A METHOD TO DETERMINE THE EFFECTIVENESS OF THE APPLICATION OF THE INVESTIGATION PROCESS FOR ELECTRICAL INCIDENTS

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DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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ABSTRACT

This study examines the *application* of the investigation process in industry to reduce electrical arc flash incidents. Literature indicates that three streams (policies, completed investigations and investigators) influence the application of the investigation process; however, these are traditionally analysed independently without examining the dynamic influences between them. This study combines and analyses those dynamic interactions, and testing at a steel plant demonstrates that this approach allows industry to identify site specific deficiencies.

The investigation process requirements, identified in literature, were used to qualitatively and quantitatively analyse the three streams. The results were interpreted using triangulation. Deficiencies around disseminating reports and using experienced investigators were identified. These plant specific deficiencies are an improvement from generic findings in literature. This study contributed to knowledge in the field of incident investigations by proposing a holistic approach that is operationally ready, and identifies deficiencies specific to the industry in which it is used.

To the families

who have suffered

due to

electrical injuries

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LIST OF ABBREVIATIONS

Alternating Current	AC
Cause and Effect Diagram	CED
Direct Current	DC
Electricite de France	EDF
Events and Causal Factors Charting	ECFC
First Aid	FA
Hazard Identification and Risk Assessment	HIRA
Human Factors	HF
Institute of Electrical and Electronic Engineers	IEEE
Kaiser-Meyer-Olkin	KMO
Lost Time Injury	LTI
Mine Safety and Health Administration	MSHA
Minor Injury	MI
Original Equipment Manufacturers	OEM
Personal Protective Equipment	PPE
Post-Traumatic Stress Disorder	PTSD
Principal Component Analysis	PCA
Subject Matter Experts	SMEs
Systematic Cause and Analysis Technique	SCAT
United Nations International Children's Fund	UNICEF
United States of America	U.S.

1 INTRODUCTION

This research aims to further knowledge in the field of electrical incident investigations by determining the effectiveness of the *application* of the incident investigation process. This chapter introduces electrical arc flash incidents and explains the investigation process and its application in industry. Some limitations pertaining to existing literature on the application of the investigation process are discussed and a method to address such limitations is proposed. The chapter concludes with the organisation of this study and a summary of the chapter.

1.1 Electrical Arc Flash Incidents

Electrical incidents, especially those around electrical arc flash, are a global phenomenon injuring thousands of workers, with lifetime reported costs of up to $12.8 million US Dollars (Floyd II, 2008). Arc flash incidents also result in a loss of revenue through equipment damage and production interruptions. These incidents are prevalent globally, injuring several hundred workers in industry (Mashreky, et al., 2012) (Cawley, 2003). Further details pertaining to arc flash incidents, such as the number of victims, costs, and the protracted impact of such incidents, are detailed during the review of literature in the next chapter.

Not much can be done after an incident has occurred other than learning to prevent a recurrence. It can be claimed, however, that learning from incidents can be challenging since most root causes remain deeply veiled in complex organisational structures and multivariate, nonlinear processes. It is for this reason that organisations follow a comprehensive incident investigation process to allow for learning through experience (Saleh & Pendley, 2012).

1.2 The Investigation Process and Application of the Process

The incident investigation process identifies weaknesses in the organisational management system that lead to harm or loss, and facilitates improvements through remedial actions (Pham, et al., 2010) (Vincent, et al., 2000). Such remedial actions are paramount to preventing recurrent accidents (Chua, et al., 2004), to the extent that incident investigations are regulated by law. The South African Occupational Health and Safety Act, 1993 (Act No. 85 of 1993), General Administrative Regulations, 2003 requires that (in the event of certain incidents) an investigation shall be performed. Clause 9 (2) stipulates that incidents "*shall be investigated*" and, clause 9 (4) stipulates that actions "*are implemented and followed up to prevent the recurrence of such incident*".

The incident investigation process consists of several steps that generally include: describing the details of the incidents, collection and chronological arrangement of information, analysis of the information using an investigation technique[1], developing remedial actions, implementing and testing such actions, and a final review of the process (Jørgensen, 2011). Incident investigations are required to follow this predefined process (Alonzo, 2003).

The investigation process is a theoretical model, while the *application* of the investigation process is a practical model that is specific to the industry in which it is used (Ferjencik, 2011). The *application* of the investigation process is dependent on three streams within an organisation. These are the organisational policy governing the investigation process, the investigators performing the investigations, and records of completed

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[1] Investigative techniques facilitate the analysis of the raw incident data to provide corrective actions (Katsakiori, et al., 2009) (Lehto & Salvendy, 1991). Examples include, the Cause and Effect Diagram, 5 Whys, Event Tree and Fault Tree Analysis, Systematic Cause and Analysis Technique, amongst others. Investigation techniques form an integral part of the investigation process.

investigations (Jooma, et al., 2016a). These three streams are briefly discussed next, followed by a more detailed discussion in the next chapter.

Firstly, the organisational policy on incident investigations governs the application of the investigation process. The work that best describes the evaluation of the organisational policy was performed by Lunderg, et al. (2009). It was an evaluation of eight organisational polices against requirements of the investigation process found in popular literature (Lundberg, et al., 2009).

Another stream in the application of the investigation process is the investigator or investigation team. The influence of the investigators is addressed in a 2008 survey of 108 investigators (Rollenhagen, et al., 2010). The author used generic investigation process requirements to draft the survey questions, however, the survey leaned towards the investigators' experiences and their specific ways of investigating.

The next stream in the application of the investigation process is the study of completed investigation records; several examinations of such are presented in literature (Le Coze, 2013) (Pham, et al., 2010) (Saleh, et al., 2010) (Phimister, et al., 2003). Each of these references provides valuable, but specific, lessons from a particular investigation, such as the need for engineering controls, maintenance management, and management control through balancing production and safety (Jooma, et al., 2016b) (Deepwater Horizon Study Group, 2011) (Ferjencik, 2011) (Blair, 2004) (Amyotte & Oehmen, 2002).

Comparing the summary of the investigation process theory to the summary of the practical application of the process, it is clear that the two are materially different. With the aim of this study being the application of the process, the focus shifts to the summary of the three streams discussed above.

1.3 Problem Statement

The three streams in the previous section present certain limitations to the end user in industry that may influence the effectiveness of the investigation.

Firstly, the review of literature indicates that the three streams have been presented and examined independently of each other in literature. There is no literature that has combined the three streams to examine the interaction and mutual influences among the three streams. In addition, the evaluation of each stream in literature is presented as a checkbox (one-dimensional) compliance inspection, which does not explain the dynamic, three-dimensional, interactions between the elements in the system. Such multidimensional influences are more important to understand and address in complex systems than checkbox type (yes/no) one-dimensional inspections (Ee, 2010).

Secondly, each independent study of the three streams provided generic conclusions, which may or may not be a problem to a specific industry. Hence, the existing literature is unable to provide industry with guidance to comment on the effectiveness of the application of their *specific* investigation process.

Industry end users may not have the expertise to combine the three streams, limiting their ability to determine the effectiveness of the application of the investigation process, as a whole, specific to their industry.

1.4 Research Aims and Research Question

This research aims to build on existing literature by studying the dynamic influences among the three streams to identify site specific deficiencies in investigations. In order to examine relationships across the three streams, each stream is first evaluated to common criteria, consisting of the investigation process requirements. These evaluations are performed using a combination of qualitative methods and quantitative methods. Then, the results from the first evaluations are interpreted using a triangulation research method. If the findings across the three streams are convergent, then the holistic approach proposed is successful and can be used in industry. If the findings are divergent, deeper examination of the information may be required or it may be possible that the approach is not working.

It is hypothesised that combining and evaluating the dynamic interactions of the three streams in industry allows for evaluating the effectiveness of the *application* of the investigation process. This leads to the research question, which is then:

> **Can evaluating the three streams in which the investigation process is applied against a common set of requirements determine the effectiveness of the application of the investigation process?**

A steel plant in South Africa was considered as a case study, mainly due to the researcher having access to the investigation policies, completed investigations and the investigators involved in the process[2]. Although several findings were obtained, the study presents only the top three findings to demonstrate that the process works. Once deficiencies were identified, recommendations for improvements were provided, but such recommendations are to be considered supplementary and not the core focus of this research.

1.5 Organisation of this Study

The remainder of this dissertation is presented as follows:

Chapter 2 - Literature Survey. This chapter focusses on establishing prior work in the field of incident investigations. It aims at introducing the subject, identifying existing research and possible gaps (which should be addressed by this research) and provides the vocabulary used in the research area. It defines the investigation process requirements. Part A of the chapter is

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[2] Researcher bias is addressed in Chapter 3.

dedicated to the investigation process whilst Part B introduces investigation techniques commonly used in industry (a more detailed discussion of the investigation techniques is available in Appendix A).

Chapter 3 – Research Methods. The research methods chapter establishes the research procedure and defines the research design. The qualitative, quantitative and triangulation methods are discussed. It explains how the hypothesis is tested in a manner that facilitates repeatability of this research. The research protocol explains the case study plant, samples and sampling, and the investigator survey. The chapter concludes with a section on the data analysis.

Chapter 4 – Results and Discussions. The results of the analysis of the organisational policy and completed investigations are presented and discussed. The results from the survey of the investigators are presented using descriptive statistics. The results from the three streams and the discussions are then amalgamated to demonstrate the triangulation research method. The three main findings from the case study plant are presented: the lack of Subject Matter Experts in the investigation, lack of experienced investigators and a lack of dissemination of completed investigations.

Chapter 5 – Recommendations and Conclusion. This chapter revisits the aim of the research, presents limitations of the research, offers recommendations to address the limitations and summarises the findings. The research question is answered and the chapter concludes.

Four white papers were published from this research and are included in Appendix D. These published materials are referenced in this research.

1.6 Summary

This section introduces electrical incidents and investigations as a means to reduce the prevalence of such incidents. Evaluating the effectiveness of the application of the investigation process can address recurrent arc flash incidents.

The investigation process is a theoretical model, while its application in industry is a practical model. This practical application of the investigation process occurs through three streams, each of which is examined by independent studies in existing literature. The three streams are not combined and evaluated against a common evaluation criterion; as a result, the complex interactions and mutual influences of the three streams are not examined. Also, the findings in literature present generic problems that may or may not be applicable to a particular industry.

These gaps create an opportunity to build on existing literature and contribute to knowledge by combining and examining all three streams against a common evaluation criterion, being the investigation process requirements. This allows industry to comment on the effectiveness of the application of their specific incident investigation process. Identifying deficiencies specific to their plant is considered more beneficial than the generic deficiencies identified in existing literature.

A review of existing literature is the focus of the next chapter. Arc flash incidents are examined in more detail, with the aim of justifying the need to advance knowledge in the field of incident investigations. Existing literature is reviewed to establish the investigation process requirements. A select number of applicable investigation techniques are also discussed.

2 LITERATURE SURVEY

2.1 Introduction

This chapter reviews literature related to the taxonomy of the investigation process as well as the application of the investigation process. It presents the generally accepted vocabulary and in identifying existing research allows for maintaining a focussed research approach. Arc flash incidents are revisited before a detailed discussion on the investigation process is presented in Part A. An integral part of the investigation process is the investigation technique, which is covered in Part B (section 2.3), followed by a summary of the chapter.

2.2 The Universality of Electrical Incidents

An electric arc is the formation of plasma through the ionisation of an insulating medium around a conductor. The ionisation is a result of external influence (e.g., dropping a conductive tool across a copper bus) or internal influence (e.g., failure of a circuit breaker to extinguish an arc whilst switching). The resultant plasma acts as a short circuit in the electrical system. The plasma produces very high temperatures which can lead to fatal burns to personnel combined with unsafe exposure to noise, light and hot gas inhalation. It can also result in substantial damage to the electrical apparatus (Clark, 2013) (U.S. Department of Labor, 2011). Having established that electrical incidents result in harm to people and damage to equipment, it is important to understand whether this is a localised or global phenomenon.

Arc flash and shock incidents appear to be well documented in the United States. During a 10-year period ranging from 1990-1999, the United States Mine Safety and Health Administration (MSHA), utilising compulsory incident reporting data, reported 1926 electrical accidents including 75 fatalities (Cawley, 2003). Burns accounted for 65% non-fatal and 7% fatal injuries whilst shock accounted for 24% non-fatal and 93% fatal injuries. The number of lost working days peaked at 31 for electrical shock and 21 for electrical burns. The medical costs of such electrical injuries are estimated at approximately $21,000.00 per incident while the lifetime medical costs for severe cases could reach $12.8 million (Floyd II, 2008).

Electrical incidents have also been reported in Europe and Asia. In 2003, a UNICEF funded study in Bangladesh and Dhaka showed that of 604 non-fatal electrical injury patients, 282 suffered from temporary disabilities for varying periods (Mashreky, et al., 2012). In Iran, 202 patients were admitted to a hospital in Tehran with electrical injuries between March 2011 and June 2012. Severe complications required limb amputations and fasciectomy (Salehi, et al., 2014). In the ten-year period between 1996 and 2005, Electricite de France (EDF) reported 311 electrical injuries. Physical injuries as a result of burns were indicated as the most prevalent while neurological symptoms such as Post-Traumatic Stress Disorder (PTSD) were second most prevalent. The EDF study authors recommended the need for specific psychological management after physical recuperation (Piotrowski, et al., 2014).

Arc flash related fatalities also occur in South Africa (Pistorius, 2009). Data over the period 2001-2004 showed 126 electrical (non-lightning) related fatalities with 91 cases involving low voltages and 35 involving high voltages (Blumenthal, 2009). It is not only factories which are exposed to electrical safety risks; the mining sector also experiences electrical incidents. The South African coal mining sector, for example, experienced 234 incidents directly caused by electricity between 1984 and 1993 (Phillips & Landman, 1994). These incidents were not categorised into burn and shock events. Apart from harm to workers, equipment damage and loss in productivity, indirect influences such as reputational harm are possible. These typically occur when organisations are implicated in safety related legislative proceedings. Electrical injuries involving the South African power utility Eskom have been defended in the South African Supreme Court. These include Eskom Holdings Ltd versus Hendricks (Supreme Court of Appeal - SCA 262/2004) and Hendrik Johannes Pitzer versus Eskom (Supreme Court of Appeal ZASCA 44 [2012]). More recently, in South Africa, news sources have reported:

"*The transformer burst and started releasing huge flames, burning him in front of the onlookers* " (Khomo, 2015)

"*Two firefighters who died from severe smoke inhalation were trapped after an explosion … the fire started in the basement with the transformer...* " (News24, 2015)

"*One man died and three others were seriously injured when a transformer exploded in Rosslyn … paramedics found two of the workers sustained more than 80-percent burns to their bodies, and one sustained 30-percent burns. A fourth worker suffered from inhalation burns. Tragically one of the men died soon after his arrival at hospital due to the extensive injuries that he had sustained* " (SAPA, 2010).

Pictures from incident investigations convey the gruesome reality of electrical arc flash incidents. Two pictures from investigations in South Africa are shown as Figure 2.1 and Figure 2.2. In addition to the pain and suffering from electrical arc flash exposure, there is also the cost of medical expenses. The medical costs of electrical injuries and associated equipment damage can cost several million dollars.

Figure 2.1 Arc flash burns from an incident in 2010[3]

Figure 2.2 Victim in high care from an incident in 2009[4]

[3] Used with permission from the injured and the employer. Victim made a full recovery. Source of picture protected under a confidentiality agreement.
[4] Used with permission from the victim's family. Victim deceased. Source of picture protected under a confidentiality agreement.

Equipment damaged from an electric arc as shown in Figure 2.3 had to be replaced. Personal injury and equipment damage combined with production losses warrants the need to reduce the prevalence of arc flash incidents.

Figure 2.3 Electrical arc flash on a Low Voltage Distribution Board[5]

An incident is defined as an undesired outcome based on an action, event or occurrence (U.S. Department of Energy, 2012). It is made up of an "accident" and a "near-miss" or "near hit" event. A near-miss or near hit event is one which has a potential to result in loss or harm, whilst an accident is an event which *has* resulted in harm or loss (Phimister, et al., 2003). Incident investigations are a reconstruction of the events surrounding an incident in order to learn and prevent recurrence of such incidents (Lundberg, et al., 2009). Learning can be achieved through disasters like Chernobyl and Piper Alpha (Saleh, et al., 2010), or from smaller incidents such as a trip and fall (Jørgensen, 2011) and near-miss events (Phimister, et al., 2003).

[5] Used with permission from the case study plant. Source of picture protected under a confidentiality agreement.

The knowledge gained from incidents produces actions that are implemented in the safety management system and result in improved safety (Chua, et al., 2004). The corollary is, then, that if the investigation process is not applied effectively, learning is inadequate, ultimately resulting in recurrent incidents (Salmon, et al., 2014). This creates the need to critically analyse the application of the investigation process.

2.3 The Application of the Investigation Process

Literature has indicated that work which aims to study the effectiveness of the application of the investigation process does exist. The three streams used to determine the effectiveness of the application of the investigation process consist of the analysis of the **investigation policy** (Lundberg, et al., 2009), the analysis of **completed investigations** (Nicolini, et al., 2011), and finally the **survey of investigators** (Rollenhagen, et al., 2010).

In the previous chapter, organisational policies was introduced as a stream to test the application of the investigation process. A study of organisational policies from eight large organisations was performed in Sweden (Lundberg, et al., 2009). These included organisations such as rail, maritime, civil, and nuclear. In the study, the evaluation of the organisational policies was based on investigation process requirements considered important to authors in the safety community and investigation practitioners. These investigation process requirements included initiating the investigation, data collection, analysis of the data, recommendations, remedial actions, reporting and close-out. The authors, however, claimed that the evaluation criteria were not complete.

The main conclusion is that the policies focussed on linear investigation techniques. Thus, management systems became a stronger focus at the expense of findings closer to human control aspects, which may then be overlooked. Instead, the authors recommend the use of nonlinear models that are able to balance findings from operations to management systems. Another notable observation was that recommendations and remedial actions were not as well developed as the mechanistic processes of collecting evidence and writing the report. These observations are important aspects of the investigation process and should be examined as part of this chapter.

Another stream was the examination of records from completed investigations, commonly expressing the theme of learning from past experiences. Le Coze (2013) explains that learning from disasters in diverse industries is of pivotal importance. Beyond the technical and organisational learning on how to prevent a disaster, the author argues that learning from the past may lead to improvements in (industrial) psychology, sociology, and politics (organisational and legal), amongst other socio-technical systems and role players (Le Coze, 2013). Phimister's (2003) extensive work, somewhat different from Le Coze's, focusses on near-miss learnings instead of learning from disasters. The work was performed in the chemical and pharmaceutical arena, and led to the development of a seven-stage framework that relied extensively on the investigation process. Saleh (2010), however, provides a different route to support the "learning from the past" concept. The work proposes that using past learning to undertake a probabilistic risk assessment promotes improved resilience to incidents. A similar approach was adopted much earlier using the Westray coal mine disaster that occurred in May 2002, as Amyotte (2002) used public domain resources to learn from the Westray disaster. The author provided technical, operational and management system improvements (Amyotte & Oehmen, 2002). Finally, Nicolini (2011) demonstrates how studying completed investigations across business units identifies gaps which would otherwise go undetected. Some of these gaps were the need for a more comprehensive training program for all role-players in the investigation process and the need for independent investigators (Nicolini, et al., 2011). Although the literature supports the need for industry to learn from records of completed investigations, it is observed that the evaluation criteria did vary between the different studies.

The other stream introduced was the influence of the investigator on the application of the investigation process. In 2008, a major study focussing on investigators was undertaken with the aim to support investigators through training and seminars (Rollenhagen, et al., 2010). A survey of 108 investigators who were experienced in nuclear, healthcare, transportation, and rescue services, amongst other disciplines, was administered. The survey utilised a questionnaire that contained both open questions and free text for the investigators to complete (Rollenhagen, et al., 2010). The evaluation criteria were based on the investigators' background, the investigators' understanding of the process, preferred investigation techniques, opinion on perceived causes of incidents and opinion on the close-out phase of the investigation. Although Rollenhagen, et al. (2010) claim that the evaluation was based partly on the work performed by Lundberg, et al. (2009), the focus of the two studies was different. Rollenhagen, et al. (2010) focussed on the investigators' viewpoint on salient aspects of the investigation process, while Lundberg, et al. (2009) focussed on specific investigation process requirements.
The main conclusions were that investigators should be trained on the overall investigation process instead of focussing only on the investigation techniques, facilitate networking to broaden the investigators' field of experience, and develop stronger recommendations and action implementation.

Although each of the works in the three streams presented above contributes to the advancement of knowledge, each piece of work is independent of the other and each is evaluated against a different set of criteria. Practically, within an organisation, a weakness in any one stream may render the application of the entire investigation process ineffective. Therefore, all three streams should be considered and evaluated as mutually dependent. However, it is not possible to simply integrate all three streams from literature due to the differing evaluation criteria used for each stream. A common set of evaluation criteria is required. The rest of this chapter aims at developing such a comprehensive evaluation criteria based on the requirements of the investigation process. Part A of this chapter studies literature in order to identify the investigation process requirements that will be used, as a common basis, to evaluate the three streams. Part B of this chapter then examines investigation techniques to supplement Part A.

