states. The lack of an appropriate training process to train new and fresh employees along with the lack of a comprehensive work instructions that describe the job in details were discovered. The variability introduced by the lack of training would result in increasing number of rejected units and risk of injury to workers correspondingly.

Table 4 - Summaries of responses to the questions for the System 2

Objective	**Question Sets**	**Response**
Work-as imagined	1. Are there any controlled documents to describe the job?	1. There is general instruction but no specific style instruction for each unit
	2. Are the main factors of the job recognized?	2. No. Trying to implement a program per station to highlight the key process
	3. Are there any prerequisites before starting the job?	3. Need to be trained on a particular station and they keep training logs
	4. Are there any instructions for the changing conditions?	4. All changes go through the engineer change notice data to be approved in the house
	5. Are there any controls applied to limit the deviation/variation?	5. There is an established process to control deviation
Work-as-done	1. What is the best possible way to do the job?	1. No special training. Perform the job based on the remarkable experience
	2. How close is the best way you do the job to the pre-employment training?	2. Training is inadequate
	3. Has the team lead or supervisor enforced you to change the way you are doing the job? If so, how often?	3. Workers are more experienced than supervisors in order to identify the errors
	4. Has anything unpredicted ever happened? If so, explain it.	4. No real supervises rather than come machine errors
	5. Do you think that would be something beneficial to improve the work procedure? (By changing the material or the methods)	5. Add more work space and some features
	6. Are the tools a right fit to the job?	6. Tools are good but should be borrowed rarely
	7. Is the material being used the best you have ever seen? (According to the previous changes)	7. Cheaper materials are being used recently
	8. How do you distinguish if the quality is acceptable?	8. Based on the appearance of the unit and the correctness of the terminals
	9. Do you call the team lead whenever you detect a problem in the work or keep working until you they come to you?	9. Sometimes call supervisors but most of the time tag the unit and send it back to fix the problem that has happened in assembly

Risk Matrix/Safety-I	1. Do you think there are any hazards that would hurt you? Are they recognized by the HSE team?	1. Cuts, pinches, tool injuries
	2. How is the severity of the hazard? • LOW - ‘‘Band-Aid type injuries” • MEDIUM - ‘‘A day off” • HIGH – ‘‘More than day off”	2. Medium
	3. How often does it happen? • Unlikely – “Less than one time in the past 3 years” • Possible – “One time in the last year” • Likely – “More than one time in the last year”	3. Unlikely
	4. What are the controls used to lower the risks?	4. PPE and lifting crane
FRAM/Safety-II	1. How often does the process change due to the material/process issued?	1. No major change within the 30 years
	2. How do you select the employees? Tell me about the training and turnover.	2. Using temp agencies. Hire tall men. On the job training up to 4months. Very low turnover
	3. When and why is a unit rejected?	3. Rejected for bad serial number and bad terminals
	4. What is the most common reason to reject a unit?	4. Bad terminal and sleeve part left
	5. How would the potential hazards, due to the changes, be identified and controlled?	5. EHS review new equipment and it has to be approved by multiple people (change in process)
	6. Can you stop the running process in order to maintain an adjustment?	6. Have power to stop the process
	7. How do you manage an unexpected situation?	7. Based on the severity call supervisor or handle the situation
	8. How long does it take to solve a problem?	8. Typically, same day. If engineers are involved, takes longer

4.3 Summaries of responses to the questions for the System 3

System 3 has been selected as it was recognized with low variability and high control characteristics, based on the discussion with quality engineers and the safety manager of the plant, which is confirmed by the responses to the question set 1 that are shown in Table 5. Responses to the question sets 2 and 3 provided data confirming that the job is highly controlled and the variability is extremely low. The only issue that the workers mentioned during the interviews was minor spots on some steels which was due to the inconsistency in the production of the stock materials. Based on the size of the spots, some may result in the rejection of the assembly and some may not. Moreover, the observation of the job confirmed that all functions present a highly controlled operation with a minor unrecognized hazard by the EHS team.

Question set 4 identified minor instantiations of the system and the sources of variability leading to resonant states. Again like System 1 and System 2, the lack of a proper training time was identified by the question set 4. However, the fact that the job has a high level of control by its nature the existence of the proper work instruction and guidance lower the level of variability dramatically.

Table 5 - Summaries of responses to the questions for the System 3

Objective	**Question Sets**	**Response**
Work-as imagined	1. Are there any controlled documents to describe the job?	1. Available work instruction with description of the job
	2. Are the main factors of the job recognized?	2. All major steps are included in the instructions and also in quality control instructions
	3. Are there any prerequisites before starting the job?	3. Cross training from other jobs and initial quality control
	4. Are there any instructions for the changing conditions?	4. Using engineering notice
	5. Are there any controls applied to limit the deviation/variation?	5. Control the process by using engineering approval before applying any change
Work-as-done	1. What is the best possible way to do the job?	1. The best way is the way they were trained
	2. How close is the best way you do the job to the pre-employment training?	2. The training is very close to the best way that the job can be done
	3. Has the team lead or supervisor enforced you to change the way you are doing the job? If so, how often?	3. No force from team leads to change the process
	4. Has anything unpredicted ever happened? If so, explain it.	4. No unpredicted events happened except the machine's gauge issues
	5. Do you think that would be something beneficial to improve the work procedure? (By changing the material or the methods)	5. By not having to take the components apart (Was projected in work instructions)
	6. Are the tools a right fit to the job?	6. No specific tools are used (except the machine)
	7. Is the material being used the best you have ever seen? (According to the previous changes)	7. Rivets usually have some issues
	8. How do you distinguish if the quality is acceptable?	8. The shape and cleanliness
	9. Do you call the team lead whenever you detect a problem in the work or keep working until you they come to you?	9. Call coworkers or maintenance
Risk Matrix/Safety-I	1. Do you think there are any hazards that would hurt you? Are they recognized by the HSE team?	1. Fibers particles get into the gloves and makes