PART A

2.4 The Investigation Process

Now that the three streams through which the investigation is applied have been identified, the investigation process is introduced. The investigation process requirements will serve as the evaluation criteria for determining the effectiveness of the application of the investigation across the three streams. Before proposing an evaluation criteria, however, it is important to ensure that the global investigation process requirements are aligned; otherwise, the applicability of this work may be limited.

The investigation process, according to Lundberg, et al. (2009) of Sweden, consists of the following steps:

- Initiation – what types of incidents require further investigation
- Planning – timelines and resource planning. Collecting the relevant data pertaining to the investigation
- Data collection - from people, systems and site. Could include simulations and experimentations
- Representation – arrangement of data pertinent to the investigation. The investigation technique is used at this stage
- Analysis – builds on the representation phase by bringing all the information together and formulates the story line or reconstruction of the incident
- Recommendations – produce actions which aim at addressing the findings from the reconstruction

- Documentation – provides the detailed investigation report. The report is circulated for review
- Decisions – once reviewed and approved, the implementation of actions should be enforced
- Conclusion – follow up on the effectiveness of the implemented actions

The CHAIN model (chain of accident investigation steps), proposed by Lindberg, et al. (2006), also in Sweden, is well aligned to the Lundberg, et al. (2009) model. The six-step CHAIN model consists of initial reporting, selection of incidents requiring further investigation, the investigation process using investigation techniques, the dissemination of results, implementation of preventative measures, and the post-implementation evaluation step. A similar six-step investigation process was presented by Ferjencik (2011) in the Czech Republic.

Research produced in Denmark by Jørgensen (2011) describes the salient investigation process for near-miss incidents and incidents with simple or trivial consequences. These align strongly with the research from other countries by maintaining the same process requirements:

- Investigator or investigation team – the minimum experience and qualifications of the investigator and the members within the investigation team must be clearly defined
- Mapping phase – an information gathering phase which must take place as soon as practically possible
- Analysis phase – the analysis of data using established investigation techniques
- Preventative phase – the prioritisation and execution of corrective actions as well as a review of prior investigations or actions

It was observed during the literature review that research published in France by Le Coze (2013) aligned closely with the investigation process requirements already presented. Four aspects consisting of reporting, competence of the investigating team, analysis using an investigation technique, and the post-action implementation step of organisational improvement were discussed.

When examining research beyond Europe, the United States Department of Energy handbook titled *Accident and Operational Safety Analysis* (2012) was analysed. The second chapter of the handbook focusses on the investigation process, which includes organising and managing the investigation, data collection, analysis of the data, establishing preventative actions, reporting, and a close-out phase consisting of verification analysis and a quality review. Other literature examined from the U.S. was *Lees' Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control* (Mannan, 2014). This literature refers to four stages in the investigation that include the identification of what happened and how it happened (data collection), why it happened (data analysis), how to prevent it (findings and recommendations) and implementation of improvement actions.

The literature demonstrates that the investigation process requirements are consistent from one country to another. It is important to establish such a commonality before proceeding to define the investigation process requirements, as it facilitates referencing of works without limitations based on the origin of the literature.

The investigation process requirements are now examined in detail. Such detailed requirements pertaining to the investigation process are enshrined in an organisational policy regulating incident investigations (Chua, et al., 2004). The organisational policy also promotes standardisation and prevents varying interpretation of the process by different individuals (Ishikawa & Lu, 1985). The organisational policy was thus chosen as the starting point.

To keep track of the investigation process requirements, each requirement was underlined and italicised as it was identified. The investigation process requirements were then consolidated in Table 2.1 at the end of Part A of this chapter.

2.4.1 Standardisation of the investigation process

A system to ensure that incidents are investigated thoroughly should exist (Mannan, 2014). Such a system would ideally reside in an organisational policy that forms part of the global safety management system. The organisational policy should describe the following in detail (Le Coze, 2013) (U.S. Department of Energy, 2012) (Jørgensen, 2011) (Lundberg, et al., 2009):

a. The types of incidents which require investigating (this would generally include all incidents, but exceptions could exist)
b. The role players in the investigation process (investigating team, organisation, Subject Matter Experts, injured, etc.) and the expectations of each role player (training, readiness, resource planning, etc.)
c. *What* happened (the actual incident with precursors and consequences guided by the investigation technique, raw data, and human factors – the *what* aspects)
d. *Why* the incident happened (the investigation technique, management systems, and human factors – the *why* aspects)
e. The preventative measures (actions to address the findings, consider information from other investigations or actions, review, etc.)
f. Dissemination and communication (roll out the actions, communicate with all role players)
g. Regulation (test for effectiveness, audit the investigation, address improvements to the investigations policy)

The organisational policy on incident investigations is a pivotal component of the investigation process. As such, the policy itself should be audited periodically to determine gaps or areas of poor compliance or non-compliance and the reasons for such (Amyotte & Oehmen, 2002) (Ishikawa & Lu, 1985).

The next sections elaborate on items 2.4.1 (a) – (f) in more detail in order to determine the specific requirements of the investigation process.

2.4.2 Incidents requiring investigation

Reporting of Reporting is widely accepted as the first stage in initiating an investigation (Lindberg, et al., 2010). Reporting of incidents is noted across a range of countries such as the United Kingdom, United States, Australia, Switzerland and South Africa and in diverse fields ranging from medical, maritime, and aviation to steel industries (Vincent, 2014) (International Labour Organization, 2005) (General Safety Regulations Gazette No. 929, 2003) (Rothblum, et al., 2002).
Deviations from detailed reporting or the absence of a system for reporting has resulted in serious incidents such as the train derailment in India in 2010 (Kim & Yoon, 2013), the Chernobyl disaster and various maritime and aeronautical accidents (Reason, 2000) (Sasou & Reason, 1999).

Effective reporting can be used for statistical purposes and to establish whether the incident does require detailed investigation. Reporting should be standardised, provide sufficient detail to decide on whether to investigate further and must reach the key decision makers promptly (Lindberg, et al., 2010). Once the report reaches the key decision makers, the report may be filed or investigated further. Organisations which display high reliability and safety decide which reported incidents to investigate further, and then initiate the formal investigation process with a sense of urgency (Saleh, et al., 2010). This includes collecting information from the scene, performing interviews and recording statements as soon as possible (Jørgensen, 2011).

In summary, *a structured guideline should be established which defines the types of incidents which require investigation*. In addition, this guideline should provide sufficient detail to ensure that *incidents which require investigation are being investigated.* The formal *investigation process* *begins as soon as practically possible* with important *initiating events such as the collection of statements* and interviews.

Reported (and unreported) incidents which do not result in harm or loss are termed near-misses, whereas accidents are defined as incidents which result in harm or loss (IRCA Global, 2010). Near-misses have the same root causes as accidents and provide invaluable opportunities to prevent accidents. Learning from near-misses is encouraged to the extent that some policies even require the organisation to study events which occur *outside* of its business (U.S. Department of Energy, 2012). Cases such as the 1986 Space Shuttle Challenger, 1997 Hindustan refinery explosion, 1999 Paddington train collision, and 1998 Morton explosion were all preceded by near-miss events which were not effectively resolved (Phimister, et al., 2003). Upon completion of the 1999 Paddington investigation with 31 fatalities and 400 injuries, it was found that eight similar incidents had already occurred. In summary, *Near-misses must be investigated in detail.*

2.4.3 Investigation role players

The responsibilities of the various role players in an investigation process are established in this section. These role players include the investigation team, the organisation and the requirements for training and experience.

2.4.3.1 The investigation team

a) Establishing the correct mix

The Toyota Way Fieldbook requires that all levels of organisation, including Safety, Operations, Commercial and Financial, understand the skill of problem solving or incident investigations (Liker & Meier, 2006). *Although one person may have the necessary skills to investigate, excellence is achieved by the collective knowledge of various Subject Matter Experts* (Saleh, et al., 2010) (Johnson, 1973). Subject Matter Experts may be defined as knowledgeable and experienced persons in the fields of engineering, maintenance, human resources, finance, safety management, and systems. A single individual may produce inferior results compared to a competent multidisciplinary investigation team (U.S. Department of Energy, 2012). The investigation team should consist of persons knowledgeable in the investigation process, persons knowledgeable in the operation of the plant equipment or the plant process, the site manager, and possibly the injured as well as *independent persons* (Mannan, 2014) (U.S. Department of Energy, 2012).

The inclusion of an independent person helps to prevent the influence of unrelated factors. For example, a manager or engineer may presuppose the root causes based on generic unrelated issues within the department before the investigation commences. Such presumptions can influence the investigation team, which must maintain neutrality and explore all options (Broadribb, 2012). Investigators who have a preconception on the root causes are likely to work backwards and match the evidence to their hypothesis (U.S. Department of Energy, 2012).

b) Human factors

Literature indicates that while analysing aerospace incidents (pre-2000), most reports stopped after assigning blame to a person and failed to identify the root causes (Leveson, 2001); also, more than 75% of maritime accidents had some form of human error component (Rothblum, et al., 2002). Investigators may be tempted to separate a worker's individual action from the organisation. Such actions are clearly biased towards an organisation's reputation and moreover are likely to mitigate legal exposure and further claims (Reason, 2000). Such biases and subjectivity can produce ineffective outcomes. This can be seen when investigators attribute the root causes to human error while the actual root causes continue unabated (Brown, et al., 2000). It is thus important that human error be considered a direct or contributory cause and never a root cause (U.S. Department of Energy, 2012).

The investigation team should not merely stop at *what* was found but further investigate *why* the human error occurred or was allowed to occur.

Understanding these underlying root causes is commonly known as human factors analysis and identifies shortcomings in the organisation or management systems (Rashid, et al., 2014) (Reason, 2000) (Vincent, et al., 2000). *Such findings create a context to look beyond the blaming culture*. This requires a mind-set change to explore the various types of human error and produce methods to reduce such errors. It allows the investigator to explore the interactions of multivariate systems on the human decision-making process. Such interactions also produce an unintended benefit in that addressing human performance variations (which lead to errors) may also produce multivariate process improvements (U.S. Department of Energy, 2012).

Incident investigation techniques now require some form of human performance analysis (Broadribb, 2012) (IRCA Global, 2010). It should be noted, however, that although human performance analysis necessitates further exploration into human error, it does not completely absolve the investigator from determining i) wilful dangerous behaviour or ii) the ability of the investigator to differentiate between culpable and non-culpable unsafe acts (U.S. Department of Energy, 2012). Risky behaviour or a flippant attitude towards safety are antecedents to incidents. It has been shown, however, that such behaviours can be effectively addressed with human performance interventions (Brown, et al., 2000). Human error based on human fallibility can be beneficial in cases where simulations are performed or where knowledge-based learning is being tested (Reason, 1997). Such learnings, however, can only materialise through effective human factors analysis. It is the *responsibility of the organisation to provide guidelines on human performance analysis* which can be used by the investigation team (U.S. Department of Energy, 2012). Providing such guidelines allows the investigation team to probe the *management systems as root causes and human error as causal factors* (U.S. Department of Energy, 2012).

The risk assessment management system was cited as a key element in the safety process and appears often in investigations (U.S. Department of Energy, 2012), (Government of Singapore, 2010), (IRCA Global, 2010). Although people populate the risk assessment templates, *it is important that the risk assessment management system be investigated for root causes rather than assigning blame as a root cause* (Knox & Eicher, 1994), (Johnson, 1973). Guidance on human factors analysis is discussed later in this chapter (Part B) and again in later chapters.

c) Other Subject Matter Experts (human factors, engineering and maintenance)

The investigation team should consist of Subject Matter Experts (SMEs). A differentiation is made between the plant SMEs, investigation process SMEs and other SMEs, since each has a very specific role. *A plant SME is an expert on the plant and an investigation process SME is an expert on the investigation process, and both are essential to any investigation*.

Certain SMEs are generic in the organisation and play a key role in the investigation process. An example would be a SME on human factors (discussed in the previous section). However, generic investigators do not have the expertise to comment on the finer details within each discipline, and this could lead to an omission in the investigation (Le Coze, 2013). The International Labour Organisation identifies the three major players in safety as *human factors, engineering and maintenance* (International Labour Organization, 2005). Literature makes several references to maintenance and engineering shortfalls in investigation handbooks and their role in proactive risk assessments (Saleh & Pendley, 2012) (U.S. Department of Energy, 2012) (Wagenaar & van der Schrier, 1997) (Johnson, 1973).

Engineering systems encompass engineering change management, design, drawings, specifications, engineering / maintenance / operations technical specifications, risk management, equipment life-cycle analysis, failure analysis, record keeping, peer review, quality assurance and authorisation processes (du Toit, 2014) (McNair, 2013). Maintenance systems consist of diagnostics, condition monitoring, maintenance planning, logistics, spares management, repairs, asset management, cost control, outage planning, quality control and training (Duffuaa & Raouf, 2015) (Kajko-Mattsson, et al., 2011).

To illustrate the importance of engineering and maintenance SMEs, investigations in certain heavy industries by the Chemical Services Board in the United States are presented in Figure 2.4. The three leading causes of incidents are related to maintenance procedures (11), process hazard analysis (10) and engineering design and review (8). The top three causes were thus in engineering and maintenance management systems.

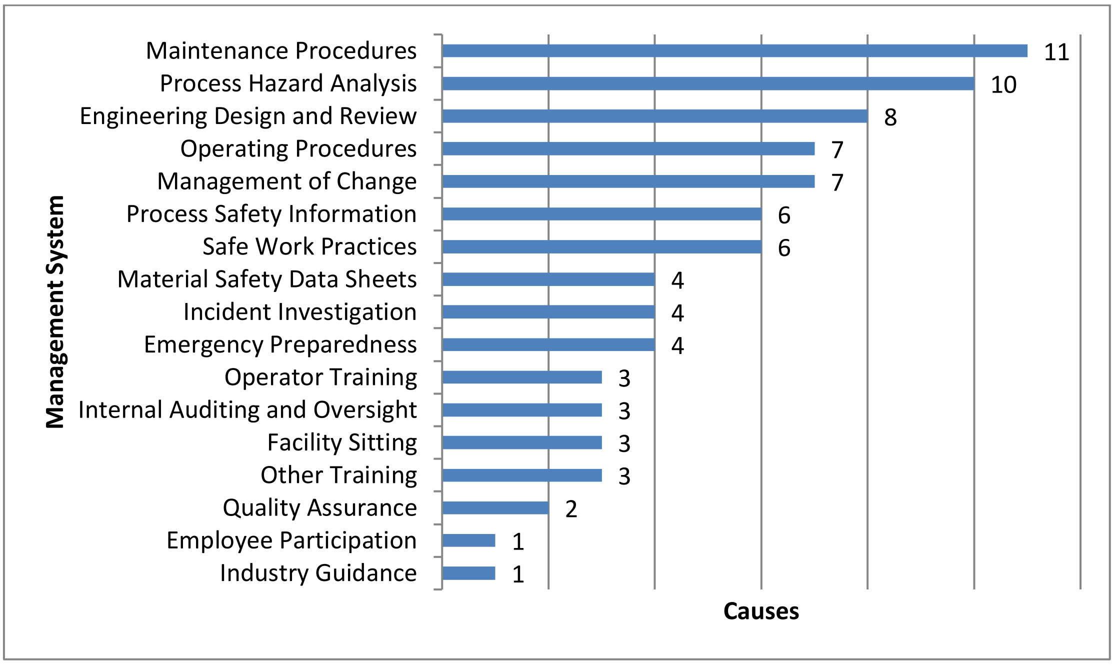

Figure 2.4 Representation of management systems categories identified as causes of incidents (adapted from Blair (2004))

SMEs in the areas of risk, maintenance and engineering are thus pivotal role players in the investigation process. Further guidance on engineering and maintenance systems is discussed later in this chapter and again in other chapters.

As shown in this section, the role players in the investigation team extend beyond the plant personnel team. They must also include independent persons and Subject Matter Experts on the investigation process, operations, human factors, engineering and maintenance.

2.4.3.2 Training and experience

The importance of incident investigation training was emphasized by the fact that some authors call for formalising this training at tertiary level (Saleh & Pendley, 2012). Ideally, both practical and academic training should be required. *Prospective investigators should be formally trained on the investigation process and investigation techniques* so that they are ready to investigate. Having performed investigations provides practical experience which cannot be achieved from classroom training (Ishikawa & Lu, 1985). Although experience may be an adequate refresher, formal refresher training should still be enforced (Mannan, 2014). Pedagogical aspects which include the manner in which the training was developed, presented and examined may result in gaps which can be addressed through experience in investigations. *The lead investigator must be experienced* over and above being trained. *Other investigators on the investigation team must at least be trained and preferably experienced* on the various investigation techniques which could possibly be used in the investigation (U.S. Department of Energy, 2012).

2.4.3.3 The organisation

The organisation is the most important role player in the safety environment which encompasses incident investigations, as it must balance safety against production and economic pressures, never sacrificing safety for production (Saleh, et al., 2010). When studying 108 completed incident investigations, Rollenhagen (2010) found that production pressures, not surprisingly, have influence on worker behaviour. Since the investigation team is expected to comprise a manager, engineer and production workers, they may all have similar production influences. The organisation has a critical role to protect the investigators against such influences by *releasing an adequate amount of competence to focus on the investigation* (Reason, 1997). Although the organisation is expected to free up resources from production influences, it cannot do so indefinitely. All parties must know the process requirements, their roles, responsibilities and timelines. *The roles and responsibilities of members of the investigation team must be predefined* (International Labour Organization, 2005) (Johnson, 1973). *The organisation must clearly set out timelines and deliverables from the investigation and follow up to ensure that such timelines are met*. This sense of urgency can be driven by the fact that the organisation remains exposed to the root causes until resolved (U.S. Department of Energy, 2012).

Clearly the focus on the investigation is crucially important; however, the post-investigation recommendations and action implementations are equally as important. Lundberg, et al. (2009) undertook a study of eight investigation policies in Sweden and concluded that, within these organisations, the policies focussed most on the analysis and reporting, less on the planning, recommendations and following up, and least on implementation. This shows that the organisation must be able to balance the key elements of the incident investigation process itself. This balance can be achieved through periodic audits of completed investigations and improvements in the organisational policy on incident investigations (Kjellén & Hovden, 1993) (Ishikawa & Lu, 1985) (Johnson, 1973).

2.4.4 The investigation

Following the establishment of an organisational policy regulating the investigation process, each employee should be clear on which incidents require investigating and on the exact reporting protocol. Once an incident is reported, the investigator assigned to the investigation should collect as much relevant data as possible. Several handbooks provide information on what type of data should be collected and describe how it should be collected (Mannan, 2014) (U.S. Department of Energy, 2012) (IRCA Global, 2010). With the data in hand, the investigating team incorporating the relevant role players should be formed and clear roles and responsibilities defined and assigned, following which the formal investigation phase can begin.

The investigation phase is initiated with the review of the raw data. Decisions regarding the adequacy, admissibility and accuracy of data are finalised. At this juncture the investigation techniques are introduced into the investigation process. The investigation process up to this point assisted the investigation team in synthesising the raw data to determine *what* happened. The investigation technique determines *why* it happened (Mannan, 2014) (U.S. Department of Energy, 2012) (Lindberg, et al., 2010). The investigation techniques are presented in Part B of this chapter so as not to interrupt the flow of the discussion of the investigation process. The discussion in Part B outlines the process of determining both *how* and *why* the incident occurred.

The investigation phase should produce the following deliverables (U.S. Department of Energy, 2012) (Jørgensen, 2011) (Lindberg, et al., 2010):

- A detailed description of the incident and evidence (may include a sketch, drawing or pictures)
- The details of the investigation team and preferably the relevant roles and responsibilities
- Similar prior investigations or actions (why did the incident recur?)
- Direct causes and root causes
- Persons to review the report and approve and authorise the investigation (discussed in the next phase)

Once these are ascertained, the next phase of the investigation process begins.

2.4.5 Investigation actions and recommendations

The process of determining exactly what went wrong and understanding why it went wrong does not by itself improve safety, as the root causes are merely known and not resolved. The organisation remains exposed to the root causes of the incident (Sweedler, 1995). *It is only when recommendations to address the root causes are reviewed and deemed effective that the investigation may be considered completed* (Le Coze, 2013).

Rollenhagen (2010) observed in several investigations that the investigators were left on their own to propose recommendations due to the absence of other role players. This problem was further compounded by the fact that succinct guidelines and standardisation on developing recommendations were lacking. The absence of succinct guidelines and standardisation also suggested the absence of change control on recommendations and the absence of risk assessments on recommendations. Change control is a process of recording and assessing changes so as to minimise unintended risk to an organisation (du Toit, 2014). One possible solution would be the review of investigations (Rollenhagen, et al., 2010) and the compulsory inclusion of the relevant Subject Matter Experts in the recommendation phase (Duffuaa & Raouf, 2015) (du Toit, 2014) (Reason, 2000). Possible technological, policy and similar changes could also be linked to the investigation through change or review comments (Le Coze, 2013). Recommendations and specific actions must be scrutinised through a detailed risk assessment process (Saleh, et al., 2010).

Once the recommendations are made, the investigation can provide the deliverables of the recommendation phase, which include the following (Mannan, 2014) (Jørgensen, 2011) (Rollenhagen, et al., 2010):

- Detailed description of the recommended preventative actions with sound justification
- Persons responsible for implementing the actions and the timeline
- Guidance on ways to test or audit the effectiveness of the action

- A detailed report encompassing the entire investigation (the deliverables which were discussed in the previous section) and resulting recommendations (the deliverables described in this section)
- The detailed audit of the investigation to ensure compliance to the organisational policy
- Initiation of the review, approval and authorisation process

Only after these factors are considered can the next steps of disseminating the information begin.

2.4.6 Dissemination and regulation

The localised implementation of corrective actions which does not address the global organisational deficiencies is considered a gap (Lundberg, et al., 2009). This creates a need to *audit the investigation report* (Amyotte & Oehmen, 2002) and ensure that the *dissemination process includes the global role players* and not only the local plant role players (Phimister, et al., 2003). *Before dissemination, however, reports must be reviewed*. The review should ensure that technical and policy requirements are factual, accurate and compliant, that privacy and confidentiality requirements have not been contravened, and that the report is in line with expected standards. It is advisable to do this during the drafting of the report and not leave it to the end, as the review process is included in the investigation timeline. The level of review also depends on the circulation requirements in terms of organisational level, governmental level or open source. *The organisation should balance the time given to facilitate a comprehensive investigation against the risk faced by the organisation due to unresolved root causes* (U.S. Department of Energy, 2012).

Upon completion of the previous phases, the reviewed report is produced, and the communication phase is initiated. The communication phase has been claimed to be the most unsuccessful phase in the investigation process (Lindberg, et al., 2010), hindering effective action implementation. *The investigation should reach all possible role players who need to decide* *on the applicability of the recommendations to their operations*. A system to regulate feedback from these role players should be established. Feedback should include *confirmation of action implementation and subsequent test for effectiveness, or the reasons for the action being irrelevant* to the role player (Liker & Meier, 2006).

In the context of production pressures, action implementation can be ineffective, especially when complex and lengthy investigation reports are circulated (Rollenhagen, et al., 2010). A summarised, reader-friendly version of the report may be required for communication to the organisation and external affected parties. Another reason for ineffective investigations appears to be the reliance on staff memory rather than organisational memory. Staff turnover is a reality and organisations should periodically discuss old and new accidents in addition to training new recruits on such incidents (Lindberg, et al., 2010). In order to facilitate ease of cross referencing to previous investigations, it is recommended that a database of information, keywords and statistics be established (U.S. Department of Energy, 2012) (Rollenhagen, et al., 2010) (Phimister, et al., 2003).

The final stages of communication and regulation should ensure that the following deliverables are realised (Amyotte & Oehmen, 2002) (Phimister, et al., 2003) (U.S. Department of Energy, 2012) (Rollenhagen, et al., 2010):

- Provide a summarised report for communication and distribution
- Review and approve all reports for communication
- Ensure global communication within the organisation or external role players
- Establish a reporting and feedback system to ensure that actions are implemented
- Update the database with key words, reports and statistics

Apart from the review and auditing of the report, it is imperative that the organisation drive a continuous improvement program for the organisational policy. Systems are in constant flux and the organisation should gear towards always being proactive (Ishikawa & Lu, 1985). This may require an external audit, but an internal audit could be acceptable if it is independent of the policy makers (Amyotte & Oehmen, 2002).

2.5 The Investigation Process Requirements

The investigation process requirements, discussed in Part A, were underlined and italicised as they were identified. The relevant extracts related to these requirements are now tabulated and lead to the identification of the investigation process requirements in Table 2.1. These investigation process requirements were published in an international peer reviewed journal (Jooma, et al., 2015).

Table 2.1 Identification of the investigation process requirements

<table>
<tr><th>No:</th><th>Extracts from the Literature Survey</th><th>Investigation Process Requirements</th></tr>
<tr><td>1</td><td>The investigation process is described in an organisational policy which should be integrated into the overall safety management system (Chua, et al., 2004)</td><td>A system should exist to ensure that incidents are investigated thoroughly</td></tr>
<tr><td>2</td><td rowspan="2">Effective reporting can be used for statistical purposes and to establish whether the incident does require detailed investigation. Reporting should be standardised and provide sufficient detail to decide on whether to investigate further (Lindberg, et al., 2010)</td><td>Structured guidelines should outline what type of incidents require investigating</td></tr>
<tr><td>3</td><td>Incidents which require investigation should be investigated</td></tr>
</table>

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
4	Organisations which display high reliability and safety decide on which incident reporting to investigate and initiate the formal investigation process with a sense of urgency (Saleh, et al., 2010)	The incident investigation process should begin as soon as the incident becomes known
5	It is pivotal that the collection of information from the scene, interviews and statements begin as soon as possible (Jørgensen, 2011)	Statements and other information from the scene should be collected promptly
6	Cases such as the 1986 Space Shuttle Challenger, 1997 Hindustan refinery explosion, 1999 Paddington train collision and 1998 Morton explosion all displayed previous near-miss events which were not effectively resolved (Phimister, et al., 2003).	Near-misses should be investigated in detail as the root causes of a near-miss could produce serious and catastrophic accidents

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
7	The Toyota Way Fieldbook requires that all levels of organisation understand the skill of problem solving or incident investigations (Liker & Meier, 2006) including Safety, Operations, Commercial and Financial. Although one person may have the necessary skills to investigate, excellence is achieved by the collective knowledge of various Subject Matter Experts (Saleh, et al., 2010) (Johnson, 1973)	The incident investigation team should be represented by the correct mix of people to ensure that all important aspects are covered during the investigation [e.g. Safety, Health, Environment, Risk and Quality (SHERQ) systems experts, technical Subject Matter Experts]
8	The investigation team should consist of independent subject matter experts on the investigation process, operation of the plant equipment or plant process, as well as persons effected by the incident such as the manager, and (if possible) the injured (Mannan, 2014) (U.S. Department of Energy, 2012)	Independent Subject Matter Experts (technical and safety system related) should be included in the incident investigation group to prevent biased outcomes
9	Human factors analysis creates a context to look beyond the blaming culture by identifying shortcomings in the organisational or management systems (Rashid, et al., 2014) (Reason, 2000) (Vincent, et al., 2000)	Incident investigators should avoid blaming people for incidents (investigate beyond the blame culture)

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
10	It is the responsibility of the organisation to provide guidelines on human performance analysis which can be used by the investigation team (U.S. Department of Energy, 2012)	Where human error is a factor, investigators should be provided with a sound guideline or matrix detailing the human error causal factors and working environment factors
11	Providing human performance guidelines allows the investigation team to probe the management systems as root causes and human error as causal factors (U.S. Department of Energy, 2012)	People should not be blamed for incidents caused by a failure in a management procedure (such as safe working or safe operating procedures)
12	Although people populate the risk assessment templates, it is important that the risk assessment management system be investigated for root causes rather than assign blame as a root cause (Knox & Eicher, 1994) (Johnson, 1973)	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, investigators should study the HIRA management systems for root causes instead of concluding that the root cause was a task initiator error (blaming people)

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
13	A plant or operations subject matter expert (SME) is essential to any investigation process (Le Coze, 2013)	Incident investigators should probe operational management systems (e.g. safe operating procedures)
14	The International Labour Organisation discusses the three major players in safety as human factors, engineering and maintenance (International Labour Organization, 2005)	Incident investigators should probe human behavioural management systems (e.g. individual development plan, training matrices)
15		Incident investigators should probe engineering management systems (e.g. change management)
16		Incident investigators should probe maintenance management systems (e.g. maintenance strategies)

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
17	Prospective investigators should be formally trained on the investigation process and investigation techniques so that they are ready to investigate. Having performed investigations provides practical experience which cannot be achieved from classroom training (Ishikawa & Lu, 1985)	Investigators should have received formal training on the company's incident investigation policy
18		Investigators should have received formal training on incident investigation techniques used by the company (e.g. RCAT, CED, 5 WHYs, etc.)
19	The lead investigator must be experienced over and above being trained. Other investigators on the investigation team must be at least trained and preferably experienced on the various investigation techniques which could possibly be used in the investigation (U.S. Department of Energy, 2012)	The lead investigator should be experienced in the incident investigation process
20		Other investigators or supporting investigators should be well experienced on investigation techniques
21	The organisation has a critical role to protect the investigators against operational influences by releasing an adequate amount of competence to focus on the investigation (Reason, 1997)	Investigators should be somewhat protected from operational responsibilities and allowed to focus on a thorough incident investigation

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
22	The roles and responsibilities of members in the investigation team must be predefined (International Labour Organization, 2005) (Johnson, 1973)	The incident investigation team should be provided with clear roles and responsibilities
23	The organisation must clearly set out timelines and deliverables from the investigation and follow up to ensure that such timelines are met. This sense of urgency is driven by the fact that the organisation remains exposed to the root causes until resolved (U.S. Department of Energy, 2012)	Time frames should be specified for the completion of incident investigation reports
24		When time frames are specified, these times should be strictly adhered to
25	The process of determining exactly what went wrong and understanding why it went wrong does not improve safety since the root causes are merely known but not resolved. The organisation remains exposed to the root causes of the incident (Sweedler, 1995)	The investigation should only be considered as completed when actions are verified for successful implementation. An investigation cannot be completed upon establishing root causes.

Table 2.1 Identification of the investigation process requirements (Continued)

<table>
<tr><th>No:</th><th>Extracts from the Literature Survey</th><th>Investigation Process Requirements</th></tr>
<tr><td>26</td><td rowspan="2">A system to regulate feedback between possible exposed role players outside of the affected plant should be established. Feedback should include confirmation of action implementation and subsequent test for effectiveness or the reasons for the action being irrelevant to the role player (Liker & Meier, 2006)</td><td>A system should exist to enforce actions from other operating units' incident investigations across all departments or sections in a company</td></tr>
<tr><td>27</td><td>A system should exist to ensure that all actions are implemented and verified for effectiveness</td></tr>
<tr><td>28</td><td rowspan="3">The localised implementation of corrective actions which do not address the global organisational deficiencies is considered a gap (Lundberg, et al., 2009). This creates a need to audit the investigation report (Amyotte & Oehmen, 2002) and ensure that the dissemination process includes the global role players and not only the local plant role players (Phimister, et al., 2003). Before dissemination, however, reports must be reviewed.</td><td>Completed incident investigations should be audited against the company policy</td></tr>
<tr><td>29</td><td>Incidents that occur at other operating units should be communicated across the company's global operations. (This does not refer to a 24-hour flash or 1-page report of the incident, but rather to the completed investigation report)</td></tr>
<tr><td>30</td><td>Completed incident investigations shall be reviewed by experts on the company's incident investigation policy</td></tr>
</table>

Table 2.1 Identification of the investigation process requirements (Continued)

No:	Extracts from the Literature Survey	Investigation Process Requirements
31	The organisation should balance the time given to facilitate a comprehensive investigation against the risk faced by the organisation due to unresolved root causes (U.S. Department of Energy, 2012)	Investigators shall be offered adequate time to complete a thorough incident investigation

The investigation process requirements are central to evaluating the three streams. Since these are the investigation process requirements, an unintended benefit of this table is that it serves as a basis for organisations to develop their policy on incident investigations.

Part B of this chapter now presents a select number of investigation techniques. The presentation of investigation techniques is important, being an integral part of the investigation process. Also, understanding investigation techniques is essential for analysing completed investigations (Sklet, 2002).

PART B

An incident investigation process consists of several phases which were discussed in Part A of this chapter, with the investigation technique being a major phase. Investigation techniques are used to analyse raw data (evidence from the scene, statements, etc.), to understand *what* happened and *why* it happened (Sklet, 2004) in order to prevent recurrent incidents. An understanding of the techniques commonly used in industry assists in evaluating the effectiveness of the application of the investigation process (Jooma, et al., 2015).

2.6 Incident Investigation Techniques

Over time many experts have examined several hundreds of investigations, discovered shortcomings and rectified those. This prompted the increase of new investigation techniques from a mere 30 in 1980 to over 100 in 2010 (Ziedelis & Noel, 2011). Early rudimentary investigation techniques evolved over time. In the early 1900s events leading up to an incident were considered coincidental and the incident was classified as an Act of God. First generation investigation techniques (1920s) focussed on workers' unsafe traits, while second generation investigation techniques (1930s) went wider and were based on a domino theory. These techniques were the first to look at a sequence of events considering both unsafe acts and unsafe conditions, e.g., sequential analysis and causal technique (Amyotte & Oehmen, 2002) (Heinrich, 1959). Third generation techniques (1960s) were termed epidemiological models and studied all possible energies in a variety of environments which could cause harm to a worker, e.g., Management Oversight and Risk Tree (MORT). Fourth generation techniques (1970s) examined multiple systems running in parallel, encompassing sociotechnical systems (Khanzode, et al., 2012). Second generation to fourth generation techniques are widely used in modern investigations (Amyotte & Oehmen, 2002) (Liang, et al., 2011).

Literature recommends the use of multiple investigation techniques, since each investigation technique displays inherent limitations (Jacinto & Aspinwall, 2003) either in the results produced or the type of incident being investigated. This has proven to be successful over a number of investigations across many countries (Ziedelis & Noel, 2011) (U.S. Department of Energy, 2012) (Mannan, 2014). Considering the aim of this research, it was impractical to critically analyse over 100 techniques, especially since literature has demonstrated the process using actual industrial incidents (Le Coze, 2013) (Liang, et al., 2011) (Blair, 2004) (Amyotte & Oehmen, 2002) (Brown, et al., 2000). It was considered more important to focus on specific techniques that support the objectives of this research. The following criteria were thus considered when selecting which techniques to analyse:

- Inclusion of the second, third and fourth generation investigation techniques
- Commonly used in industry, according to references in literature
- Relatively easy to understand and utilise without being dependent upon investigation specialists
- Available in the public domain

Using these criteria, five incident investigation techniques were shortlisted: the Events and Causal Factors Charting analysis (fourth generation); Management Oversight and Risk Tree (third generation); Systematic Cause Analysis Technique (second generation); 5 Whys (second generation), Fault Tree, Event Tree and the Cause and Effect Diagram (Ziedelis & Noel, 2011) (Lundberg, et al., 2009) (Boraiko, et al., 2008) (Sklet, 2004) (Wagenaar & van der Schrier, 1997) (Lehto & Salvendy, 1991).

A brief analysis of each technique, consisting of the salient points together with benefits or limitations referenced in literature, is discussed next. This section does not aim to examine why these are used in industry, but rather to understand them in order to critically assess the application of the investigation process. A more comprehensive presentation of each technique can be found in the appendices. This discussion aims to assist the novice reader or to provide a refresher for the more experienced reader.

2.6.1 Systematic Cause and Analysis Technique (SCAT)

The concept of SCAT evolved from the domino model proposed by Heinrich (1959). The ease and simplicity of use, even by a novice investigator, led to the wide use of this technique (Jacinto & Aspinwall, 2003). It is a bidirectional model which sequentially examines the accident from the standpoint of loss, incident, immediate causes, root causes and an organisational deficiency (Kjellén & Hovden, 1993). The technique was later refined by Bird (1986), who introduced concepts of energy. The primary shortcoming of this model is the inability to address complex interactions and a lack of risk review at each step. Another disadvantage of this model is that it allows the investigator to focus on the unsafe acts and implement behavioural interventions whilst the unsafe conditions can slip through unchanged (Khanzode, et al., 2012).

The bidirectional reference is made to the sequence progressing in an *Incident Causation Model* and working backwards in a *Problem Solving Model* (IRCA Global, 2010) as shown in Figure 2.5.

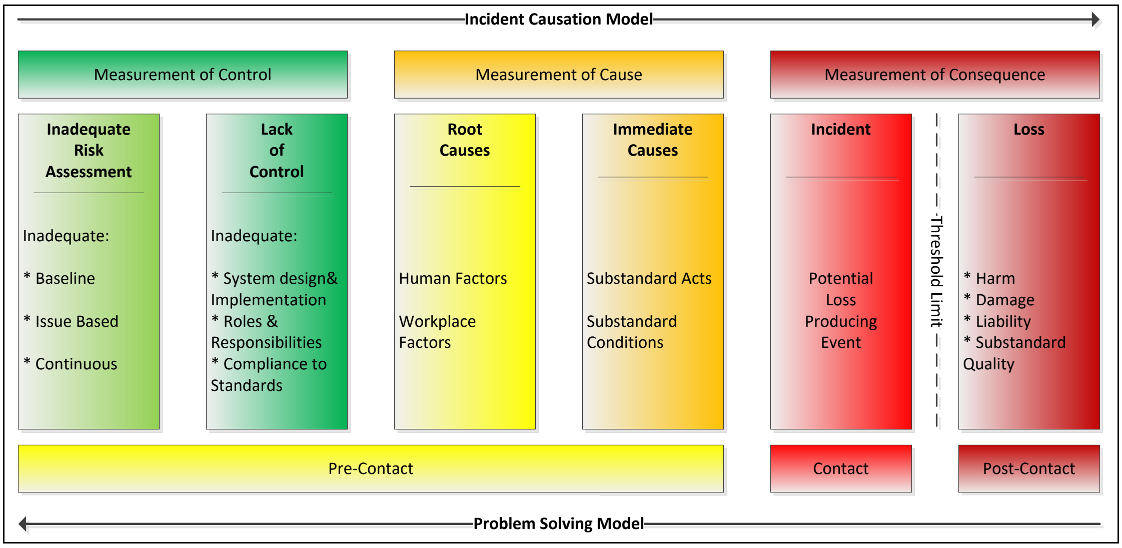

Figure 2.5 Systematic Cause Analysis Technique (adapted from IRCA Global, 2010, Bird & Germain, 1986, Amyotte & Oehmen, 2002)

The application of the method is achieved through a chart with the six blocks shown, a worksheet or commercial software. The investigator, trained in the method, applies the facts gained through the application of choice, such as a flow diagram, spreadsheet or chart (Sklet, 2002). The problem solving model aims to address deficiencies in the safety management system. A more detailed discussion of the SCAT investigation technique can be found in Appendix A.1.

2.6.2 Fault Trees and Event Trees

Fault Tree Analysis (FTA) is a diagrammatic representation which displays the incident as an initiating event (shown as the tip of a tree) and *branches* downwards until the *root* causes are established. Event Tree Analysis (ETA) is also a diagrammatic representation which is initiated by an incident and then splits into the various causal events which may or may not have occurred to facilitate the incident. Both the fault tree and event tree may be a qualitative or quantitative model (Sklet, 2004). The event tree and fault tree can be used in combination to assess risks through a probabilistic assessment (Xu & Dugan, 2004). In reverse, they can be used as an investigation tool (Colli, 2012).

The key benefit offered by the qualitative tree representation is the simplicity of linear causal relationships. This, however, makes it difficult to incorporate non-linear influences and feedback between distant branches. Further, only the influence of causes related to the initiating incident is described. Literature discusses latent organisational defects which may not be classified as an "event" but could contribute to the incident (Leveson, 2004). The branches of the tree can spread out to form roots, without necessarily distinguishing the most contributory systemic causes from other causes. A more detailed discussion of the Fault Tree and Event Tree investigation techniques can be found in Appendix A.2.

2.6.3 Management Oversight and Risk Tree

MORT was proposed and largely finalised as an analytical tree diagram in its fourth revision in a technical report presented to the U. S. Atomic Energy Commission in the early 1970s (Johnson, 1973). Although it was developed for investigation purposes, like many investigation techniques, it can also be used to design or evaluate safety systems without an incident as a precursor (Johnson, 1973). Although the report was presented to a nuclear industry, the application of the technique has been wide and diverse. The technical report makes references to steel plants, noting that these concepts were first used in epidemiology studying disease vectors (Kingston, et al., 2004).

MORT has a distinct advantage as it analyses multiple parallel systems such as engineering, maintenance, human resources, and operations in the context of existing risks and possible future risks. A disadvantage created by such a complex model is that extensive training is required for in-depth analysis (Sklet, 2002). The comprehensive MORT analysis is reserved for major scale or complex incident investigations as it presents around 100 risks which can produce some 200 causes. Such investigations require notable human resources and other resource funding to complete successfully (Ziedelis & Noel, 2011) (Johnson, 1973). A more detailed discussion of the MORT investigation technique can be found in Appendix A.3.

2.6.4 5 Whys

Questioning “why” until the root causes are achieved is the basis of certain simple investigation techniques such as the 5 Whys analysis. This method does not require advanced software or reading material. A disadvantage is that it presents only one root cause at a time. This implies that several iterations along different causes may be required to identify all root causes (Ji & Zhang, 2012). The 5 Whys technique has the ability to derail an investigation process in the absence of critical thinking skills (Phillips & Simmonds, 2013) which makes this technique rather subjective. Such subjectivity is possibly mitigated by the use of a multi-person investigation team. This team continues asking “why” until the limit of their ability to control is reached (Kletz, 2006). At this stage the investigating team can suggest changes to management, standards or legislation. A more detailed discussion of the 5 Whys investigation technique can be found in Appendix A.4.