		scratches. Not recognized by the EHS team
	2. How is the severity of the hazard? • LOW - ‘‘Band-Aid type injuries” • MEDIUM - ‘‘A day off” • HIGH – ‘‘More than day off”	2. Low
	3. How often does it happen? • Unlikely – “Less than one time in the past 3 years” • Possible – “One time in the last year” • Likely – “More than one time in the last year”	3. Likely
	4. What are the controls used to lower the risks?	4. PPE
FRAM/Safety-II	1. How often does the process change due to the material/process issued?	1. The changes are just types of the units
	2. How do you select the employees? Tell me about the training and turnover.	2. Using temp agencies. Training is on the job and very short. Low turnover
	3. When and why is a unit rejected?	3. When blades or pins are damaged
	4. What is the most common reason to reject a unit?	4. Pin damage
	5. How would the potential hazards, due to the changes, be identified and controlled?	5. EHS review new equipment and it has to be approved by multiple people (change in process
	6. Can you stop the running process in order to maintain an adjustment?	6. Can stop the process
	7. How do you manage an unexpected situation?	7. Unexpected situations are handled by maintenance and coworkers
	8. How long does it take to solve a problem?	8. Very quick. 2-3 hours

4.4 Summaries of responses to the questions for the System 4

Like System 3, System 4 has been selected as it was recognized with low variability and high control characteristics, based on the discussion with quality engineers and the safety manager of the plant, which is confirmed by the responses to the question set 1 that are shown in Table 6. Responses to the question sets 2 and 3 provided data confirming that the job is highly controlled and the variability is extremely low. Two issues were mentioned during the interviews by the workers. The first one was some alignments in the process of the assembly that were time consuming when they try to place fuse tubes. The assemblers might miss the cycle time but there is no force from the supervisors to ignore the alignment in order to keep the cycle time. The second issue that the workers mentioned during the interview was the location of the parts. The assemblers need to walk around the working table in order to reach to the parts they need to assemble the unit. They suggested that if the location of the parts was closer the them, they would save more time and energy. Moreover, the observation of the job confirmed that all functions present a highly controlled operation with some unrecognized hazards by the EHS team.

Question set 4 identified instantiations of the system and the sources of variability leading to resonant states. Again like System 1, 2 and 3, the lack of a proper training time was identified by the question set 4. Moreover, the workers had some suggestions in order to improve the job performance in spite the fact that the job was highly controlled and the gap between the Work-as-imagined and Work-as-done was insignificant.

Table 6 - Summaries of responses to the questions for the System 4

Objective	**Question Sets**	**Response**
Work-as imagined	1. Are there any controlled documents to describe the job?	1. The work instructions are available
	2. Are the main factors of the job recognized?	2. All major steps are included in the instructions and also in quality control instructions
	3. Are there any prerequisites before starting the job?	3. Cross training from other jobs and initial quality control
	4. Are there any instructions for the changing conditions?	4. Using engineering notice
	5. Are there any controls applied to limit the deviation/variation?	5. Control the process by using engineering approval before applying any change
Work-as-done	1. What is the best possible way to do the job?	1. The best way is the training's way
	2. How close is the best way you do the job to the pre-employment training?	2. The training is very close to the best way of doing the job, with small differences
	3. Has the team lead or supervisor enforced you to change the way you are doing the job? If so, how often?	3. The only change is the order change
	4. Has anything unpredicted ever happened? If so, explain it.	4. Nothing unpredicted has happened
	5. Do you think that would be something beneficial to improve the work procedure? (By changing the material or the methods)	5. Changing the work set up in order to avoid heavy lifting and long walks
	6. Are the tools a right fit to the job?	6. Tools and materials are fit
	7. Is the material being used the best you have ever seen? (According to the previous changes)	7. Squares breaks frequently
	8. How do you distinguish if the quality is acceptable?	8. The shape and cleanliness
	9. Do you call the team lead whenever you detect a problem in the work or keep working until you they come to you?	9. Call coworkers or maintenance
Risk Matrix/Safety-I	1. Do you think there are any hazards that would hurt you? Are they recognized by the HSE team?	1. Heavy lifting, cuts, pinches and hammer/drill injuries. Not recognized by the EHS team

	2. How is the severity of the hazard? • LOW - ‘‘Band-Aid type injuries” • MEDIUM - ‘‘A day off” • HIGH – ‘‘More than day off”	2. Medium
	3. How often does it happen? • Unlikely – “Less than one time in the past 3 years” • Possible – “One time in the last year” • Likely – “More than one time in the last year”	3. Unlikely
	4. What are the controls used to lower the risks?	4. PPE and drill/driver ergo hanging rope
FRAM/Safety-II	1. How often does the process change due to the material/process issued?	1. The changes on the units happen multiple times per day
	2. How do you select the employees? Tell me about the training and turnover.	2. Using temp agencies. Training is on the job and very short. Low turnover
	3. When and why is a unit rejected?	3. When they find rust and tarnished spots on the parts
	4. What is the most common reason to reject a unit?	4. Rust
	5. How would the potential hazards, due to the changes, be identified and controlled?	5. EHS review new equipment and it has to be approved by multiple people (change in process
	6. Can you stop the running process in order to maintain an adjustment?	6. Can stop the process
	7. How do you manage an unexpected situation?	7. Unexpected situations are handled by stopping the process and calling the team leader
	8. How long does it take to solve a problem?	8. Are solved at the same day (big issues take longer)