2.6.5 Cause and Effect Diagram

The Cause and Effect Diagram (CED) was developed by Dr Kaoru Ishikawa as a quality control tool and became known as the fishbone diagram or the Ishikawa diagram (Ishikawa & Lu, 1985). The structure of the CED relies on the premise that each event is made up of a cause or causes and each of those causes has an effect; the sequence continues until the root causes are identified. Since these characteristics are common to safety investigations and quality investigations, the CED is used extensively in both arenas (Ilie & Ciocoiu, 2010).

The strength of the CED is its diagrammatic representation, allowing the entire investigation team to develop solutions collaboratively (Phillips & Simmonds, 2013). Common focus areas such as man, machine, method and materials provide a starting point to investigation teams (Schulmeyer, 2008). This provides a measure of focus toward the root causes (Arvanitoyannis & Varzakas, 2007). The focus areas, however, can be as wide or narrow as the investigation team deems relevant or effective in order to achieve the root causes. It is thus recommended that the Pareto 80/20 principle (which addresses 80% of effects by focussing on 20% of the most important causes) be followed (Ishikawa & Lu, 1985) . Using the Pareto principle in combination with the CED, however, leaves the organisation exposed to 80% of the less important causes. Although this may be acceptable for quality related work (Ahmed & Ahmad, 2011), its application to safety may warrant further consideration. This is especially relevant within larger teams where opinions instead of facts may dominate and misinformed democratic votes are possible (Walton, 2013). With fewer role players, however, complacency can lead to superficial CEDs. Further, the CED displays the effect and causes as images of equal weight. As such, no priority can be given to any cause unless data which has been vetted for accuracy is available. A lack of data (or inaccurate data) can lead to opinions and provide incorrect focus areas which could lead to superficial CEDs (Hedley, 2005). A more detailed discussion of the CED analysis technique can be found in Appendix A.5.

2.6.6 Events and Causal Factors Charting

The Events and Causal Factors Charting (ECFC) method was established by the United States (U.S.) Safety System Development Center as a method to understand *what* happened and *why* it happened and to develop recommendations to prevent recurrence. It was expanded by the U.S. Department of Energy (DOE) to include human performance improvements and is detailed in the DOE Handbook "Accident and Operational Safety Analysis" Vol. 1: Accident Analysis Techniques (U.S. Department of Energy, 2012). The handbook states that no single method is capable of covering all the causal factors in a complex incident and stipulates the use of multiple methods which can complement and easily cross-check one another (U.S. Department of Energy, 2012). The handbook recommends the use of five methods:

- Events and Causal Factors Charting (ECFC) and Analysis
- Barrier Analysis
- Change Analysis
- Root Cause Analysis
- Verification Analysis

Human Performance, Safety Management Systems and Culture Analysis can integrate into each step and are discussed later. The sequence is implemented as shown in Figure 2.6.

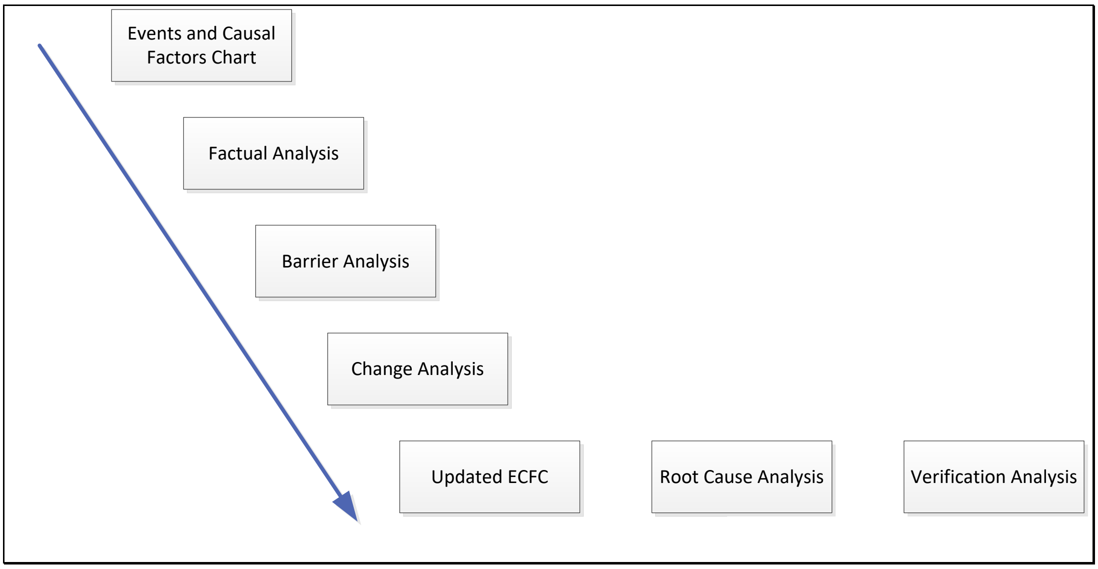

Figure 2.6 Analysis Process Overview (U.S. Department of Energy, 2012, pp. 2-42)

The following five definitions are summarised from the Accident Investigation Terminology in the DOE Handbook (U.S. Department of Energy, 2012):

- **Events and Causal Factors Charting (ECFC)** is a chronological plotting of the incident. Each event is preceded by an action and the worker's decision. It establishes the context in which the worker made the decision.
- **Causal Factors** determine the direct causes (usually a physical action), root causes (usually a management control) and contributing causes (important finding which should be addressed but did not directly lead to the accident).
- **Barrier Analysis** studies the hazards, targets and barriers that prevent the hazard from reaching the target. Barriers can be physical or administrative interventions by an organisation.
- **Change Analysis** is a method to investigate the impact of planned or unplanned changes as a contributor to accidents.

- **Verification Analysis** is the final assessment which shows that the analysis and recommendations align to the original flow of data in the ECFC (U.S. Department of Energy, 2012) (Sklet, 2004).

The benefits of the U.S. DOE core analytical techniques are their comprehensiveness while providing sufficient guidance for the novice users. They address human factors and other management weakness whilst being equally strong on equipment and design related weaknesses. The expected disadvantage with such comprehensive systems is the intensive time and human resources requirement (Ziedelis & Noel, 2011). A more detailed discussion of the Events and Causal Factors Charting technique can be found in Appendix A.6. The ECFC concludes the literature on investigation techniques.

2.7 Summary

Literature references show that electrical shock and arc flash incidents occur globally. Not only do these incidents cause loss of life and disabling injuries, but result in financial loss, operational losses and reputational harm. Medical expenses from these incidents cost several million U.S. dollars.

The three streams, consisting of the organisational policy on incident investigations, records of completed investigations and the investigators, were examined in more detail. It was noted that due to the importance of each stream, as observed from literature, a deficiency in any single stream could derail the effective application of the investigation process. The streams had to be evaluated as mutually dependent, but this was not possible unless a common criterion to evaluate the three streams was developed.

In Part A of this chapter, thirty-one requirements for the investigation process were identified and listed in Table 2.1. These requirements were established from literature pertaining to the investigation process. The salient investigation process requirements included the standardisation of the investigation process through policies and procedures, training and experience, initiating the investigation, roles and responsibilities, investigation techniques, operational and human factors, actions and recommendations, review and effectiveness checks, dissemination, and close-out. The investigation process requirements are the criteria used to evaluate the three streams.

One of the streams is the evaluation of records from completed investigations. In order to evaluate completed investigation records, however, knowledge on the correct use of investigation techniques is essential. As a result, five different investigation techniques commonly used in industry were examined. These included the Events and Causal Factors Charting analysis, Management Oversight and Risk Tree, Systematic Cause Analysis Technique, 5 Whys, Fault Tree, Event Tree and the Cause and Effect Diagram. Unique observations from the investigation techniques were used to supplement the investigation process requirements.

This chapter used literature to establish the evaluation criteria for the three streams. The next chapter presents the research methodology. It examines exactly how the three streams are evaluated against the investigation process requirements in a mutually dependent manner.

3 RESEARCH METHODOLOGY

3.1 Introduction

The previous chapter provided an extensive review of literature which elaborated on the streams and established the investigation process requirements. This chapter details the methodology used to determine the interactions and mutual influences among the three streams while facilitating repeatability or extrapolation of the research. The research procedure, research instruments, design, protocol, sampling, data analysis and ethical considerations are presented.

3.2 Research Procedure

It was hypothesised that combining and evaluating the dynamic interactions of the three streams in industry allows for evaluating the effectiveness of the *application* of the investigation process. The three streams of the investigation process are: a) the organisational policy on investigations, b) completed investigations, and c) investigators; the investigation process requirements are those established in Table 2.1 in the previous chapter.

The organisational policy and records from completed investigations were evaluated against the investigation process requirements. The records of the completed investigations were also evaluated against the organisational policy, prompted by literature that indicated this as an area of general non-compliance (Amyotte & Oehmen, 2002). The survey of the investigators followed a method similar to that observed in literature (Rollenhagen, et al., 2010), requiring statistical analysis. Although this research was predominantly qualitative, the survey of the investigators included some quantitative methods, which warranted the use of a mixed methods research design. In order to examine the interactions and mutual influences among the three streams and present a single interpretation of the results, a triangulation design was selected (Creswell, 2003).

This design allows for the independent data collection, data analysis and results from each stream to be brought together and interpreted to produce findings related to possible interactions and mutual influences (Hanson, et al., 2005). Convergent findings imply that the approach works. Divergent findings imply that further exploration as to underlying reasons should be explored (Creswell, 2003) (Jick, 1979). If divergent findings can be justified, then the approach works. Further details follow in the research design section.

3.3 Research Design

This section describes the research method adopted in this study. The concepts of quantitative, qualitative and triangulation methods are presented. Thereafter, the method adopted for the analysis of each stream is presented individually.

3.3.1 Quantitative, Qulaitative, and triangulation methods

Quantitative and qualitative methods: Two broad categories of research methods are qualitative research methods and quantitative research methods (Nguyen, et al., 2011).

Qualitative research is a form of observation by a researcher followed by the use of theory to explain that observation. The evaluation of the organisational policy and the record of complete investigations are thus examples of qualitative research.

Quantitative research tests a hypothesis using a numerical approach. The analysis of the raw survey data using descriptive statistics is an example of quantitative research (Newman & Benz, 1998).

Irrespective of the research method adopted, reliability and validity of data are important considerations in research. A reliable study can be reproduced using the same methodology. Validity refers to whether the research accurately measures the hypothesis and whether the research is actually answering the research question (Golafshani, 2003). The research findings cannot be claimed in the absence of reliable and valid data.

The reliability and validity of quantitative data are evaluated using statistics and scored numerically. These results are presented in the data analysis section later in this chapter. In qualitative methods, however, a different approach is required to measure the quality of a qualitative method. The differentiation between good and bad qualitative research resides in traits such as trustworthiness, quality and rigour (Golafshani, 2003) and are discussed later in this section.

Triangulation: In cases where qualitative and quantitative studies are analysed independently, but the results require a single dependent interpretation, concurrent triangulation is used (Hanson, et al., 2005). The concurrent triangulation method (herein referred to as triangulation) was demonstrated by Creswell and Plano (2011) and is shown in Figure 3.1.

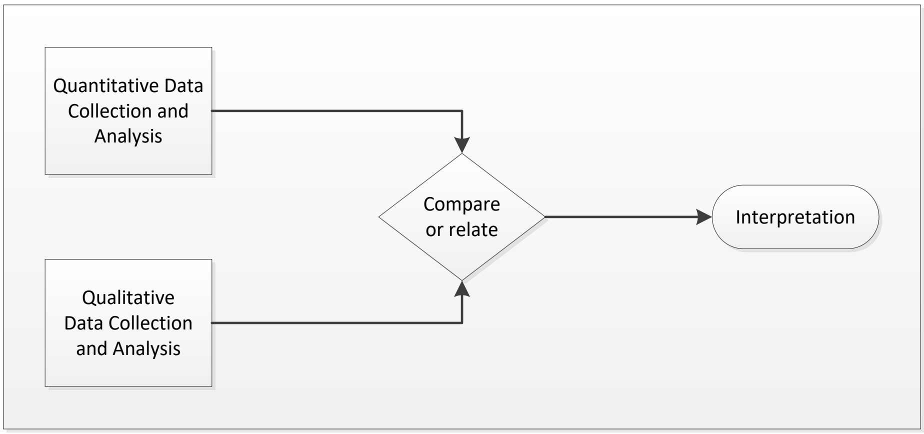

Figure 3.1   Diagrammatic representation of concurrent triangulation (Creswell & Plano Clark, 2011)

The ability to utilise qualitative and quantitative methods in a complementary fashion to achieve a convergent validation of the research is widely supported in literature (Flick, 2007) (Mertens & Hesse-Biber, 2012) (Denzin,

1978) (Smith, 1975) (Webb, et al., 1966). In cases where the interpretation is divergent or the results are inconsistent, it provides the researcher with the opportunity to uncover deeper meaning in the data. Although convergent results are easier to interpret, divergent results may provide useful information and conclusions (Patton, 2002) (Jick, 1979). The interpretation of both divergent and convergent findings will be demonstrated in the next chapter.

Two variations of the triangulation method were used in this study: the within-method and the between-method. The within-method allows for analysis between qualitative methods or between quantitative methods. An example demonstrating the within-method for a qualitative analysis is shown in Figure 3.2. The between-method allows for analysis between a qualitative method and a quantitative method (Nøkleby, 2011) and is similar to the representation shown in Figure 3.1. Between-method triangulation is a measure of validity in qualitative studies, while the within-method for qualitative data establishes reliability (Denzin, 1978). If the within-method and between-method triangulation are providing meaningful results, reliability and validity of the qualitative method can be claimed.

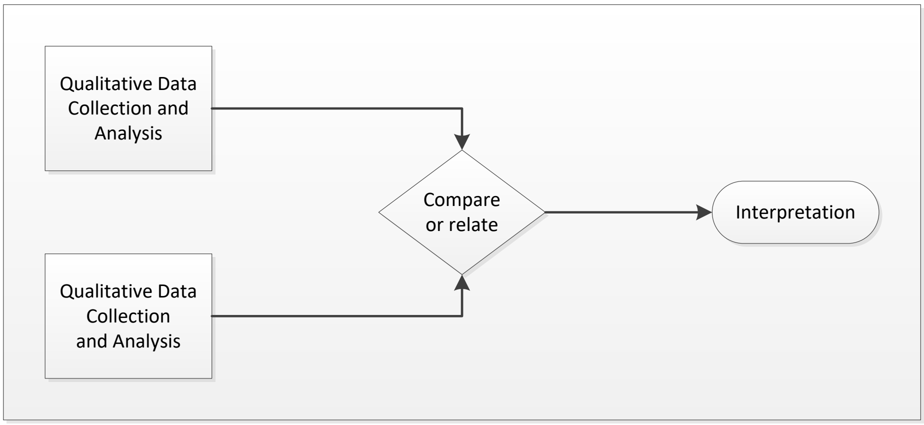

Figure 3.2 Diagrammatic representation of the within-method triangulation (Creswell & Plano Clark, 2011)

3.3.2 Method adopted for each stream

This section describes, in detail, the method adopted for the analysis of each stream and describes how the results are interpreted using triangulation.

The organisational policy on incident investigations: The analysis is performed by comparing the content of the organisational policy document to the investigation process requirements (from Table 2.1). For the purposes of this research, a case study plant is used to test the approach (details presented later in this chapter). This type of documentary analysis and observation against literature is qualitative research. The review of the organisational policy should be performed first as it provides the context in which the remaining two streams exist.

The record of completed investigations: Records of completed investigations are collected from an organisational database. These may be in the form of hardcopy reports or electronic software copies from a database. The completed investigation reports are reviewed by the researcher in detail. The first stage of the analysis is the comparison of the completed investigations to the requirements of the investigation process (from Table 2.1). Having already analysed the organisational policy, stage two of the analysis requires the examination of the completed investigations against the organisational policy. Stage one and stage two, in practise, are executed simultaneously. This analysis employed a qualitative research method.

The survey of investigators: The investigation process requirements were used as questions in a survey. These 31 questions were based on the 31 investigation process requirements shown in Table 2.1. The survey was issued to the investigators (details of this process follow later in this chapter). The data received from the survey process was analysed using descriptive statistics that were processed in statistical software. This analysis employed a quantitative research method.

Triangulation of findings: The analysis of the three streams produced several findings, some of which were common across all three streams. Among all findings, just the top three findings were considered adequate to demonstrate the influence and mutual dependence of the three streams. The criteria for selection were findings that reflected a high level of non-compliance in one stream and also presented as a finding (compliance or non-compliance) across the remaining streams. The top three findings were then interpreted using the between-method and within-method triangulation. The summary of this process is presented in Table 3.1 and represented in Figure 3.3.

Table 3.1 Summary of the research design

No.:	Research Focus	Source	Method	Interpretation	Results
i.	Investigation process requirements	Literature study	Literature review	Review of applicable literature	Literature chapter, Table 2.1
ii.	Organisational policy	Case study plant policy	Qualitative	Analysis from (i)	Triangulation: • Within-methods triangulation • Between-methods triangulation
iii.	Completed incident investigations	Case study plant archives	Qualitative	Analysis from (i) and (ii)	
iv.	Investigators	Survey of investigators at the case study plant	Qualitative Quantitative	Requirements of the investigation process Descriptive Statistics	

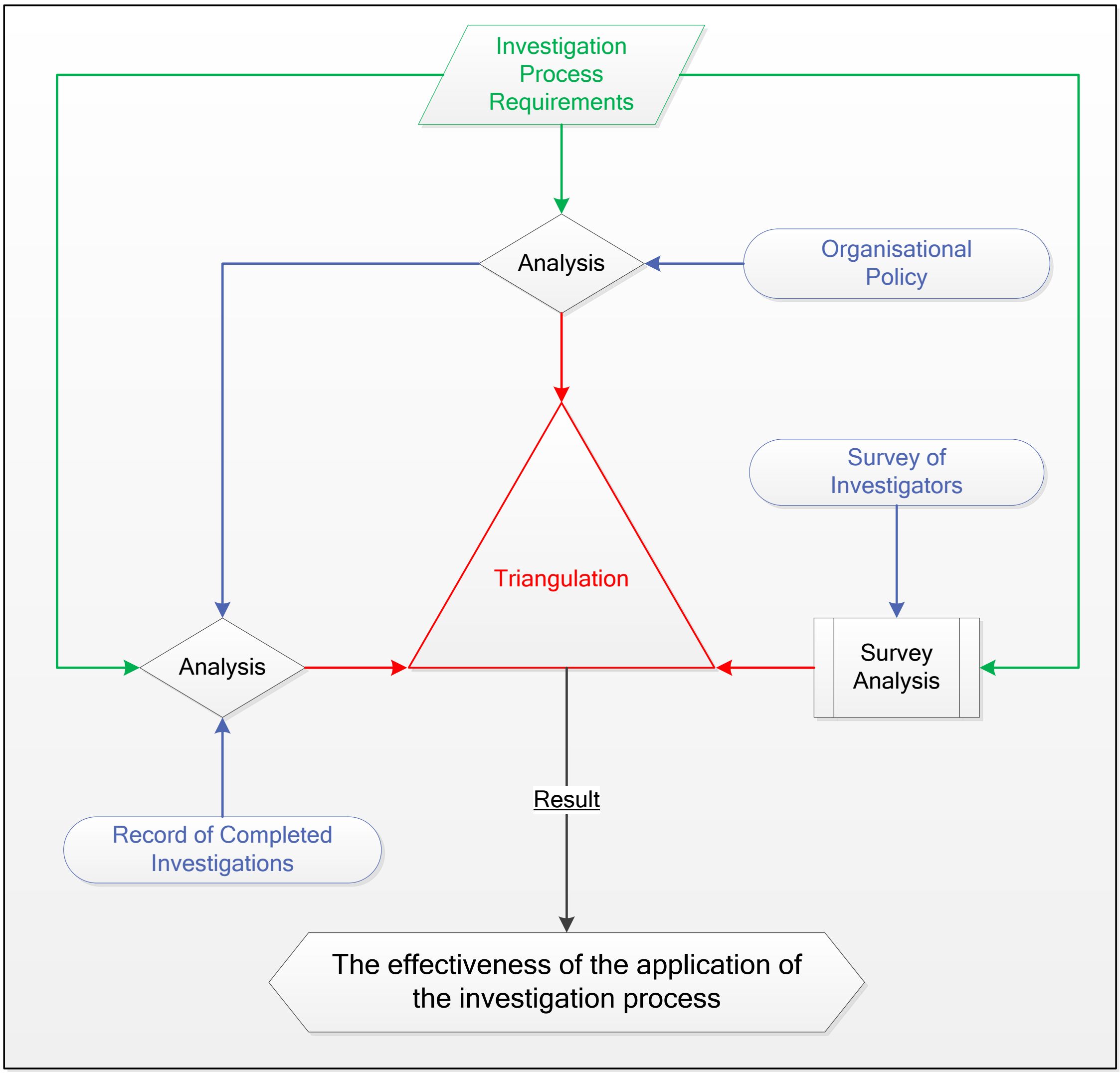

Figure 3.3 Representation of the research method adopted

3.4 Research Protocol

This section details the execution of the study. The case study plant, the survey, and participants are discussed. The analysis of the organisational policy and completed investigations is adequately covered in the previous section. Further discussion on the case study plant, the survey, and participants are provided in the section.

3.4.1 The case study plant

The literature survey was largely, although not exclusively, based on work done in industry. The type of industry described in the literature survey has numerous employees, multiple sites, highly regulated work environments and complex monitoring systems (Piotrowski, et al., 2014) (Khanzode, et al., 2012) (U.S. Department of Energy, 2012) (Arvanitoyannis & Varzakas, 2007). The scope of this research is thus limited to industry, and a plant that met these requirements was chosen as a case study.

The main operational site of a multinational steel producer in South Africa was selected as a case study for this research. The case study plant (herein referred to as plant) has a large employee base (> 4000 personnel), operates multidisciplinary systems (e.g., steam generation, power generation, power transmission, power distribution, air generation, water treatment and AC and DC machines) and consists of support (non-operational) services (e.g., human resources, procurement and marketing).

Multiple serious electrical incidents have occurred at this site in which personnel were severely injured, but no fatalities were experienced in the period under review (2010-2015). The plant offered the researchers full access to its organisational policy on incident investigations, access to lead investigators and the investigating team, and access to completed investigation records.

<u>Organisational Policy:</u> The plant had a single global organisational policy and referenced certain sub-procedures which described specialist applications like human performance indicators and cost/loss financial guidelines. A comparison was performed between the organisational policy and the investigation process requirement as collected from the literature.

<u>Completed Investigations:</u> In 2010, the organisation established a formal incident investigation software system (called the PIVOT system). 12 electrical arc flash incidents were identified between 2010-2015. Reports of earlier investigations, in hardcopy format only, were not archived by cause, so the study was limited to the 12 incidents captured electronically. These 12 incidents were examined in a similar fashion to the organisational policy, where a gap analysis against the applicable requirements for the investigation process collected from the literature was performed.

Investigators: The main operational site of the plant employed more than 200 operational employees (junior to senior managers and junior to senior technical specialists) who were expected to lead incident investigations as a function of their job grading. Details of these personnel were provided by the human resources department. A survey was issued to the investigators, which is discussed next.

3.4.2 The survey

The requirements of the investigation process from Table 2.1 were used to develop a survey for the investigators. A six-step method was employed: The first three steps included the planning, development and issuing of the survey, and the second three steps included results, reporting and review (Ansari, 2012).

The survey used Likert-type statements with five choices ranging from "strongly agree" to "strongly disagree". Although the questions could be broadly categorised as "yes/no" or "agree/disagree", it was important to consider the aggregated feedback of differing experiences and include a neutral option. Adding "neutrally agree" and "neutrally disagree" creates a five-point scale that is beneficial as it allows for more degrees of choice (McLeod, 2008). It has also been shown that there is a substantial increase in the reliability of the data from a two (yes/no) or three (yes/no/neutral)-point scale to a five-to-seven-point scale (Rasmussen, 1989). The responses and results from the survey are presented in Chapter 4.

3.4.3 Participants, samples and sampling

A survey was issued at the plant to a population of 214 operational incident investigators and potential investigators. A potential investigator is one who may be called upon to investigate but has not yet investigated. Incidents of a predefined severity are required to be investigated by middle management, technical specialists or higher-level employees. This group has access to the internet and this enabled the distribution of the survey electronically. Although 314 prospective investigators were employed at the plant at the time of the survey, 100 personnel were employed in non-operational roles (specifically finance, procurement, sales and marketing) and were excluded from the survey. An internet-based survey was chosen. This allowed investigators to complete the survey at their convenience and ensured that the data would be readily available for statistical analysis.

Piloting the survey: Before the survey was issued, ethical considerations were addressed (discussed later in this chapter). The survey was issued to a pilot group consisting of one academic at the University of Witwatersrand and two engineers, one electrical supervisor and a safety specialist at the plant. The aim was to test the interpretation of the questions, measure the average time to complete the survey, identify technical or grammatical errors and ensure that the software used to issue the survey was functional. Upon feedback from the pilot group, minor grammatical and content changes were made. The survey was issued to all investigators at the plant in September 2014, with all ethical disclosures and instructions on how to complete the survey. The survey was issued via a free online survey website, SurveyMonkey® (www.surveymonkey.com).

A disadvantage of online surveys is a poor response rate. In order to mitigate this disadvantage and cover both peak and low business activities, the survey was issued at five different times: September 2014, October 2014, December 2014, January 2015 and June 2015. As can be seen in Figure 3.4, the response rates fluctuated from 25-35 respondents per month with the exception of January. The very poor response rate in January could be due to the fact that January is considered a vacation period in South Africa. The survey was issued once more in June 2015 with a better response compared to January. Although it could be argued that further issuing the survey could have increased the sample numbers, a representative sample (see details below) had been achieved and the survey was not issued again.

A total of 120 responses were received for a response rate of 56%. A total of 14 responses were not considered due to incomplete responses, reducing the usable total to 106. A sample mean is representative of the population mean for a sample size exceeding a count of 30 (or n = 30) in populations exceeding 500 (StatTrek, 2014) (Health, 2014) (Khan, 1998). Since the population was only 214, a 50% response rate (n = 106) provided a representative sample of the population

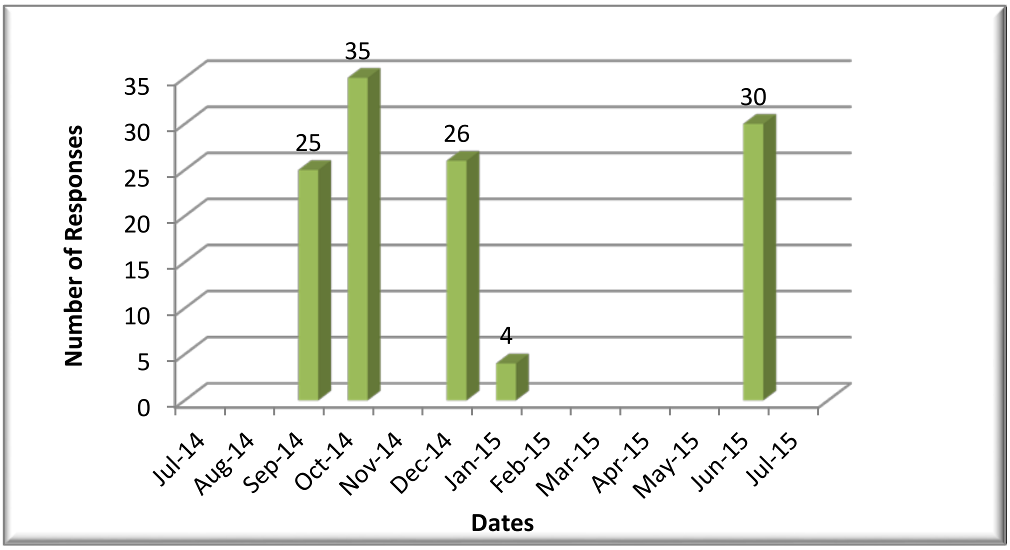

Figure 3.4 Trends of responses received over the survey period

3.5 Data Analysis

The survey data was analysed using IBM® SPSS® Statistics Version 23. Guidance on both statistical analysis and the IBM® SPSS® software was largely referenced using the SPSS Survival Manual (Pallant, 2005) and the LAERD website (Lund & Lund, 2013). The detailed validity and reliability of the survey data are presented in Appendix B.1 and summarised below.

A Principal Component Analysis (PCA) based on a correlation matrix and Kaiser-Meyer-Olkin (KMO) index were used to determine the validity of the results. All items in the survey, except two, were identified as non-redundant and retained. The two exceptions were:

(a) In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.

(b) Incident investigators blame people for incidents

These are linked to another item:

(c) Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).

All three items tested whether investigators blame people for accidents. These questions were paraphrased to test whether the investigators perceived themselves or others blaming people during investigations. This focus area was based on literature which described blaming as a common occurrence (Reason, 2000) (IRCA Global, 2010) (U.S. Department of Energy, 2012). The PCA did not justify the reduction of the 31 items, and all items were used in the analysis of the survey data. The overall KMO index was 0.734.

Cronbach's Alpha was used to measure the reliability of the data, as it is widely used when working with Likert items (Lund & Lund, 2013). A Cronbach's Alpha (α) value above 0.7 or higher is considered a good level of reliability (DeVellis, 2003) (Kline, 2005). The 31 items of the survey showed a high measure of reliability, as determined by a Cronbach's Alpha $\alpha = 0.878$.

Once the validity and reliability of the 31 items were proven, descriptive statistics using means, medians, frequency and graphs were used to analyse the survey data (presented in the next chapter).

3.6 Ethical Considerations

The plant was supportive of this research, as the improvement of safety resulting in the decrease of harm or loss is a core organisational value. The organisation provided the researcher with full access to relevant resources required. A confidentiality agreement was entered into by both the researcher and the plant.

Researcher bias was a factor since the researcher had professional ties with the plant. Researcher bias was avoided by ensuring that the researcher did not participate in any surveys and did not evaluate any work that the researcher was involved in directly. The data was analysed on the basis of literature thus avoiding personal influence and subjectivity.

Before accessing the plant information or communicating with parties relevant to this research, the researcher requested formal approval from the University of Witwatersrand Human Research Ethics Committee (Non-medical clearance number H14/07/17). The committee approved the application and a copy of the approval form can be found in Appendix B.2 - Ethical Considerations, Information, Consent and Clearance.

A Participant Information Sheet and a Consent Form were given to investigators. Using the online survey tool, the participants firstly had to acknowledge that they had read and understood the information provided in the Participant Information Sheet. The software then loaded the consent page where the respondent was required to provide written consent to taking the survey. Once these details were checked and approved online, the respondent could proceed to the survey. The Participant Information Sheet and a Consent Form can be found in Appendix B.2 - Ethical Considerations, Information, Consent and Clearance.

3.7 Summary

This chapter provided the research methodology, which would be used to combine and examine the three streams against the investigation process requirements. The organisational policy and records of completed investigations were analysed qualitatively against the investigation process requirements. The results from the survey of the investigators were analysed quantitatively using descriptive statistics. The results from the qualitative and quantitative analysis were interpreted using two variations of the triangulation method. The between-method allows for interpretation of results across quantitative and qualitive studies. The within-method allows for the interpretation of results from either a qualitative analysis or a quantitative analysis. Convergent or divergent findings that can be explained using the two variations of the triangulation method demonstrate that this approach is working. This approach is used to determine the effectiveness of the application of the investigation process.

In order to demonstrate this theoretical approach, a steel plant was used as a case study site. The process, as described above, was executed at the plant using an organisation policy and twelve completed arc flash incident records. A survey was issued to the investigators at the plant. The results of the survey were valid with a KMO measure of 0.734 and reliable with a Cronbach's Alpha of 0.878. All the results and findings from executing the approach at the plant are presented in the next chapter. A discussion on the findings follows the presentation of the results and findings.

4 RESULTS AND DISCUSSION

4.1 Introduction

In the previous chapter the approach to combine the streams and evaluate these against the investigation process requirements was defined. In this chapter, the results of the proposed research methodology are presented and discussed. The aim of this chapter is to demonstrate the interactions and mutual influences of the three streams when combined and evaluated, thus achieving the aim of this research.

Each of the three streams is discussed in Part A, Part B and Part C of this chapter respectively. The analysis and discussion of all three streams are consolidated and summarised in Part D of this chapter, leading to the demonstration of the triangulation method in Part E. The chapter concludes with a flow diagram presenting the between-method and within-method triangulation findings.

4.2 Analysis, Results and Discussion of the Three Streams

In Part A of this chapter, the organisational policy was evaluated against the investigation process requirements (Table 2.1). The results were then discussed. In Part B of this chapter, records of 12 completed investigations are evaluated against the investigation process requirements. The discussion of the results also included discussions from the analysis of the organisational policy requirements (from Part A). The results from the survey of the incident investigators are presented in Part C of this chapter. The discussion of the results included findings from the analysis of both the organisational policy (Part A) and completed investigations (Part B).

PART A

4.2.1 Organisational Policy

The organisational policy on incident investigations governs the investigation process in industry. It ensures that the process is followed in a thorough and effective manner, and addresses variability and misinterpretation by individuals (Liou, et al., 2008) (Ishikawa & Lu, 1985) (Johnson, 1973). This section examines the organisational policy on incident investigations at a case study plant. The organisational policy (Anon., 2013)[6] was compared to the established investigation process requirements and is shown in the next section (Table 4.1).

In the case study plant (herein referred to as plant), the organisational policy was first published in September 2008 in Europe and enforced across all operating units globally. In July 2013, the policy was revised in South Africa to include local legislation and updating of reference documents. This study reviewed the latest policy[7]. This section, denoted Part A in the chapter, does not examine whether the requirements in the policy are actually executed or understood in practise. Such aspects are examined when discussing the completed investigations and the investigator survey in Part B and Part C, respectively.

4.2.1.1 Analysis of the organisational policy

The audit and analysis of the organisational policy are now presented in Table 4.1. Certain positive findings, notable findings and recommendations for improvement are highlighted in bold text.

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[6] The case study organisational policy is not included due to confidentiality clauses which served as precursors for the Ethics Clearance Certificate with Protocol Number H14/07/17. The Harvard Style Referencing Guideline allows for anonymous referencing *In text*: (Anon., {Date}) and *In reference list*: {Organisational Reference}

[7] The reader should exercise caution when referring to the section numbering and section references in the analysis of the organisational policy section. References which state "policy section" refer to a particular section in the organisational policy and not to sections within this document. The referencing of sections within the organisational policy is provided to assist possible changes which the case study plant may wish to implement on the organisational policy.

Table 4.1 Analysis of the organisational policy

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	**Comments** Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
1	Near-misses should be investigated in detail as the root causes of a near-miss could produce serious and catastrophic accidents	Yes	1: "…investigation of incidents including potential (near hits) incidents…"	The investigation of near hits or near-misses is discussed extensively throughout the policy.
2	Structured guidelines should outline what type of incidents require investigating	Yes	1: "…incidents in the field of safety, health, environment, risks and quality…"	The policy covers all fatalities, lost time injuries, restricted work day cases, adapted cases, medical attention, first aid, near-miss. In addition, quality, health, equipment damage, technical incidents, environment, fire and emergency preparedness, legal compliance and external complaints should be investigated Any incident which could have potentially resulted in any of the items mentioned above should be investigated.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
3	The incident investigation process begins as soon as the incident becomes known	Yes	1: "…ensure the prompt reporting, recording and investigation of all work related incidents…" 5(1): "All incidents must be reported before the end of the shift"	The policy requires that the entire investigation process begins promptly and not just the evidence collection. The formal reporting of the incident can also flag the initiation of the investigation process.
4	Statements and other information from the scene should be collected promptly	Yes	6.4: "Activity 1 – Collect incident data…interviews"	Section 6.4.1 provides step by step guidelines on interviews and data collection to support the lead investigator.
5	Incidents which require investigation should be investigated	Not Applicable		It is possible to determine which incidents should be investigated (question 2). It is, however, not possible to determine whether such incidents *are* being investigated through a policy analysis. The survey and completed incident investigations may provide more insight into this question.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	**Comments** Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
6	Independent Subject Matter Experts (technical and safety system related) should be included in the incident investigation group to prevent biased outcomes	Yes	6.2: "Outside interested and effected [sic] parties"	This section in the policy covers incident investigation role players. The use of the wording "interested" and "effected" [sic] does not instruct the involvement of an independent expert. An independent expert may neither be "interested" nor "effected" [sic] and does not need to be part of the investigation. The policy does not instruct the lead investigators to appoint such Subject Matter Experts. The policy also fails to guide the lead investigator on the proper identification, selection and recruitment (the *who* and the *how*) of such Subject Matter Experts.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	**Comments** Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
7	The incident investigation team should be represented by the correct mix of people to ensure that all important aspects are covered during the investigation (e.g. Safety, Health, Environment, Risk and Quality (SHERQ) systems experts, technical Subject Matter Experts)	Yes	5.1: "Others experts, outside and interested parties can be involved in incident investigations where required" 6.2: "Investigator, reporter, injured (involved party), witnesses, SHERQ, Health and Safety Representative, union or employee representative, Outside interested and affected parties" 6.4.1: "Persons who can contribute because of their knowledge of equipment, procedures or past experience (e.g., trainers, Maintenance, Engineering, Asset Protection Services) – Subject Matter Experts"	The first reference to include the correct mix in the investigating team is rather vague by using terms such as "interested" and stating "experts" without defining the field of expertise. Similar to the notes in question 6, this point focusses on SHERQ personnel and omits to discuss the compulsory inclusion of technical Subject Matter Experts This point provides the final clarity requiring subject matter expert involvement. It is still unclear on how the policy addresses subjects (and subject matter experts) which the investigator may incorrectly consider irrelevant

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
8	Investigators should have received formal training on incident investigation techniques used by the company (e.g. RCAT, CED, 5 Whys, etc.)	Yes	6.3.2: "The organisation shall ensure that employees conducting incident investigations are adequately trained in the incident investigation process, including the root cause analysis and critical decision analysis methods or their equivalencies"	It should also be noted that throughout the document the investigator is guided on the application of techniques such as the CED, the 5 Whys, SCAT and MORT. The policy references these techniques by name and further stipulates the stage of the investigation in which these techniques should be used.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
9	Investigators should have received formal training on the company's incident investigation policy	Yes	5.1: "The incident investigation policy expert should present incident investigation workshops to align basic principles" 9.1 "After training, the investigator must be declared competent to ensure that they have acquired the understanding, knowledge and skills necessary to safely and honestly perform their duties"	The person responsible for this policy in South Africa and at each operational unit shall present workshops to ensure that investigators understand the principles of the policy. Section 9.1 of the policy requires that investigators be trained on the policy every 2 years supported by an annual refresher training class. The policy further requires a competency declaration.
10	The lead investigator should be experienced in the incident investigation process	No	9.1: "All incident investigators must be trained and declared competent"	Section 9.1 of the policy requires that investigators be trained on both the policy and investigation techniques and declared competent. There is no reference in the policy which requires that investigators be experienced.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
11	Other investigators or supporting investigators should be well experienced on investigation techniques	Not Applicable		This question is examining the perception of the team members towards the lead investigator and vice versa. It is examined in the investigator survey and not meant to be discussed in this section.
12	The incident investigation team should be provided with clear roles and responsibilities	Yes	6.2: Section titled: "Incident investigation role players" 6.4.1: "Acting as the lead investigator, incident investigations are normally organised and conducted by the immediate supervisor of where the incident occurred"	The roles and responsibilities for each person in the investigation team are provided in section 6.2. The onus is on the lead investigator, however, to assign these responsibilities to specific personnel as required in section 6.4.1.
13	Time frames should be specified for the completion of incident investigation reports	Yes	5(3): "Safety related injuries to be investigated within 7 days. Other incidents to be investigated within 14 days"	Time frames are stipulated.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
14	When time frames are specified, these times should be strictly adhered to	Not Applicable		Cannot be determined exclusively from an organisational policy. Question 13 above stipulates the time frames for investigations. It is, however, not possible to determine if time frames are adhered to from a policy. Examining completed incident investigations may provide more insight into this question.
15	Investigators should be somewhat protected from operational responsibilities and allowed to focus on a thorough incident investigation	Yes	6.32.: "The organisation shall ensure that employees participating in an incident investigation are provided with adequate time and resources to participate effectively in the incident investigation process"	An organisation can only provide investigators with more time by freeing them from day-to-day responsibilities and allowing them time to focus on the investigation.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
16	Investigators shall be offered adequate time to complete a thorough incident investigation	Yes	5(3): "Safety related injuries to be investigated within 7 days. Other incidents to be investigated within 14 days."	Although 7-14 days may be considered adequate for an investigation, the requirement from question 15 should be in place. The organisation is required to support investigators by allowing them to focus on the investigation instead of daily operational responsibilities.
17	Where human error is a factor, investigators should be provided with a sound guideline or matrix detailing the human error causal factors and working environment factors	Yes	6.4.3 (Human factors as root causes): "If the investigation comes to the conclusion that the human factor has contributed …it is necessary to investigate why this occurred… an investigation is needed into the why of the detected Human Factor so actions can be taken to avoid repetition."	It should be noted that three pages are included in the body of the policy describing and assisting the investigator. There is also a separate policy dedicated to human performance indicators for more in-depth theory and support on corrective actions.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
18	People should not be blamed for incidents caused by a failure in a management procedure (such as safe working or safe operating procedures)	Not Applicable		Questions 18-20 are established to judge any predisposition toward blaming. It is examined in the study of completed incident investigations and the survey. It is important to note, however, that the policy does provide sound guidelines to ensure that human factors are addressed through changes in management system rather than assigning blame. See notes from question 17.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
19	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, investigators should study the HIRA management systems for root causes instead of concluding that the root cause was a task initiator error (blaming people)	Not Applicable		See notes from question 18
20	Incident investigators should avoid blaming people for incidents (investigate beyond the blame culture)	Not Applicable		See notes from question 18
21	Incident investigators should probe human behavioural management systems (e.g. individual development plan, training matrices)	Yes	5(8): "plants must manage all changes to related documents such as plant procedures, HIRA's, training modules and assessments, checklists, etc. where applicable."	The policy does not specifically state which systems should be investigated, but rather mentions it via the corrective actions. This is considered a less effective and indirect approach via the use of the word "*etc.*". It is nonetheless covered in the policy.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	**Comments** Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
22	Incident investigators should probe engineering management systems (e.g. change management)	Yes	5(8): plants must manage all changes to related documents such as plant procedures, HIRA's, training modules and assessments, checklists, etc. where applicable.	See notes from question 21
23	Incident investigators should probe maintenance management systems (e.g. maintenance strategies)	Yes	5(8): plants must manage all changes to related documents such as plant procedures, HIRA's, training modules and assessments, checklists, etc. where applicable.	See notes from question 21
24	Incident investigators should probe operational management systems (e.g. safe operating procedures)	Yes	5(8): plants must manage all changes to related documents such as plant procedures, HIRA's, training modules and assessments, checklists, etc. where applicable.	See notes from question 21