Chapter 5

DISCUSSION

As it was explained in the methodology section in detail, the question sets that have been asked in this research was created based on a semi-structured interview process for three major reasons: (i) to avoid the potential poor response (Austin, 1981), (ii) to have the opportunity to evaluate the validity of the respondent's answers by observing non-verbal indicators such as facial expressions, postures, hand gestures and in general body language (Gordon, 1975), (iii) to simulate the real time risk assessment on the job (Albery, *et al*., 2016) . During the research, the questioning style of the both interviewer and the second coder was matured as the understandings of the systems and interactions between the researcher and employers developed. The questions illustrated in Table 2 were applied to investigate each system for each objective of the research in order to preserve consistency.

The first set of questions satisfies the first objective of the research which is to explore how the work is imagined and provides data that describes each system comprehensively. It looks at the job from a top-down perspective in order to discover how detailed the jobs are described (Silbey, 2009). Responses to the questions below helped to obtain sufficient data that is needed to recognize the systems as they are described. Furthermore, observation of the systems provided data regarding to the level and number of controls that were used in order to control the risks that are associated with the identified hazards (Lundberg, *et al.*, 2009).

- *"Are the main factors of the job recognized?"*
- *"Are there any perquisites before starting the job?"*
- *"Are there any controls applied to limit the deviation/variation?"*

The second set of questions satisfies the second objective of the research which is to explore how the work is done. The narratives of the questions are opposite of the first set of questions. It reversely looks at the job from a bottom-up perspective in order to discover the hidden sides of the job that are not described in work instructions (Silbey, 2009). Considering the first and second sets of questions side by side, it can be discovered that different stakeholders possess different views within the system and it can be intensified when the job becomes more detailed and more complicated (Lundberg et al., 2009). The amount of variability in all four systems was different. System 1 and 2 were selected with high variability and low control characteristics and it was expected to identify high amount of variability. Ironically, a low amount of variability was observed within System 1 while System 2 introduced a high amount of variability. System 3 and 4 were selected with low variability and high control characteristics that was confirmed by the first set of questions. Both System 3 and 4 introduced a very low amount of variability with minor interventions that were used to achieve the work objectives. The amount and level of variability were determined when workers were asked the questions,

- *"Do you think that would be something beneficial to improve the work procedure?"*
- *"What is the best possible way to do the job?"*

In most cases the responses proved that there was not a high amount of activities to suggest in order to improve the work situation. Only in System 2 numerous hidden activities were identified that the workers were performing in order to achieve the system goals. Also in System 4 a low level of variability was observed that was due to the work set up and not the current processes. All in all, the documentation and controls were aligned with work-as-imagined in most cases (Lundberg et al., 2009)

The third set of questions was applied to merely look at the systems from the traditional risk assessment point of view using a risk matrix approach. The questions were arranged to identify uncontrolled hazards or by other words the actual variability that are not described. The responses to these questions confirmed the presence of some uncontrolled hazards. The two questions,

- *"Do you think there are any hazards that would hurt you? Are they recognized by the HSE team?"*
- *"What are the controls used to lower the risks?"*

encouraged the workers to start an open discussion and tell about the hazards associated with their activities. Moreover, they were asked to state whether the mentioned hazards identified by the EHS team or not in order to recognize if the current controls that were applied are enough to lower the risks. Also the frequency and severity of the hazards were measured based on the discussion with the workers and observation of the job cycle. A full cycle of the job was observed then evidence of the frequency and severity of the hazards was revealed based on the items the workers have to perform in order to complete a task. Additionally, an open narrative with the workers about the possible hazards that they would face when performing the job confirmed the observations.

Lunderberg et al., (2010) demonstrated in his research that Safety-I style linear action-consequence risk assessment reveals a lower order control of hazards since it does not investigate the deeper systemic problems which have roots in other areas and do not instantly affect the system. Having the third question set been conducted in isolation would have not been efficient enough because it cannot have the systems examined beyond the hazards (due to a lack of a deeper understanding of the system) and consequently it cannot recognize the hazards that the workers were been exposed to when maintaining the success of the system.

Although the traditional Safety-I risk assessment approach (risk matrix) does not investigate the deeper systemic problems, the last set of questions develops the required variety of the risk assessment which are needed in order to have the system examined beyond the hazards. As it was mentioned earlier in the previous paragraph regarding to the third question set, if this question set had been in isolation, the sufficient data that are needed to identify intonations would have not been yielded (Ashby, 1956).

The fourth question set was set to satisfy the fourth objective of the research which is to investigate the validity of the hazards, associated with linear risk assessment methods, mitigation using the Safety-II perspectives (Albery et al., 2016). Accordingly, the two questions,

- *"How do you select the employees? Tell me about the training and turnover"*
- *"What is the most common reason to reject a unit?"*

played a crucial role in the transition from the traditional Safety-I approach to the newly proposed approach, Safety-II. Therefore, the fourth question set created the opportunity to recognize the states in which the systems resonate and provided the appropriate adjustments in order to lower the risks of undesired events (Hollnagel et al., 2014).