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
25	Incidents that occur at other operating units should be communicated across the company's global operations. (This does not refer to a 24-hour flash or 1-page report of the incident, but rather to the completed investigation report)	Yes	7.3 "If the incident and the actions being taken have any application to other Business Areas/departments or areas and they have not been involved in the investigation to-date, a copy of the investigation should be shared with the other Business Areas/departments/areas as soon as possible." 7.5: "A formal system must be in place to communicate and manage activities with similar risks and potential failures within the entity. This includes communication between operating units, departments to site to workshop etc. This includes significant incidents."	The policy is clear on the dissemination of completed incident investigation reports.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	Comments Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
26	A system should exist to enforce actions from other operating units' incident investigations across all departments or sections in a company	Yes	7.8 "All applicable incidents should be distributed to the relevant area." 7.8 "Applicable plant area manager should identify applicable corrective and preventive actions and manage it on an action sheet." 7.9 "The Departmental manager needs to sign-off the actions and verify the effectiveness of the actions, before the experience sharing would be seen as closed." 7.10: "Lessons learned from the outcome of an incident investigation should be communicated to prevent a similar incident from occurring."	The policy does require completed investigations to be shared and places the onus on the relevant departmental managers to sign off on the effectiveness of each action. One concern, though, is exactly how such "relevance" would be determined in a large and diversified organisation. Further clarity may be required on this point.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	**Comments** Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
27	The investigation should only be considered as completed when actions are verified for successful implementation. An investigation cannot be completed upon establishing root causes.	Yes	5(6): "Implemented actions must be followed up to close out and be verified for effectiveness (after 3 months)"	Incidents are not completed once the root causes are identified. The policy does spur the investigator to go beyond the root causes by stipulating that actions must be implemented and then tested for effectiveness.
28	A system should exist to ensure that all actions are implemented and verified for effectiveness	Yes	5(6): "Implemented actions must be followed up to close out and be verified for effectiveness (after 3 months)."	Although the policy states that actions should be verified for effectiveness, it fails to explain the details of such a verification process. Since this is a policy, the fact that verification was requested is considered adequate. The plant shall demonstrate exactly how the verification for effectiveness is performed.

Table 4.1 Analysis of the organisational policy (Continued)

No.:	Investigation Process Requirements	Referenced in policy	Examples quoted from the organisational policy (direct quotes)	**Comments** Note 1: Further comments are discussed in section 4.2.1.2 Note 2: Comments in this section are presented by the author. Wording within inverted commas are extracts from the organisational policy.
29	A system should exist to ensure that incidents are investigated thoroughly	Yes	4: “All proposed corrective and preventative actions must be reviewed through a risk assessment process prior to change and implementation.”	This vetting process tracks only part of the incident investigation process, viz., the actions. There is no requirement for the investigation to be checked before actions are implemented. See question 31 for more information.
30	Completed incident investigations should be audited against the company policy	Yes	5.1: “Perform cross site or internal audits to measure compliance”	This action is specifically assigned to the expert on the incident investigation policy.
31	Completed incident investigations shall be reviewed by experts on the company’s incident investigation policy	No		Although the auditing requirement is in place (question 30) for completed investigations, there is no review requirement specified; i.e., the final review and sign-off of the investigation is missing. There is, however, a review of actions required 6.4.4(6): “Responsible person for 1st and 2nd review and sign-off”

4.2.1.2 Discussion on the organisational policy

The organisational policy was compared to the applicable investigation process requirements. The comparison resulted in 23 “Yes” responses, six “Not Applicable” responses and two “No” responses. Removing the six not applicable questions yields 92% compliance and an 8% deviation from the literature-based requirements. Positive findings, notable findings and recommendations for improvements are highlighted in bold text. The comparison from Table 4.1 indicated two deviations.

First Deviation:

An investigation process requirement is: “Completed incident investigations shall be reviewed by experts on the company’s incident investigation policy”. There are two very similar requirements established from the literature. One requirement attempts to address whether “c*ompleted incident investigations are audited against the company policy*”. This is a management audit to identify improvement opportunities in the investigation policy as part of a continuous improvement program. It is not performed on each investigation. The requirement that “c*ompleted incident investigations are reviewed by experts on the company’s incident investigation policy*” is different. It requires that each investigation report be reviewed by an investigation specialist to verify thoroughness and compliance aspects. It ensures that: the synthesis of information has led to appropriate actions (Lundberg, et al., 2009); factual accuracy of the information is preserved (U.S. Department of Energy, 2012); and line management has reviewed and approved the investigation reports (Mannan, 2014).

The organisational policy requires that *actions* are firstly risk assessed and secondly reviewed for effectiveness (policy section 5.4). These two items, however, exclusively refer to the review of actions and not the review of the investigation report. The review of the final investigation report is absent from the investigation policy.

The absence of the review of the completed report can influence the quantity and quality of recommended actions. Although there are sufficient instructions on the review of actions in the policy, there are no references requiring the review of the completed investigation report.

Second Deviation:

The requirement that "*the lead investigator should be experienced in the incident investigation process*" was not mentioned in the organisational policy. Effective investigations require an investigation team which is both knowledgeable and experienced in the investigation process (Mannan, 2014). The "knowledgeable" aspects are covered in policy section 9.3, which states that "*it must be confirmed that investigators have acquired the understanding and knowledge to perform their duties.*" Experience is covered solely in the context of technical Subject Matter Experts in the policy section 6.4.1. **The organisational policy did not stipulate that investigators be experienced and (also) did not provide guidelines on how such experience may be gained**.

Errors and omissions owing to an inexperienced investigator may go unnoticed since the previous deviation in the organisational policy highlighted the absence of a need to review the investigation. There is a need for investigators to be educated, thus knowledgeable, at either tertiary facilities (Saleh & Pendley, 2012) or by the organisation (Jørgensen, 2011) but the organisational policy should further stipulate how experience is gained. **It is also recommended that investigations be reserved for experienced investigators.**

Compliance:

The organisational policy displayed 92% compliance to the generic requirements for investigations as established from literature. Although commentary on the compliance is provided in Table 4.1, there are other references from the literature that warrant further discussion.

i. Effective investigations require the involvement of independent persons as well as the correct mix of technical and systems knowledge in the investigation team (Mannan, 2014). These needs are expressed in two separate investigation process requirements. Firstly, "*independent persons are included in the incident investigation group to prevent biased outcomes (e.g., an engineer from another plant)* " ensures that section specific biases or a local plant culture do not influence the outcome of the investigation (Broadribb, 2012).

ii. Secondly, "the incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)". The Toyota Way Fieldbook requires that all levels of organisation, including safety officers, operators, engineers, maintenance, commercial and finance personnel, understand investigations (U.S. Department of Energy, 2012) (Liker & Meier, 2006). Although one person may have the necessary skills, excellence is achieved by the collective knowledge of various Subject Matter Experts (Johnson, 1973).
The case study plant policy addresses the correct mix of persons (policy section 6.4.1) "Persons who can contribute because of their knowledge of equipment, procedures or past experience (e.g., trainers, maintenance, engineering, asset protection services) – Subject Matter Experts".
Regarding the use of the independent persons, policy section 6.2 stipulates role players as "*outside interested and affected [sic] parties* ". The concern with this wording is that the policy does not instruct the involvement of independent persons but implies it. As mentioned previously, outside parties may not be interested nor may such parties believe that they are affected by the incident. Policy section 6.4.1 then requires that "*persons who can contribute because of their knowledge of equipment, procedures or past experience*

(e.g., trainers, Maintenance, Engineering, Asset Protection Services) – Subject Matter Experts" form part of the investigation team. The concern with this clause is that it is left to the lead investigator to determine which subject matter expert should form part of the team. In the absence of specific requirements for the investigating quorum, subjectivity or oversight by the lead investigator could possibly influence the investigation. **Although the inclusion of independent persons is addressed in the organisational policy, the revision of wording which may provide more sound guidelines to the lead investigator can be beneficial.**

iii. The benefit of using several investigation techniques allows for cross checking and harnesses the individual strengths of different techniques to support the common goal of the investigation (Philley, 1992) (Sklet, 2004) (U.S. Department of Energy, 2012). When considering the requirement that "*Investigators should have received formal training on incident investigation techniques used by the company (e.g. RCAT, CED, 5 WHYs, etc.)*" several references are made within the investigation policy. Firstly, section 9 specifies the need for training on investigation techniques over and above training on the policy. Secondly, there are several references where the policy attempts to both train and stipulate the use of multiple investigation techniques. Section 5.1 calls for the use of the SCAT technique for major incidents while section 4(1) discusses the CED. Section 6.3.1 refers to a "critical decision analysis" as a human performance indicator while section 6.4 covers the 5 Whys and Management Oversight and Risk Tree (MORT). These techniques have been used historically in industry (Amyotte & Oehmen, 2002) (Doggett, 2004) (Jørgensen, 2011) (Lundberg, et al., 2009) (Phimister, et al., 2003). The fact that all these methods are covered in the policy indicates that **comprehensive guidelines and reference materials are available to the investigator. Although these**

make the policy lengthier, they are beneficial to an inexperienced investigator.

iv. Blaming people or ending an investigation when human error is detected does not address the latent conditions which resulted in such behaviour (U.S. Department of Energy, 2012), (Leveson, 2001) (Rashid, et al., 2014) (Reason, 2000) (Vincent, et al., 2000). The investigation policy firstly informs the investigator why it is necessary to go beyond blaming people in section 6.4.3 (Human factors as root causes): "*If the investigation comes to the conclusion that the human factor has contributed …it is necessary to investigate why this occurred… an investigation is needed into the* ***why*** *of the detected human factor so actions can be taken to avoid repetition.*" The policy then provides three pages of information guiding the investigator on how to establish human factors root causes and how to implement preventative and corrective actions. In addition, a separate four-page reference procedure (Anon., 2012) is made available for more detailed guidance to the investigator. Human factors experts are discussed later in this section.

v. The dissemination of information across business units and departments is considered a critical learning point and an essential element of an investigation (Lundberg, et al., 2009; Rollenhagen, et al., 2010) (Phimister, et al., 2003). The requirement that "a *system should exist to enforce actions from other operating units' incident investigations across all departments or sections in a company*" addresses the improvement principle that root causes are resolved in the global safety management system and not merely by a local or plant-specific procedure (Chua, et al., 2004) (U.S. Department of Energy, 2012). The enforcement of actions globally is required irrespective of how remote or small a plant may be since gaps in a safety management system may manifest in incidents in various ways and areas.

It is thus imperative that the organisational policy provide a clear and unambiguous instruction that actions should be enforced globally. The organisational policy in section 7 describes that all applicable actions should be distributed to plants with similar risks. In such a large and diverse organisation, the policy fails to describe exactly how such risks are quantified. Since investigation reports are very detailed, are such reports understood by workers who are not specialists? If so, should a summary not be considered? It is likely that such concerns can influence the dissemination of information in the other streams.

vi. Several important compliances are noted in the organisational policy. These include:

- Clear definition of roles and responsibilities
- Timelines with the instruction to free up personnel to focus on the incident
- Guidance to investigators on calming personnel and extracting statements as soon as the accident is known
- Assessing actions for risk before implementing
- Tracking all actions to closeout
- Auditing the action to test for effectiveness three months after completion

General notes on the investigation policy

Certain findings could not be classified simply as conforming or non-conforming but require clarification in the policy.

i. The organisational policy requires that investigators are trained and declared competent on investigation techniques and the policy. Policy section 9.3 further states that "after completion of training investigators must be declared competent to ensure that they have acquired the understanding, knowledge and skills necessary to safely and honestly perform their duties". Synonyms to the adjective “competent” include words such as “accomplished” and “skilled”, whilst the Merriam-Webster dictionary defines “competent” as the ability to do something well enough to meet a standard. The South African Occupational Health and Safety Act, 1983 (Act 6 of 1983) summarises the requirements of a Competent Person in the General Machinery Regulations (GN1521 of 5 August 1988) as a person who has been educated in the particular discipline through a tertiary institution followed by a minimum number of years of relevant practical experience, then examined for competence supported by ongoing practical experience.

The organisational policy does not state exactly how an investigator is declared competent. Training and post training tests do not warrant competency, as some form of practical exposure is required. The absence of stating exactly how competency is achieved is linked to the non-compliance discussed in the previous section regarding the policy failing to stipulate that experienced investigators lead the investigation.

The policy also fails to stipulate what constitutes a subject matter expert. The organisational policy in section 6.4.1 refers to an investigation team consisting of “*persons who can contribute because of their knowledge of equipment, procedures or past experience (e.g. trainers, maintenance, engineering) – Subject Matter Experts*”. This omission may be considered rather trivial; however, a plant maintenance subject matter expert may be prone to plant biases. In a large plant consisting of more than 4000 employees, identifying independent Subject Matter Experts may not be trivial. In addition, it is expected that the lead investigator involves relevant Subject Matter Experts. An alternative approach may be that the Subject Matter Experts comment on the need for their involvement in combination with the lead investigator (U.S. Department of Energy, 2012).

Finally, the organisational policy calls for Subject Matter Experts, but there is a level of expectation that the investigating team addresses the human factors and human error causes. Policy section 6.4.1 stipulates that the investigation team must systematically follow the additional human factors procedure while section 6.4 stipulates the determination of human factors as a key activity in the investigation process. Although the investigator is not explicitly prohibited from including a human factors expert in the investigation team, there is no mention of a human factors subject matter expert in the policy. The policy does provide detailed guidelines pertaining to human factors and does require training and a validation of competency. The effectiveness of these requirements is further investigated below when examining the human factors causes in completed incident investigations.

ii. Although the plant has several operating units across South Africa which operate as independent businesses, the organisational policy originated at the European head office. The policy was then revised to reference South African legislation and other operating policies in the plant.

The impact of the policy originating in Europe and being adopted in South Africa should be considered. The literature used to establish the investigation process requirements was based on international references (outside of South Africa) and the policy largely aligned to the literature requirements. As a result, not much can be said looking at the compliance with literature alone. It was found, however, that the policy was minimally altered and adapted to reference South African legislation. These references and interpretations appeared throughout the policy using common language in an easy to understand manner. Practical examples used in the policy are based on similar equipment and processes used in the South African operations, creating a sense of familiarity. **It is thus unlikely that the international origin of the organisational policy has a notable bearing on the effectiveness of the investigation process.**

The next section (iii-v) discusses items contained in the investigation policy which are not considered a minimum requirement for an effective investigation but are relevant to the research.

iii. Formal Incident Management System (FIMS): A readily accessible background of information, preferably a software database, is important to track past similar incidents (U.S. Department of Energy, 2012) (Mannan, 2014). The investigation policy requires a FIMS, a software based tool. FIMS should allow for the:

(a) Incident reporting

(b) Investigation process

(c) Action risk assessment, action allocation and action implementation

(d) Pre-investigation and post investigation risk assessment

(e) Investigation tracking

(f) Investigation reporting

(g) Investigation data storage

The FIMS established at the plant is called the PIVOT system. Not all investigation techniques and requirements discussed in the investigation policy were functionally available in the PIVOT software tool. This is due to the fact that the policy does not require PIVOT to be a software manifestation of the policy. The FIMS only needs to achieve items (a) to (g) above. All data including the investigation report may be uploaded using the PIVOT data storage functionality.

iv. Classification of incidents: The investigation team or management may escalate the classification of an incident based on the potential loss or harm. Section (2) of the policy states that "*Any incidents that* *could have led to a fatality, loss time injury or significant damages*" will be investigated. This point is elaborated in section (6.5) of the policy, which states that "*near hits will be investigated based on the potential risks that could lead to a fatality, loss time injury or significant damage*". This implies that any incident may be classified based on the potential severity instead of the actual severity.

v. Investigation requirements: The organisational policy provides a table on the documentation requirements per incident category. The information is shown in Table 4.2.

Table 4.2 Investigation requirements as per the organisational policy

Category	**Minor Injury**	**First aid and medical Treatment**	**Lost time injury**	**Serious incident (technical)**	**Fatality or significant incident**
Deliverables	None	Sequence of events reporting Photo report	Sequence of events reporting Photo report Portfolio of evidence	Sequence of events reporting Photo report Portfolio of evidence	Sequence of events reporting Photo report Portfolio of evidence
Capture on FIMS (PIVOT)	Yes	Yes	Yes	Yes	Yes
Investigation on FIMS (PIVOT)	Yes	Yes	Yes	Yes	Yes
Sign-off (upon completion)	Junior manager	Junior manager (first aid) Middle manager (medical)	Plant manager	Production or engineering manager	General managers (operating unit and SHERQ)

Minor injuries are classified as those which do not require any form of first aid or medical treatment. A first aid treatment is any treatment provided by a basic first aider whilst medical treatment requires a doctor or nursing assistant's intervention. According to Table 4.2, all incidents should be investigated. Accidents of greater severity require higher levels of management to approve (sign off) the investigation.

The portfolio of evidence is a hard copy (physical) file placed in storage for audit and legal requirements. It consists of the following items:

- A detailed investigation
- Investigation data
- A PowerPoint presentation on the incident in the prescribed format, the sequence of events, and photographs
- A detailed investigation report

The portfolio of evidence is only required for lost time injuries and other significant incidents. It is not required for first aid and medical treatments. This reduced documentation requirement with lower levels of management approval for first aid and minor injury incidents should be noted. Considering the fact that near-misses and fatalities have common root causes, reduced recording and approval requirements for minor injuries may negatively influence the investigations. This is discussed further when examining the completed investigations in the next section.

A summary of the results and discussion of this section were deferred to Part D of this chapter. This allowed summarising the core findings before demonstrating the triangulation method.

PART B

4.2.2 Completed incident invetsigations

Records of completed incident investigation were reviewed to understand how well investigations were performed. If the completed incident investigations are ineffective, identifying the reasons and proposing corrective actions will make the organisational policy more robust and subsequently improve the investigation process (Nicolini, et al., 2011) (Ishikawa & Lu, 1985) (Johnson, 1973). The analysis of the completed investigations was also in the form of a comparison against the investigation process requirements collected in the literature. In addition, completed investigations were critically analysed using the requirements from the organisational policy; this is a form of the *within-method* data triangulation. It was expected that non-compliances (deviations) identified in the organisational policy would have an impact on the completed investigations. Part B of this chapter examines whether the organisational policy has been effectively applied to completed investigations; in other words, whether what happens in practice is according to the policy. The analysis of the completed investigations is based on the investigation process requirements as well as the requirements from the organisational policy.

4.2.2.1 Analysis of completed investigations

The plant has a software database of incident investigations dating back to 2010. This database is accessed via the PIVOT software system and consists of completed investigation reports, pictures and correspondence. Prior to 2010 only hard copies of the completed investigations were available. The hard copy archives lacked a formal indexing system. It was therefore, not possible to sort and extract the relevant electrical arc flash investigations from the archives containing several hundred hard copies. The search of the PIVOT database system was more successful, yielding 12 electrical arc flash incidents which occurred between the years 2010-2015. Eleven of these were incidents which resulted in harm and loss while one was a near-miss incident. No electrical related fatalities had occurred during this period. These 12 investigations form the basis of the analysis of completed investigations at the plant.

As discussed in the introduction and the analysis of the organisational policy, each investigation process requirement may not be applicable to all three streams. A review of all 31 of the requirements to determine applicability to the completed investigations is presented in Table C1 (Appendix C). Certain questions were rephrased to improve readability when discussing the results.

Applicability of an investigation process requirement was determined on the basis of the literature. As an example, the literature required that structured guidelines should outline what types of incidents require investigating. This requirement is applied through the organisational policy on incident investigations. The interpretation of this requirement is tested by surveying the investigators. The study of completed investigation records does not seek to determine if such guidelines are present. Such an investigation process requirement is thus not applicable to this stream.

Of the total 31 requirements, 19 were determined to be applicable investigation process requirements [presented in Table C2 (Appendix C)]; these were used to comment on the 12 completed investigations. If the process requirement is met, then the evidence supports the audit question and it is noted as compliant. Where no evidence is found or the intent of the audit question is not fulfilled, it is noted as non-compliant.

A discussion on each investigation is presented together with the percentage of compliance and non-compliance achieved. After the 12 investigations are analysed, a discussion on the overall compliance per audit question is presented.

In order to provide a background on the incident, extracts of the plant internal communications were presented in Table 4.3. A picture from the communication was also included and minimal changes were made to improve the grammar or to remove names. Following the description of the incident, Table 4.4 provides the qualitative analysis against the investigation process requirements. Discussions on the findings are then presented.

The organisational policy required differing levels of reporting and approval depending on the severity of the incident. These are presented in section 2.4.4.2 (e). Minor Injuries (MI) and First Aid (FA) injuries required a junior manager's approval while lost time injuries required the plant manager's (departmental manager's) approval. Minor Injuries did not require any form of reporting, but the investigation had to be captured on PIVOT. These incident types are marked "MI" and the report type is indicated as "None". First Aid treatments required a photo report. These types of investigations were presented as 24-hour reports with a sequence of events usually not more than 2 pages long. These are marked "FA" and the report type is indicated as "Short". Lost time injuries require a portfolio of evidence in hard copy consisting of a detailed investigation, detailed investigation report, all investigation data, and a presentation on the incident in the prescribed format, the sequence of events and photographs. These incident types are marked "LTI" and the report type is indicated as "Full". The report types are categorised as: a) "Short" - a one-page report, b) "None" - a report was not required, and c) "Full" - required a detailed investigation report. The number of people involved in the incident implied the number exposed or injured.

The comparison of all 12 electrical arc flash incidents was performed. One of each incident category (except two LTIs), is presented next and the remaining comparisons are available in Appendix C, Table C3 and Table C4. One MI (Inv 1 of 12) and one FA investigation (Inv 4 of 12), two LTI investigations (Inv 3 of 12 and Inv 12 of 12), and the near-miss investigation (Inv 11 of 12) are now presented.

Table 4.3 Completed investigation 1 – Inv 1:

No:	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv1	25 August 2015	15:10	The injured employee was connecting the output cable from the battery charger to the battery set (220V DC). A washer remained on the terminal. The employee attempted to remove the washer using gloves but failed and then removed the left glove in order to remove the washer. The employee placed the washer on the bolt through the cable lug. While attempting to connect the bolt and cable lug on the battery terminal the polarities were mixed. A flash occurred, resulting in burns to the three (3) left middle fingers	MI	Full	1	Not wearing gloves while connecting the last terminal	Install isolating switch on the charger Retrain the artisans on the procedure	Test for polarity on DC circuits Use PPE and correct tools

Table 4.3 Completed investigation 1 - Inv 1 (Continued)

Table 4.4 Analysis of completed investigation 1 – Inv 1:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	Yes	Incident registration on PIVOT VDB127-201508 (< 24 hours)
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	Yes	Independent SHERQ specialist involved
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	SHERQ, subject matter expert and professional electrical engineer
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Trained on investigation techniques 10 October 2004 & 26 February 2003
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate no training received on the investigation policy
6	An incident investigation team is provided with clear roles and responsibilities	Yes	Stipulated on the investigation report

Table 4.4 Analysis of completed investigation 1 – Inv 1 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
7	If time frames are specified, these times are adhered to	No	Investigation completed after 9 days
8	Investigators are given adequate time to complete a thorough incident investigation	No	The investigator missed the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator failed to examine why the incorrect terminals were connected to each other, resulting in a short circuit and arc flash – they focussed on why the gloves were removed. A balanced inquiry appears lacking
10	Are investigators blaming people?	Yes	Employee was disciplined for not using PPE
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	The employees were trained on the new task procedure

Table 4.4 Analysis of completed investigation 1 – Inv 1 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Engineering safety into the system was considered by means of an isolating switch
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	No evidence found in completed investigation records
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	A new operational procedure was registered
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 "Are investigators blaming people?" is negatively phrased. A "yes" should count as a non-compliance.

(a) Commentary on Inv 1:

(i) The investigation process was handled systematically and displayed 63% compliance and 37% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. A simple examination of the context within which the person committed the error and the context of the task could have provided further improvements. The injured claimed that he was unable to remove a washer from around the battery with the glove on. The electrician received a final written warning for removing the glove. This decision was taken without following the human performance analysis, which goes against the requirements of the incident investigation policy.

(iii) The investigation was completed in 9 days instead of the required 7 days. Similar investigations were completed in the allotted timeframe. Three possible reasons for delays are external influences (day-to-day responsibilities), lack of commitment to the investigation, or awaiting forensic information. Since no forensic analysis was required in this case, external influence or a lack of commitment are possible.

(iv) The sequence of the investigation process consists of a preliminary investigation, identification of root causes and remedial actions, implementation, verification and close-out. This is referred to as the application of the incident investigation process. Literature requires that the preliminary investigation is reviewed for compliance. In this investigation, the lack of review was a deviation from the investigation policy and is now seen to manifest in completed incident investigations. There is, however, a formal review once all actions are verified. The investigation is then routed through the various management and SHERQ functionalities for review and close-out. Review after action verification is not in line with the literature requirements for effective incident investigations. Errors and omissions detected after the investigation process is completed can result in the frustration of rework. It can further result in unnecessary exposure to safety risks from not implementing effective corrective and preventative actions in due time.

(v) The Cause and Effect Diagram was used as the investigation technique.

(vi) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

(vii) It was noted that a full investigation report was not required for minor injury incidents, but one was provided in this instance. The investigators did not indicate (in the report) why this was done. Following the full report format appears to be the key driver in this MI investigation achieving the best compliance rating compared to the other MI investigations.

Table 4.3 Completed investigation 3 – Inv 3:

No:	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 3	19 May 2014	10:38	The injured persons were busy inspecting a 3.3 kV breaker that was reported to be faulty. The senior injured opened the cubicle to inspect the faulty breaker. The breaker was in the open position and did not want to close. A pin came out of a link on the latching mechanism and the injured tried to establish where the link should be connected. At that very instance the breaker failed mechanically and caused a flash between earth and the three 3.3kV phases. All three employees were burnt.	LTI	Full	3	Breaker mechanically faulty and not picked up by the safety mechanism	Will be determined during full investigation	During fault finding always treat equipment as LIVE!

Table 4.3 Completed investigation 3 – Inv 3 (Continued)

Table 4.4 Analysis of completed investigation 3 – Inv 3:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	No	Incident registration on PIVOT VDB136-201405 (> 24 hours)
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	Yes	Independent SHERQ specialist involved; engineer from other plant
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	SHERQ, subject matter expert, electrical engineer, mechanical engineer, maintenance manager, plant manager
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Investigators were trained on the RCAT investigation techniques (13 May 2005)
5	Investigators are trained on the investigation policy	Yes	Training records provided
6	An incident investigation team is provided with clear roles and responsibilities	Yes	Roles and responsibilities assigned
7	If time frames are specified, these times are adhered to	Yes	Investigation completed in 4 days

Table 4.4 Analysis of completed investigation 3 – Inv 3 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
8	Investigators are given adequate time to complete a thorough incident investigation	Yes	The investigating team adhered to the timeline
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	Yes	Human factors analysed
10	Are investigators blaming people?	No	Employee was disciplined for not using PPE but was not blamed for the incident
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	The employees were trained on the new task procedure
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Obsolete equipment replacement strategy developed
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	Yes	The maintenance philosophy on the obsolete breakers was completely revised
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	A new safe operating procedure was registered

Table 4.4 Analysis of completed investigation 3 – Inv 3 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(b) Commentary on Inv 3:

(i) The investigation process was handled systematically and displayed 79% compliance and 21% non-compliance.

(ii) The human performance analysis was effectively completed. It was established that human error was inadvertent and the root cause was identified as a "knowledge based mistake". The investigation policy guidelines then recommend the following control measure:

- Plan for abnormal "what if" situation (procedures and scenarios)
- Organisational learning (capture and share abnormal situations)
- Competence based learning (knowledge of system, decision-making techniques)

The actions implemented included the implementation of the abnormal scenario procedure, training and organisational wide communication on the topic and electricians received training on the electrical apparatus. Although other investigations did implement similar actions, the difference in Inv 3 was that the actions were developed in compliance to the investigation policy. It should be noted that the trend to study human factors was not sustained in Inv 2 and Inv 1 which were investigated after Inv 3

(iii) The investigation was completed in four days which was within the timeline. This was achieved in the context that forensic investigations were performed on the damaged circuit breaker.

(iv) Lack of review of the initial investigation was again a finding.

(v) The effects and causal factors charting technique as well as the human performance analysis techniques were used in this investigation.

(vi) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

Table 4.3 Completed investigation 4 – Inv 4:

No:	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 4	07 October 2013	09:45	The injured was busy isolating. When switching the breaker off, the fuse blew. The injured panicked and tried to escape over the handrail (1m), tripped and injured the left upper arm.	FA	Full	1	Running away because of noise when the fuse blew inside of breaker	Investigate possibility of removing the handrail partially to ensure an escape route on both sides	Establish escape route before any switching is done to ensure familiarity with the environment

Table 4.3 Completed investigation 4 - Inv 4 (Continued)

Table 4.4 Analysis of completed investigation 4 – Inv 4:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	No	Incident registration on PIVOT VDB096-201310 (> 24 hours)
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Investigation handled by plant personnel only
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	No	Only Independent SHERQ specialist involved
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Trained on investigation techniques 31 March 2009
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate no training received on the investigation policy

Table 4.4 Analysis of completed investigation 4 – Inv 4 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
6	An incident investigation team is provided with clear roles and responsibilities	Yes	As described in investigation report
7	If time frames are specified, these times are adhered to	Yes	Investigation completed after 2 days
8	Investigators are given adequate time to complete a thorough incident investigation	Yes	The investigator kept to the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	Yes	Human factors analysis was attempted. The effectiveness of the human factors analysis was, however, not fully harnessed. The investigators could have probed the employees' emergency preparedness and emergency response planning. This was not done in the investigation.

Table 4.4 Analysis of completed investigation 4 – Inv 4 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
10	Are investigators blaming people?	No	Employee was not blamed for the employee's actions
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	No	The opportunity to expand on the human factors analysis was missed. It is important to have a defined human error before performing a human factors analysis. It appears that the human factors analysis in this case was done more as a compliance action than a value adding action. This statement is based on the fact that all branches of the human factor analysis flowchart were included in the investigation.
12	Incident investigators probe engineering management systems (e.g. change management)	No*	Barriers were modified to include a "free" swinging gate. *The reason for the fuse failure during switching-off was not investigated.

Table 4.4 Analysis of completed investigation 4 – Inv 4 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	No evidence of maintenance expert inclusion was found in the investigation records.
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	No	No operational related aspects were examined. Simple opportunities for operational improvement did exist. An example would be standing to the side of the breaker during switching or the use of hearing protection (as required by the electrical safety policy)
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(c) Commentary on the Inv 4:

(i) The investigation process displayed 42% compliance and 58% non-compliance.

(ii) The investigation policy required human performance analysis, which was done in the investigation. It appears that the human factors analysis flowchart from the organisational procedure was copied and pasted in the investigation report. No initiating human error or human performance improvement area was pursued. Simple items such as emergency preparedness and hearing protection were plausible areas to examine. These could have identified system deficiencies or compliance issues, but this opportunity was missed. Once again a link must be established between these omissions and the review of the preliminary investigation. Several good actions are risk assessed and implemented which tends to mask the gaps and non-compliances within the initial investigation process.

(iii) The investigation was completed in 2 days.

(iv) The events and causal factors charting (ECFC) investigation technique was used.

- It is of concern, however, that the reason for the fuse operation under switch-off conditions was not examined. This is a relatively infrequent occurrence which may have had a basis in improper operating – such as load removal before switching.
- This could also be indicative of:
    a) not having the correct mix of expertise,
    b) ineffective application of the ECFC ,
    c) failure to undertake a preliminary investigation review,
    d) failure to probe engineering aspects and
    e) failure to reference historical events

(v) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

(vi) A full investigation report was noted for this first aid injury investigation. The policy does not require a full report and the investigators did not provide information on why a full report was provided.

Table 4.3 Completed investigation 11 – Inv 11:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 11	14 February 2012	16:15	A new substation was being built and supplies were being transferred. Over its 60 year history many undocumented changes had taken place. The knowledge was lost through staff turnover. After looking at drawings and trying best to trace the network, the plant was isolated and the contractor began pulling through cable. While performing cable length measurements for a new installation, a cable was lifted within close proximity to a suspected isolated bus. The 11kV busbars were live and when the cable touched the busbars an arc flash occurred.	Near Miss – Possible LTI	Full	3	Accessed wrong chamber	Implemented a special procedure for this type of work	Always test before touch

Table 4.3 Completed investigation 11 - Inv 11 (Continued)

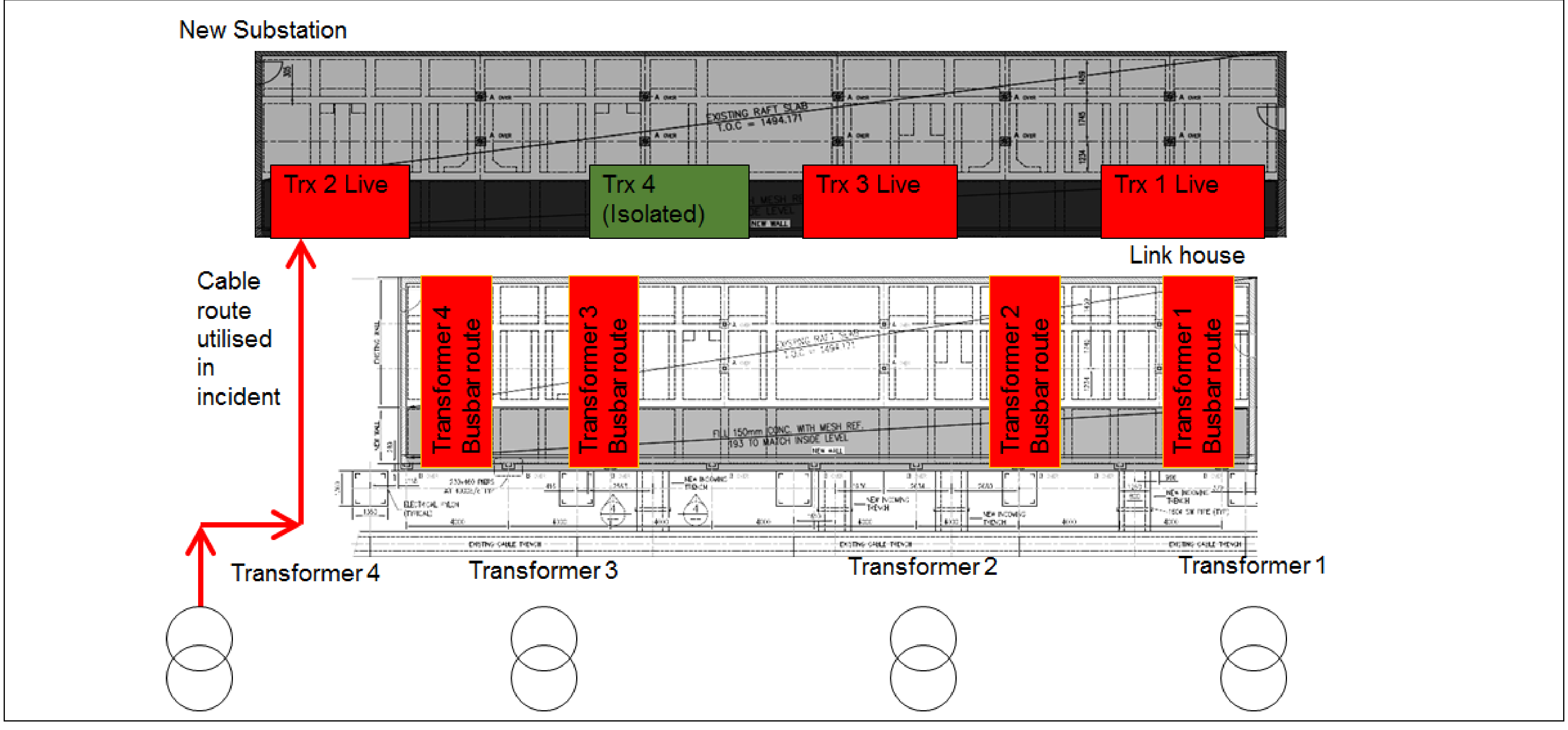

Table 4.4 Analysis of completed investigation 11 – Inv 11:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	No	Incident registration on PIVOT was not available or not uploaded
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	Yes	Electrical engineer from another plant
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	SHERQ specialist , electrical technician, project manager
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	No	Training records provided for all investigators indicate that no training was received on investigation techniques

Table 4.4 Analysis of completed investigation 11 – Inv 11 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate that no training was received on the investigation policy
6	An incident investigation team is provided with clear roles and responsibilities	Yes	As per investigation record
7	If time frames are specified, these times are adhered to	Yes	Investigation completed in 7 days
8	Investigators are given adequate time to complete a thorough incident investigation	Yes	The investigator was within the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	Yes	The investigator followed the investigation policy guideline on investigating human factors. The team probes a lack of knowledge, inadequate supervision and inadequate leadership

Table 4.4 Analysis of completed investigation 11 – Inv 11 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
10	Are investigators blaming people?	No	No employee or contractor was blamed for the accident
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	The employees developed a communication plan for the workforce
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	All drawings were updated and issued to all parties

Table 4.4 Analysis of completed investigation 11 – Inv 11 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	Yes	This was a maintenance task and the expert responsible was part of the investigation team.
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	Re-enforcement of test before touch rule and a new isolation policy was drafted
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(d) Commentary on Inv 11:

(i) The investigation process displayed 68% compliance and 32% non-compliance.

(ii) The investigation policy required human performance analysis, which was done in the investigation. During the investigation it was found that drawings and discussions had identified a rather complex network and isolation point. When the contractor tried to pull a cable into the work area, the equipment was still live. The failure of the technical information, the failure to test before touch and the absence of leadership were all explored. This human factor analysis produced several practical actions.

(iii) The investigation was completed in 7 days

(iv) The events and causal factors charting, 5 Whys, and human performance analysis techniques were used.

(v) The correct mix of investigators, combined with engineering and operational expertise, ensured a thorough investigation with minimal deviations.

(vi) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

Table 4.3 Completed investigation 12 – Inv 12:

No:	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 12	09 September 2010	09:00	Load removal was required on the 525V auxiliary board for the servicing of 11kV breakers and the transformer by the High Voltage (HV) qualified electrician. The corresponding 525V breaker had to be switched off by the Low Voltage (LV) qualified electrician. The 525V breaker did not want to trip manually (no remote closing facility). The HV electrician went to assist the LV electrician with fault finding. After the HV electrician attempted to probe the breaker with a stick an arc flash occurred damaging the right hand side of the 525V panel. The LV electrician used the prescribed PPE and was treated for trauma. The HV electrician received serious 2nd and 3rd degree burns	LTI	Full	2	The hazards pertaining to an abnormal situation, e.g., the 525V incomer breaker that did not want to trip, was not sufficiently addressed.	The board was isolated and the area was demarcated for further investigation and repair work.	If an abnormal or dangerous situation occurs in an electrical panel, isolate the section of the panel in question in order to do further fault finding safely.

Table 4.3 Completed investigation 12 – Inv 12 (Continued):

Table 4.4 Analysis of completed investigation 12 – Inv 12:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	Yes	Incident registration on PIVOT VDB221-201009 on the same day
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Plant personnel only
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	SHERQ specialist and professional electrical engineer
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Trained on investigation techniques 10 October 2004
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate no training received on the investigation policy
6	An incident investigation team is provided with clear roles and responsibilities	Yes	Stipulated on the investigation report

Table 4.4 Analysis of completed investigation 12 – Inv 12 (Continued)

No:	Investigation Process Requirements	Yes / No	Comments
7	If time frames are specified, these times are adhered to	No	Investigation completed after 9 days
8	Investigators are given adequate time to complete a thorough incident investigation	No	The investigator missed the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator failed to examine why the electrical permit was not revoked following a change on scenario. The investigator failed to examine why the injured chose not to use PPE
10	Are investigators blaming people?	Yes	Employee was disciplined for not using PPE
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	The employees were re-trained on the task. New training on arc flash hazards developed.
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Forensic investigation performed with breaker supplier

Table 4.4 Analysis of completed investigation 12 – Inv 12 (Continued):

No:	**Investigation Process Requirements**	**Yes / No**	**Comments**
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	No reference to this action in the records.
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	A new operational switching procedure was registered
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(e) Commentary on Inv 12:

(i) The investigation process displayed 58% compliance and 42% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. The permit allowed for the switching of the 525V breaker. When the breaker failed to trip, the permit fell away and a new work permit should have been requested. The injured HV electrician deviated from the permit requirements and tried prodding the 525V breaker when it exploded. The seriously injured HV electrician did not use any arc rated PPE, while the LV electrician (standing beside him) used the required PPE. The HV electrician was warned about the risks but ignored the advice. Why did the workers choose not to re-issue the permit and switch the high voltage (11kV) supply off? Why did the injured refuse to use PPE? The opportunity to examine these human factors in terms of using the minimum PPE and adhering to electrical permit requirements was not pursued.