The responses to the fourth set of questions revealed the significant learnings that were generated with each instantiation. The instantiations identified variabilities that were not created by the upstream processes but by the other parts of the system which were not immediately related to the process. Subsequently, reactive variability was observed in which the employees altered the conditions in order to create an environment that maintains the desired outcomes. By other words, the employees adjusted the conditions in order to still produce a successful product Therefore, the adoption to the new condition that was generated by the variability, may lead to creation of hazards to workers and other employees. This adoption also results in some quality failures as instantiations introduce more variability (Dekker, 2006).

As it was mentioned in the methodology section, the objectives of this research are set in order to create a learning cycle. The double-loop learning happens when mismatches are corrected by first investigating and altering the primary variables and then by the actions. The linear action-consequence relationships of the traditional Safety-I risk assessment is opposed to the perspective provided by the FRAM approach in which evaluates each of the systems' goals individually (Albery et al., 2016). This double-loop learning found in Figure 10 below helped the researcher to identify the higher controls in each system that mitigate the unwanted hazards then reduce the reactive adjustments that were to dampen the variabilities in order to maintain success of the system (Dekker, 2006). As Gadd et al., (2004) stated, this process is required by the participation of all stakeholders who are the important component of the entire process. Thus, participation of all stakeholders was crucial in order to achieve the following goals:

- To understand the functions of each system that performs and also the interactions with the other systems
- To understand the sources of variabilities and the steps that should be taken in order to dampen the variabilities effectively

- To ensure that all stakeholders participate in the development of the narratives and consequently learning (Albery et al., 2016)

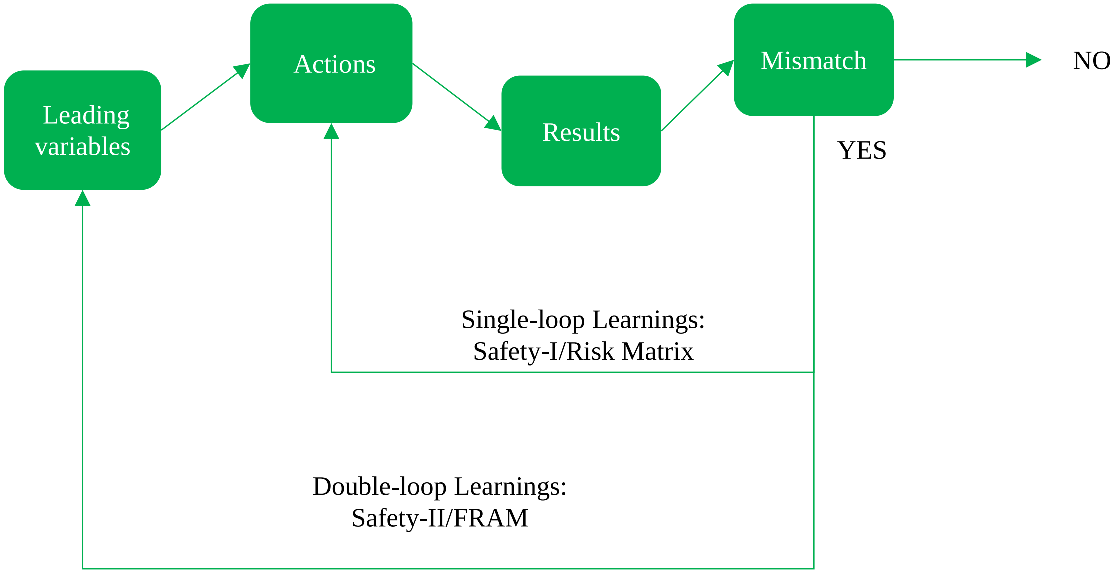

Figure 10 – Learning Cycle inspired by Aygris (1999)

Table 7 - Summary of key questions for each objective

Objective	***Questions***
Work-as-imagined	Are the main factors of the job recognized? Are there any perquisites before starting the job? Are there any controls applied to limit the deviation/variation?
Work-as-done	What is the best possible way to do the job? Do you think that would be something beneficial to improve the work procedure?
Risk matrix/ Safety-I	5. Do you think there are any hazards that would hurt you? Are they recognized by the HSE team? 6. What are the controls used to lower the risks?

FRAM/ Safety-II	9. How do you select the employees? Tell me about the training and turnover 10. What is the most common reason to reject a unit?

A risk assessment that uses all the four question sets presented in Table 2 has involved more number of resource involvement, thus result in an enhanced understanding of the systems which is more comprehensive and deeper. Using only the subset of questions illustrated in the third object, which was implement of Safety-I traditional risk assessment, cannot provide sufficient data regarding to understanding of the systems and identifications beyond the hazards. In order to obtain such understandings that know each systems and their internal and external interactions, it was required to practice the new perspective in safety that is Safety-II. The question set presented in Table 7 may yield the same result as it was found in this research. Based on the findings of this research, the questions stated in Table 7 required a shorter dialogs and thus narratives which need less time and resource cost than the full question sets presented in Table 2. Therefore, using shorter question sets will propose an efficient tool of risk assessment for future studies which uses as less as possible resources but presents a great image of the system that is needed to comprehend it (Albery et al., 2016).

Again as it was mentioned earlier in the methodology section, the purpose of this research is not to constitute FRAM models hence it is another project by itself and is out of the scope of this research. Thus, neither the question sets presented in Table 2 nor Table 7 constitute FRAM models. However, the narratives that were developed during the interviews provided sufficient background data that is required to implement a full FRAM assessment. Furthermore, as one of this study's objectives was to investigate the validity of the research conducted by

Albery at al., (2016), an approximately small number of participants were selected in order to maintain the same sample size but in a different industry. Still, this research was conducted in a course of six consecutive weeks hence the process of directing the interviews and data saturating were extremely time consuming. Although, employing a greater sample size needs enormous resources, but it may provide an opportunity for further studies to understand if there is consistency in these research findings by increasing the sample size. The Albery's study and this research both were conducted in manufacturing areas, one in the automotive industry and the other in the electrical equipment productions industry. Further concentration would be on investigation of other industries such as aviation and construction. It may benefit to identify whether the methods could be applied to other industries and the similar findings may arise.

Chapter 6

CONCLUSION

Safety cannot be guaranteed only by reacting based on a simple cause and effect relationships. It is equally important to anticipate, to identify potential new risks, and then to create barriers against them. Westrum (2006) projected a distinction between regular threats, irregular threats, and unexampled events. Regular threats are events that occur frequently and systems could damp them by standard responses. Irregular threats are infrequent events where their total number makes it practically impossible to provide a standard response. Although they are imaginable, they are typically unexpected. Finally, unexampled events are those that are virtually impossible to imagine and which exceed the responders' collective experience. In this research, it was demonstrated that some irregular events cannot be treated by the traditional perspectives. In other words, they cannot easily be described by the linear types of risk assessment approaches such as risk matrices. Indeed, they seem to emerge out of a situation (Hollnagel et al., 2006). Questions inspired by the concept of the FRAM and Safety-II (Hollnagel, 2014) encouraged stakeholders to discover sources of variability within their working systems and by creating such an environment, the adequate data that describe the systems in detail was provided.

It was also found that using this complementary approach, inquiring four sets of questions, can provide a better understanding of systems in which total systems were considered in addition to the hazards and their controls, thus safety and productivity were assessed as one activity. In comparison to risk matrix assessments which only focus on the hazards, their direct consequences and their controls (Albery, at al., 2016).

In reality, workers learn to overcome design flaws, poor planning, and functional bugs because they can recognize the actual demands and adjust their performance accordingly, and because they can interpret and apply procedures to match the conditions. Relating to the responses to the question sets, it was found that in each of the systems investigated, although work-as-done was not very different from work-as-imagined, but they introduced some variabilities which was not distinguishable through the traditional risk assessment, Safety-I/Risk Matrix. Organizational flaws were detected within the responses to the questions which raised the red flags regarding to the dedicated training time before allocating the jobs. As it was noted in literature review section, safety currently exists in the management age and it was demonstrated by numerous studies how organizationally based interventions can improve safety performance or at least the intermediate changes which it will lead to that. Among the organizationally based interventions, training is at the best necessary and a lack of appropriate training may resonate within the systems and result in undesired events (Hale et al., 2010). Lack of training time before starting the job was not an element that can be simply identified by linear approach risk assessment. It means that solutions lie in understanding of systemic resolutions through collaboration with all stakeholders which result in seeing beyond the avoidance of only limited hazards that exist merely in each system.

Furthermore, although the Safety-II approach question sets needed greater resources than traditional risk matrix in order to develop the descriptions of the systems, this perspective absolutely is required in order to enhance the requisite variety because only developed narratives can provide a comprehensive understanding of system performance in the management of variability.

Currently this research is the second study in the field of application of newly proposed perspective in safety, Safety-II. The research was faced with the substantial lack of literature about this topic. The book, Safety-I and Safety-II: The Past and Future of Safety Management, was the only book written by Erik Hollnagel in 2014 about Safety-II and the other related articles were abstractions or shares of this book that were written either by Hollnagel independently or with his collaborations. The researcher assures that the literature review was all-inclusive of the articles about this novel research inquiry, as it was the main obstacle of this study. Additionally, these conclusions are limited to the sample size which was set approximately close to the original study conducted by Albery, et al., (2016) in order to investigate the validation of it in other industries. The findings of this research is also limited to the systems that were selected for this research; however, the presented findings show that other variabilities may exist in all of the other systems that were not investigated. Additionally, based on the findings of this research, it may be beneficial to extend this proposed method to a greater sample size and other industries in order to find whether similar relationships exist in other industries or not.

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Appendix A

The dialogs between the interviewer and interviewees sorted by the objectives of the research

Objective	Interviewees	Responses by the interviewees
Work-as imagined	Production Engineer Responses for the systems 1&2 (MV Assembly, Mold build up/ Casting) with 3 years' experience	• We have general work instruction and control document data base for all the systems (specifically for the new section added to the plant, Outdoor products) but no specific one to describe every details for every single unit. • All major steps are included and the quality documents are inclusive of all the major keys as well. • The prerequisite of starting a job is the need to be trained on a particular station then supervisors should keep the training logs • All changes must go through the engineer change notice data then need to be approved in the house before taking any actions • The current control for limiting the deviations is the things the quality people do but we are trying to create gauges and fixtures to limit mechanical deviations in equipment but it is an ongoing process
	Production Engineer Responses for the systems 3&4 (Cutout Pre and Final Assembly) with 3 years' experience	• Yes. There is control document, general checklists and notes on a control document data base with multiple types based on the units. They are described from start to finish based on the process, components needed and the methods used. • No. Trying to implement a program per station to highlight the key process to help guide employees as they work. (They have got approved but not implemented)

		• On the jobs training. They have made cross training from the other jobs. They have initial for incoming parts. If they pass it constantly they discontinue the inspection. • Deviation are used. If safe, still allow jobs to work but require engineering notices. • All statistical inferences and information is attained through scrap number. They working on investigating equipment trend.
Work-as-done	Worker #1 System 1 (MV Assembly) With 5 years' experience	• The best way is the way we are trained. No deviation I have seen • I had training that is the exact way I am doing now. I have been trained to do multiple jobs. • No force from supervisor to change the process other than the product change • Nothing unpredicted ever happened • I love the way I am doing my job. No recommendation to change anything. • Tools are fit and I think they are good enough • Material are always good and I have no idea to have them differently. • Based on the cleanliness of the material. It is always good. • We ask team leader then if she/he is not available, ask the supervisor. • We have enough time to stop the process but it happens very rarely.
	Worker #2 System 1 (MV Assembly) With 5 years' experience	• She prefers the training methods as the best way doing her job. She would train someone else the same way she got trained.

		• She had never been forced to change something except the unit change which is very normal. • Working procedure changes during the trial. • No unpredicted changes or surprises. • She has nothing to say about the potential improvements. • The tools have some minor maintenance problem but she said it is not a big deal. Some tools are wear out. • She has limited knowledge about the changes in the quality of the materials but she has noticed the changes. • She makes sure everything is done based on she is trained. Nothing than quality other than her normal task. • Yes, they call team leader and supervisors.
	Worker #1 System 2 (Mold Buildup/Casting) With 37 years' experience	• There is a simple training on the computer but it is not good enough. I have got very short training from an engineer when I got hire 37 years ago. • No changes form the supervisors and also no change in the procedures has happened. • I cannot say any real surprises rather than machine errors which happened rarely. • He is happy with the current procedures. • Tools should sometimes have borrowed but most of the time is good. • The quality of the material should be better. I can say the cheaper materials are being used now to cut the costs. • Wherever he gets a problem he intercoms to call some engineer (rarely happens)
	Worker #2 System 2 (Mold Buildup/Casting) With 37 years' experience	• He has always done this job like this and there is no work instruction to follow if someone else wants to do the job. • Training is bad. There is no mentorship and also no shadowing is involved.

		• The leaders are less authorized than them in case of making any change because they are more experienced and have been working at the plant very longer. • No surprise has happened. No shocking event. The surprise would be (not for us) putting different leads into different blocks which may happen if you are new and not very familiar how to do the job • He would add more work space and remove the steel plate at top of the working station in terms of making improvements. • The quality is below average, currently. They use cheap metals to cut the costs. • Tools are good. Everybody has a toolbox and I have no issue with it. • Lots of time they handle the issue on their own but sometimes they call supervisors. • They tag the unit and fix the problem and send it back.
	Worker #1 System 3 (Cutouts Pre Assembly) With 5 years' experience	• The best possible way is the way they were trained. It was on the job training and there is no working instruction. • I have no experience to be forced to change the way I am doing my job. • The machine sometimes has gauge issues but no surprises other than that. • Making the process easier by not taking components apart (She needs to take some parts apart before doing some work on it). • No tools are involved (except that machine). • She has sometimes issues with rivets (doesn't work properly)

		• If everything goes well, it will be nothing to be worry except the shape and cleanliness of the part. • She usually calls coworkers or maintenance (but not supervisor or team leader) in case of seeing problems. • She has enough time to stop the work if she sees a problem, but not happens regularly.
	Worker #2 System 3 (Cutouts Pre Assembly) With 5 years' experience	• The best way to do the job is the same as the training. The training is very close to the best way of doing the job. • The only change is when the product type changes (changes in model/type). • She has never seen anything unpredicted. • She was hired 2 months ago and is very new. She doesn't have enough information about the changes in material and improvements. • The tools are good enough (she doesn't use so many tools). Few tools are needed for her tasks. • Not enough experience to give material information (limited knowledge) • In case of any problem she calls the team leader or coworker. She prefers to not talk to the supervisor directly. • She has enough time to stop the work if anything abnormal happen (doesn't happen so often).
	Worker #1 System 4 (Cutouts Final Assembly) With 5 years' experience	• The best possible way to do the job is the way that she got from her team leader when she moved to this job. • It is close to the training but there is a little difference.

		• She has not been forced to any changes because of the way she is doing the job. • No unpredicted situations happened before (At least I have not seen). • She would change the work set up if she wants to improve her working condition. So she would not have to walk to get the unit to her table. • Tools and materials are good (limited knowledge on material) • If there is a problem, she calls the team leader. She has time but not enough because the process is always is going (It doesn't happen often)
	Worker #2 System 4 (Cutouts Final Assembly) With 5 years' experience	• The way that she was trained is the best way of doing the job. • The training is so close to the best possible way of doing the job. • They update and change parts but it is rare and the whole process is always the same. • The supervisor only changes the procedure when orders are changed. • She would change the way the parts come to her to avoid heavy lifting and long walks. It helps to be faster and save time. • Tools are good and she has no complaints about the tools.

<table>
<tr><td></td><td></td><td>Sometimes squares (the brackets in the units) break and causes to reject the unit. She thinks the quality of squares can be better.
She calls the team leader for big issues but small ones are handled by coworkers (problems are rare)
She has limited time to get the problems solved but she is allowed to do that.</td></tr>
<tr><td rowspan="4">Risk Matrix/ Safety-I</td><td>Worker #1

System 1 (MV Assembly)

With 5 years’ experience</td><td>Cuts, scratches, bumping the head on the hanging equipment. I have minor ergonomics muscle issues but I have had it from my another job.
Low
Likely
Only controls are work station design and mandatory PPE.</td></tr>
<tr><td>Worker #2

System 1 (MV Assembly)

With 5 years’ experience</td><td>Cuts and scratches. EHS knows about and they are good in keep up with caring stuff.
Low
Possible
Controls are: house-keeping and PPE</td></tr>
<tr><td>Worker #1

System 2 (Mold Buildup/Casting)

With 5 years’ experience</td><td>Pinch points when using automatic tools, cuts and scratches. yeah, EHS has recognized what is going on here.
Medium
Unlikely
PPE, Crane for lifting</td></tr>
<tr><td>Worker #2

System 2 (Mold Buildup/Casting)

With 5 years’ experience</td><td>Cuts, pinches, tool injuries are the most common hazards
Low
Unlikely
Basic PPE and the crane</td></tr>
</table>

	Worker #1 System 3 (Cutouts Pre Assembly) With 5 years' experience	• She sees no uncontrolled hazards. The machine is equipped with the double-bottom control switch in order to prevent crush hazards • Low • Unlikely • The control is the double-bottom control switch
	Worker #2 System 3 (Cutouts Pre Assembly) With 5 years' experience	• Fibers get into the gloves and makes scratches. It is not recognized by the EHS team. • Low • Likely • PPE
	Worker #1 System 4 (Cutouts Final Assembly) With 5 years' experience	• She is happy with safety and not see any uncontrolled hazards. • Low • Unlikely • Controls are PPE (gloves and goggles)
	Worker #2 System 4 (Cutouts Final Assembly) With 5 years' experience	• Heavy lifting, cuts, pinches and hammer/drill injuries are the hazards. • Low • Unlikely • Controls are PPE and drill/driver ergo hanging rope.

FRAM/ Safety-II	Worker #1 System 1 (MV Assembly) With 5 years' experience	• No changes within the 5 years has happened. I cannot say any major change. • No knowledge of process of hiring and how often they change the employees. But the turnover is very low (there is people have been working since 1970's). • When the coils won't connect/fit and physical defects on materials are found. • Most common is the coil is not connected. • Yes, we are always being encouraged to stop the work by the supervisors if there is unusual. • She stops work, meet with team leader and have discussion. • Based on the severity. Mostly the problems are fixed in the same day but sometimes it takes longer.
	Worker #2 System 1 (MV Assembly) With 5 years' experience	• Changes are once a month but it is very minor. • No selection process is out there to elect the new employees. I was told to do this job and the training was just on the job and very short. The turnover is very low. At least I cannot say that. • When the serial number don't match, when the padding is messed up, when the coils don't match and when the sleeves are left off. • Sleeve (small metal at the bottom) left off is the most happened one. • We are being encouraged to stop the work when adjustment is necessary. • We handle the unusual events by stopping the work and going to the team leader and discuss the issue. • Depends on the severity. Most of the times, on the same day.

	Worker #1 System 2 (Mold Buildup/Casting) With 5 years' experience	• Process doesn't change. • For this area supervisors hire higher men typically and if someone wants to take my job, the training process will be up to 4 months. • We reject the units when they have tickets, serial number or bad terminals issues. • The most common is bad terminal issue. • We all have the power to stop the process (only three persons do this job). • The unpredicted issues are solved based on the severity. We either handle the situation by ourselves (most of the times) or call the supervisor. • Typically, same day or few days but when engineers are involved it takes longer.
	Worker #2 System 2 (Mold Buildup/Casting) With 5 years' experience	• The process has been always the same and there are no changes except few changes in the workstation design because of the changing the layout of the plant. • The training procedure is so bad. There is no selection based on the mechanical skills. They only hire based on the physical abilities. Also turnover is low • When making mistake in the selection of the molds. Each unit has specific mold that should be used for casting. Physical damage and wrong serial numbers are the next problems. • Physical damage and serial number issues are the most common causes.

		• They are allowed to stop the work in case of failure detection. • They handle lots of issues by their own but if there is something. with machineries, they call maintenance. • Few minutes or same day. But major problems take days.
	Worker #1 System 3 (Cutouts Pre Assembly) With 5 years' experience	• Only changes that have been happened are in products. Such as tube changes. • She came from another line and got training in few minutes. So the training is very short and easy. • She thinks the turnover is very low. • Units are rejected when blades or pins are damaged. • Pin damage is the most common on.e • She has the power to stop the process. • She prefers to handle unexpected situations by maintenance and coworkers. She rarely goes to the supervisor for the technical problems. • Problems are solved very quick, like one to three hours.
	Worker #2 System 3 (Cutouts Pre Assembly) With 5 years' experience	• The changes in the process happen when the types of units change. • Her training was just one day. She is very new but she thinks turnover is low. • She has been trained to reject units whenever she sees rusts, holes and deformities on the parts. • The most common reason to reject is rust. • She knows that she has the power to stop the process when a problem pops up. • When she sees a problem she handles the situation by stopping the work and getting the team leader.

		• Most of the problem are solved at the same day, as far as she knows.
	Worker #1 System 4 (Cutouts Final Assembly) With 5 years' experience	• She cannot call it change in the process because units and products change all the time and it is part of the process to have different types of units assembled. • She has not had any particular skills for this job and she just placed at this position. • Training was two weeks before starting this job. She was at an easier job before starting this job. • The turnover is low for this department. • Rejections come from rust and tarnished spots. • Rust is the most common. • Unexpected situations are being handled by stopping the work and going to the team leader. • Problems are solved at the same day and she would say pretty quick most of the time.
	Worker #2 System 4 (Cutouts Final Assembly) With 5 years' experience	• Changes on units happen multiple times per day. • She got to this position from another position and the training was only one week (on the job training). She thinks the whole area has low turnover. • Rejections come from rust, missing contacts and chipped tubes. • The most common reason that makes to reject a unit is rust.

		• She has the power to stop the process in case of a problem. • She stops the process and call a coworker or a team leader for unexpected situations. • Small problems are solved at the same day while big issues take couple of days (never longer than one week).
	Quality Engineer #1 Responses for the systems 1&2 (MV Assembly, Mold build up/ Casting) With 5 years' experience	• Lots of old designs from 1980s and prior that. The process changes occur annually at a minimum. • Training should be more detailed. They just see who "catches on" and quick then hanging them to get trained. • The overall turnover at the plant is high but in assembly is not too bad. • Units are being rejected based on the preliminary testing and workmanship at nearly all stages before to catch molding and final stages. surface voids and soft mix are other issues. • Partial discharge failure, over voltage test failure and insulation test failure are the most common issues. • Has hazards at all stages but main one is cut and the dropping product. Mold release spray cans usage and there is no ventilation (It is supposed to brush it on) • We are trying to implement FMEA studies at the design stages before addition or changes in new equipment happen. • Yes. Stop the line on situational basis (severity) • By ensuring all important people involved immediately to troubleshoot the problem.

		• Depends on severity. Try to solve in a day but sometime few months. Put some temporary fix to solve it systematically.
	Quality Engineer #2 Responses for the systems 3&4 (Cutouts Pre and Final Assembly) With 5 years' experience	• They practice continuous improvement so it is always changing. • They hire from temp agencies and distribute from physical capabilities and background. No established training but supervisor do it by their own. • External hardware damage, terminal breaks are also the main causes. • The largest major cause is the breaking parts during the assembly. • Heavy lifting, pinching and repetitive motions. They are recognized (with thinking). • They work with manufacturing engineers to study new equipment and perform risk assessment prior to any changes. • Every operator has the power to stop the process and all the equipment have e-stop. • They expect immediate notification and they follow the four Q methodology to determine route causes and they attain corrective action request which call it CAR (has to be made and track). • Depends on severity a day or a month (data collection slows the process).
	Supervisor #1 Responses for the systems 1&2 (MV Assembly, Mold	• There are no real changes other than minor batch to batch changes (no big changes). • They use temp agencies then interview the people are sent to them. They look for hands on skills

	build up/ Casting) With 5 years' experience	• No set training time. They start from easier and safer jobs then progress on harder job. • No high turnover for his areas. • They rejected for static issues and test parameters. • Most common reason is partial discharge (the reason is unknown) • Not a lot of repetitive motion. Heavy lifting is the only big risk • EHS review new equipment and it has to be approved by multiple people prior to any changes (the name of it is "change in process") • He and all the employees have the power to stop the process • Manage the unexpected situations: is based on severity and the area of the job. Usually EHS and engineering handle the situation. • Most of the time it takes 4 to 5 hours to fix a problem (same day).
	Supervisor #2 Responses for the systems 3&4 (Cutouts Pre and Final Assembly) With 5 years' experience	• No real changes. Material stored in the warehouse at somewhere outside of the plant • Goes through temp agencies. Look for fast pace team player • Non skilled workers: two days – skilled workers: one month • Turnover is very low. • Rejection: static and physical issues. • Most common: cracked porcelain. • Hazard: organization and housekeeping due to limited space (he did not mention to repetitive motion). • Not have to deal with potential change hazard. They manage through the other facility (Lake Marry in Florida) to get to know their needs.

		• He and all employees have the power to stop the process (never for safety but quality a lot). • He has certain people in different departments to manage unexpected situations. • Problems are solved mostly at the same day.

Appendix B

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
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Office: 252-744-2914 · Fax: 252-744-2284 · www.ecu.edu/irb

Notification of Exempt Certification

From: Social/Behavioral IRB
To: Hamidreza Shaki
CC: Michael Behm
Date: 9/19/2016
Re: **UMCIRB 16-001663**
Evaluating effectiveness of the application of the new perspective in safety, Safety-II, by Functional Resonance Analysis Method (FRAM) in a manufacturing environment

I am pleased to inform you that your research submission has been certified as exempt on 9/16/2016. This study is eligible for Exempt Certification under category #2.

It is your responsibility to ensure that this research is conducted in the manner reported in your application and/or protocol, as well as being consistent with the ethical principles of the Belmont Report and your profession.

This research study does not require any additional interaction with the UMCIRB unless there are proposed changes to this study. Any change, prior to implementing that change, must be submitted to the UMCIRB for review and approval. The UMCIRB will determine if the change impacts the eligibility of the research for exempt status. If more substantive review is required, you will be notified within five business days.

The UMCIRB office will hold your exemption application for a period of five years from the date of this letter. If you wish to continue this protocol beyond this period, you will need to submit an Exemption Certification request at least 30 days before the end of the five-year period.

The Chairperson (or designee) does not have a potential for conflict of interest on this study.