(iii) The investigation was completed in just over a week.

(iv) A combination of the MORT and SCAT techniques was used.

(v) The injured were suspended following a disciplinary hearing. In several other incidents since 2010 (when Inv 12 occurred) workers failed to use prescribed PPE. Had the human factors of why a worker would choose not to use PPE been established, some of the incidents discussed may not have transpired.

(vi) Earlier in the week, the injured worker's direct manager stated that the breaker should be inspected. The manager implied that a technician inspects and repairs; however, the workers perceived the instruction as <u>they</u> should attempt to inspect and repair. The investigation around this human factor was not pursued.

(vii) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

Table 4.5 Tabular summary of the analysis of completed investigations

No:	Investigation Process Requirements	Inv 1	Inv 2	Inv 3	Inv 4	Inv 5	Inv 6	Inv 7	Inv 8	Inv 9	Inv 10	Inv 11	Inv 12	Total Yes	Total Yes %	Total No	Total No %
1	The incident investigation process begins as soon as the incident becomes known	Yes	No	No	No	Yes	Yes	No	No	Yes	Yes	No	Yes	6	50%	6	50%
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	Yes	No	Yes	No	No	Yes	No	No	No	No	Yes	No	4	33%	8	67%
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	Yes	Yes	No	Yes	Yes	No	No	No	No	Yes	Yes	7	58%	5	42%
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	8	67%	4	33%
5	Investigators are trained on the investigation policy	No	No	Yes	No	No	Yes	No	No	No	No	No	No	2	17%	10	83%

Table 4.5 Tabular summary of the analysis of completed investigations (Continued)

No:	Investigation Process Requirements	Inv 1	Inv 2	Inv 3	Inv 4	Inv 5	Inv 6	Inv 7	Inv 8	Inv 9	Inv 10	Inv 11	Inv 12	Total Yes	Total Yes %	Total No	Total No %
6	An incident investigation team is provided with clear roles and responsibilities	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	9	75%	3	25%
7	If time frames are specified, these times are adhered to	No	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No	5	42%	7	58%
8	Investigators are given adequate time to complete a thorough incident investigation	No	No	Yes	Yes	No	No	No	Yes	No	Yes	Yes	No	5	42%	7	58%
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	No	4	33%	8	67%
10	Are investigators blaming people?	Yes	No	No	No	No	No	No	No	No	No	No	Yes	2	17%	10	83%
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	Yes	Yes	No	No	Yes	No	No	No	No	Yes	Yes	6	50%	6	50%

Table 4.5 Tabular summary of the analysis of completed investigations (Continued)

No:	Investigation Process Requirements	Inv 1	Inv 2	Inv 3	Inv 4	Inv 5	Inv 6	Inv 7	Inv 8	Inv 9	Inv 10	Inv 11	Inv 12	Total Yes	Total Yes %	Total No	Total No %
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Yes	Yes	No*	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	10	83%	2	17%
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	Yes	Yes	No	No	Yes	No	No	No	No	Yes	No	4	33%	8	67%
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	No	Yes	Yes	8	67%	4	33%
15	Did the investigator reference previous incident investigations?	No	No	No	No	No	No	No	No	No	No	No	No	0	0%	12	100%
16	Did the investigator consider the effectiveness of historical actions?	No	No	No	No	No	No	No	No	No	No	No	No	0	0%	12	100%
17	Are actions risk assessed and implemented?	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	11	92%	1	8%
18	Are completed actions verified for effectiveness?	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	11	92%	1	8%
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	11	92%	1	8%

4.2.2.2 Discussion on the analysis of completed incident investigations

Completed incident investigations were analysed against the investigation process requirements. Ultimately, the organisation must review completed investigations to measure the level of enforcement of the organisational policy and continuously improve the policy (Amyotte & Oehmen, 2002) (Ishikawa & Lu, 1985) (U.S. Department of Energy, 2012).

A total of 12 completed incident investigations were analysed and these displayed 49% compliance levels (51% non-compliance) to the investigation process requirements. None of the 12 incidents produced a compliance rating of 80% or more. The compliance score of each question is shown in Table 4.5 and the observations are now discussed.

a) Management review and verification

In the context of the poor compliance to the literature, the question testing whether "*a system exists to ensure that incidents are investigated thoroughly*" displayed 92% compliance. In the PIVOT system, once all actions are completed and verified, the investigation is signed off by the relevant manager (depending on the type of incident). Eleven investigations were signed off (hence 92% compliance). With an overall average 51% non-compliance over the 12 investigations, it is clear that the *effective* review of the overall investigation is lacking. This was also noted as a deviation in the organisational policy. The review and verification of the action followed within a day or two of the completion of the action. The organisational policy required this verification be completed after three months. These findings indicate that the verification of actions and the sign-off by management are handled more as a procedural formality than a comprehensive peer review process.

The onus is on management to verify that actions are effective (Lundberg, et al., 2009) and that management reviews the investigation report (Mannan, 2014). The poor compliance noted amongst all 12 investigations compounded by the fact that many incidents exhibited repetitive deficiencies (e.g., inadequate use of PPE in inv 1, inv 2, inv 6, inv 8, inv 10 and inv 12) highlights a level of ineffectiveness. **Allowing such deficiencies to pass through the gaps in the management systems is a notable finding**. The Chernobyl disaster's primary cause was attributed to the safety culture, which is defined as the organisation's attitude in which safety issues receive an overriding priority (Saleh, et al., 2010) and the organisational hierarchy of control (Lundberg, et al., 2009).

The organisational policy in section 6.1 requires that "*significant safety incidents…must be reported to all via a 24 hour communication report*". The policy further calls for the immediate supervisor (6.4.1) to lead the investigation and provide the 24-hour report. This 24-hour report produced by the immediate supervisor does not require review before communication. This led to interesting findings as will be demonstrated using an example. The 24-hour report in Inv 4 stated that the immediate cause was "*running away because of noise when the fuse blew*". This tends to deflect attention away from underlying events and focus on the employee and the equipment. When reading this statement, it appears that the worker reacted normally to an unexpected situation. The question that should have been raised was why the employee was permitted to stand in front of equipment which could explode whilst not using hearing protection? Why did the fuse operate (fuse blew or fuse melted) when switching off? From the review of completed investigation records, no answers to these questions could be found. This demonstrates a lack in the review of reports and feedback opportunities. Similar findings were noted in previous surveys performed in Europe (Rollenhagen, et al., 2010) and a safety climate driven by a poor safety culture (Lundberg, et al., 2009).

b) Multidisciplinary experts and independent persons

In an investigation team the independent person aims to address plant biases while the correct mix of persons ensures that the investigation aligns to the policy and that technical, economic, safety and human factors are considered and addressed.

In 67% of the investigations, no external plant or independent person was involved in the investigation, so investigator biases and lack of knowledge proceeded unquestioned. Interestingly, the top three highest compliance ratings (79%, 74% and 69%) shared one unique commonality: an independent external investigator on the investigation team. Resultantly, maintenance management systems and human factors were not examined in 67% of cases.

The correct mix of investigators was absent 42% of the time. Literature indicates that all incident investigations should include a review of engineering, maintenance, safety and human factors using a diverse group of specialists (Jørgensen, 2011). A diverse investigation team instead of a single investigator is essential to a comprehensive investigation (Mannan, 2014) (Johnson, 1973). As discussed during the analysis of the organisational policy, there does not appear to be clarity on who the Subject Matter Experts should be, nor guidelines for the lead investigator to select appropriate Subject Matter Experts.
The absence of multidisciplinary experts and independent investigators as part of the investigative team is a notable finding. It is likely that the lack of clarity in the organisational policy is a substantial contributor to this finding.

c) Dissemination and prior learning
A 100% non-compliance was noted in referencing of historical actions and a 100% non-compliance was noted in referencing previous investigations. Although 12 arc flash incidents were investigated, none of the investigations cross referenced internal or other operational units' investigations or actions. The finding that the lack of PPE was identified in six completed investigations clearly indicates that actions are not effectively verified for effectiveness and disseminated. As a result, each of these investigations is approached as a new and unique investigation. Although the availability of a software database (the PIVOT discussed previously) aims to facilitate the ease of cross referencing (U.S. Department of Energy, 2012) (Mannan, 2014), if the dissemination of information is lacking, the investigating team

will find itself at a disadvantage. The dissemination of information is critical to the investigation process (U.S. Department of Energy, 2012), (Le Coze, 2013) (Mannan, 2014) (Phimister, et al., 2003). The organisational policy requires that the learning be disseminated by the safety department and that the departmental manager remain accountable to sign off such actions where applicable. **It was found that the investigators did not reference historic investigations with similar causes. There was no evidence to support the safety department's dissemination of the completed reports and there was no evidence that such actions were indeed signed off by management.**

d) Organisational support

It was found that investigators missed the investigation deadline almost 60% of the time. Delays could be due to protracted forensic investigations, waiting to speak to the injured or the technical complexity of the investigations. These were not the case, as the majority of these incidents were rudimentary, the injured returned to work within a few hours, and in more than 50% of the investigations no forensic work was required. It is thus evident that investigators are influenced by availability of resources such as time or people. This finding is a non-compliance to the organisational policy which requires that the organisation must ensure that "*employees participating in an incident investigation are provided with adequate time and resources to participate effectively in the incident investigation process*". Sacrificing safety in lieu of production has been identified as a cause of serious incidents such as the Piper Alpha accident and the Westray and Moura Mine disasters (Saleh, et al., 2010). In addition, these smaller incidents (such as Minor Injuries and First Aid) could pose root causes which lead to serious incidents (Jørgensen, 2011), further emphasizing the need for the organisation to support investigations.

Several reasons for this finding may exist. It is possible that investigators are preoccupied with operational activities or that the organisation is relentless in operational demands, or both. Whichever the reason, this finding goes against the requirement of the organisational policy. **The lack**

of adherence to timelines, the absence of management review, and the absence of verification of actions are all considered a non-compliance to the organisational policy. The lack of enforcement of a management system is a serious finding which may possibly stem from organisational issues. Further work is required to understand and address this finding.

e) Training

A lack of training on the organisational policy was noted in 10 of the 12 completed investigations (83% non-compliance). Investigators were trained on investigation techniques (58% compliance) but some of the training occurred almost 10 years ago. The organisational policy required training on both the investigation techniques and the investigation policy every two years with annual refresher training. Investigator training need not be limited to classrooms, and experience from practical exposure is required (Ishikawa & Lu, 1985). Management is ultimately accountable to ensure that investigators are trained and experienced (U.S. Department of Energy, 2012). **The organisational policy in this instance did not require experience as a precursor to investigate.**

f) Greater severity incidents demonstrating greater level of compliance

Apart from these five major findings in the completed investigations, other important findings were noted. Figure 4.1 shows the level of compliance to the investigation process requirements per incident type.

Firstly, all incident types demonstrate some form or other of non-compliance or weakness. The most serious of these, the LTI, received the highest level of compliance. These investigations are signed off by the senior departmental managers, and the investigation team consisted of the correct mix of investigators and independent persons.

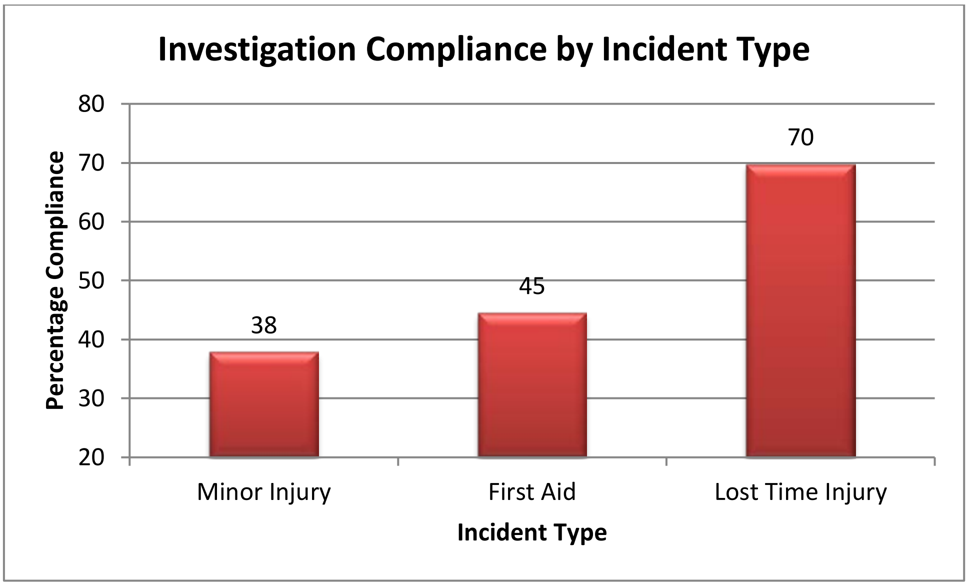

Figure 4.1 Compliance achieved per incident type

At minor injury level where the investigation did not require a detailed report, the line manager (generally a supervisor) performed the investigation. This is where the lowest level compliance was observed.
Since 67% of the incidents were investigated at a supervisor level and approved by junior or middle managers, it is possible that the importance of investigations may not be appreciated by employees in operational and junior managerial roles at the plant. It could be construed as a "tick-box" exercise instead of a key safety requirement. Further investigation may be required into this finding.

In the next section, Part C, the survey of the investigators is analysed using the 31 requirements from literature, the analysis of the organisational policy, and findings from the completed incident investigations.

PART C

4.2.3 Survey of investigators

The survey of investigators allowed for commentary on their influence in the application of the investigation process. It also served as a platform to raise possible concerns (Jooma, et al., 2017). This was expected to uncover hurdles to the effective implementation and execution of the organisational policy. A similar survey of investigators in industry has been performed previously (Rollenhagen, et al., 2010). Surveying investigators provides a context of the environment in which investigations are performed and this may not be easily determined from organisational policies or through records from completed investigations (Rollenhagen, et al., 2010).

The investigators completed a survey based on the 31 requirements of the investigation process and the results are discussed in this chapter. A survey (asking questions) is a qualitative method; however, the results from the survey were expressed as numbers, allowing for the use of a quantitative study using statistical methods. The reliability and validity of the data were examined in the previous chapter and are briefly recapped. The quantitative analysis of the data showed a high measure of reliability, as determined by a Cronbach's Alpha $\alpha = 0.878$, while the Kaiser-Meyer-Olkin (KMO) measure of validity was 0.734. KMO values greater than 0.7 are acceptable measures of validity, while Cronbach's Alpha values greater than 0.7 are good measures of reliability.

4.2.3.1 Results of the survey

The raw data from the online survey responses was uploaded into the statistical software package, which then processed the data. The computed data is presented in Table 4.6. A sample of the results of the survey issued to the investigators is shown in Table 4.6 (Questions 1 to 7 of 31) and the remaining results can be found in Table C5 (Appendix C).

In certain cases, a respondent may have not answered a question; these are indicated as "Missing". The descriptive statistics are then determined using the remaining number of valid responses. The standard error of means attempts to explain the sample mean approaching the population mean: the lower the value, the higher the correlation between the population and sample means.

Table 4.6 Results of the Survey

No:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
1	Near-misses are investigated in detail	105	1	2.99	.107	3.00	4	1.096	1.202	10.5	25.7	21.0	40.0	2.9
2	A structured guideline exists, which outlines what type of incidents need investigating	104	2	3.61	.091	4.00	4	.929	.862	1.9	12.5	21.2	51.9	12.5
3	The incident investigation process begins as soon as the incident becomes known	106	0	3.80	.087	4.00	4	.899	.808	1.9	8.5	15.1	56.6	17.9
4	Statements are collected as soon as the incident becomes known	106	0	3.92	.069	4.00	4	.713	.509	0.0	1.9	23.6	54.7	19.8
5	Incidents which require investigation are being investigated	106	0	3.73	.079	4.00	4	.811	.658	0.0	9.4	21.7	55.7	13.2

Table 4.6 Results of the Survey (Continued)

No:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
6	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	106	0	3.10	.105	3.00	3	1.086	1.180	5.7	26.4	30.2	27.4	10.4
7	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	105	1	3.49	.095	4.00	4	.972	.945	1.9	17.1	22.9	46.7	11.4

4.2.3.2 Discussion on the results of the survey

In certain instances, the qualitative findings from the previous sections are incorporated into this section to support the discussion. In the next section, the findings are displayed in a flowchart to demonstrate the between-method and within-method triangulation used to prove the hypothesis of the study through convergent findings.

Prevalence of highest "disagree" outcomes

As discussed in the research methodology, once more than 30 independent responses are received for a small population (approximately 100 in this survey), the sample is considered representative of the population. This is further supported by the fact that 71% of survey questions produced a standard error of means that was less than 0.1, while 29% produced a standard error of means less than 0.13. Table 4.7 displays notable findings. Where more than 30% (roughly 30 in this survey) of respondents disagree with an item, a high level of confidence is associated with that question.

Table 4.7 Highest ranking of "disagree" responses

Question No:	Question	Percentage Disagree
25	I am aware of the outcomes of incident investigations which occur at other operating units. (Please note that this point does not refer to a 24 hour or 1-pager report of the incident, but rather to the detailed accident investigation)	58
20	Incident investigators blame people for incidents	54
15	Investigators are somewhat protected from operational responsibilities and are allowed to focus on a thorough incident investigation	43

Table 4.7 Highest ranking of "disagree" responses (Continued)

Question No:	Question	Percentage Disagree
18	Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).	40
27	An incident investigation is considered to be completed once the root causes are established	38
19	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.	37
1	Near-misses are investigated in detail	36
6	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	32

i. Question 25: It was found that 58% of respondents believe that completed investigations are not communicated, as shown in Figure 4.2. The dissemination of information is a key requirement for effective investigations (Le Coze, 2013) (Lundberg, et al., 2009) (Phimister, et al., 2003). It allows for other departments and operating units to identify similar risks and update local or global safety management systems. Changes should not be exclusive to the affected plant but should take place in the global safety management system (Chua, et al., 2004). This question regarding "*outcomes of the investigation not being communicated*" was found to be 100% noncompliant in the analysis of completed investigations. The organisational policy places the onus of the dissemination of information on the safety department. During the analysis of the organisational policy it was noted that all applicable actions should be distributed to plants with similar risks; however, the policy failed to describe exactly how this should be done. The safety department is requested to distribute the report, and no evidence of this action could be found.

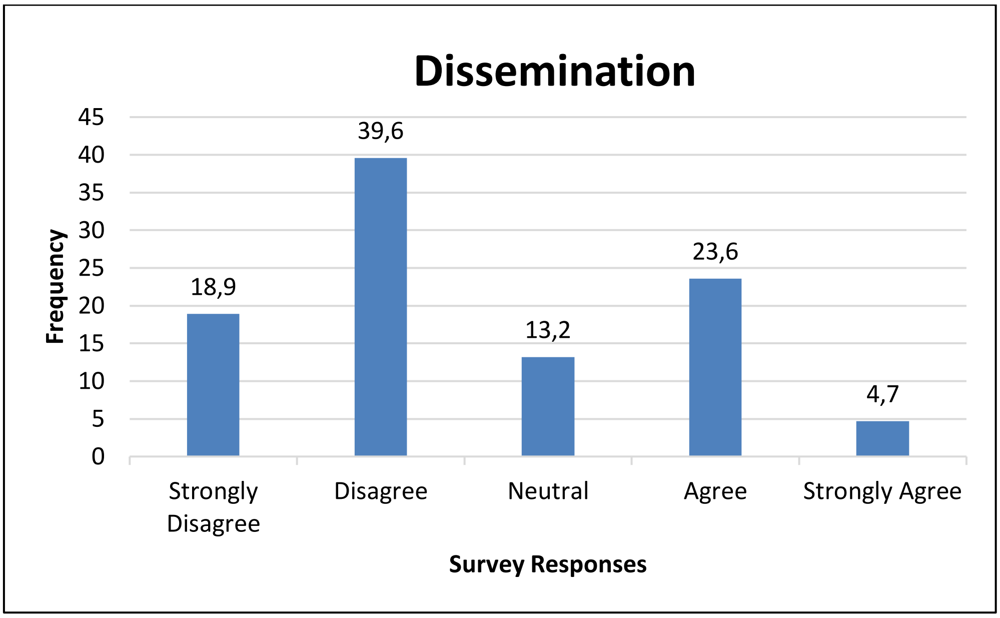

Figure 4.2 Communication of completed investigations

ii. Question 20: Notably, 54% of respondents felt that investigators do not blame people for incidents. This finding aligns favourably with the requirements in the literature (Reason, 2000) (U.S. Department of Energy, 2012). It was also noted that in the majority of completed investigations which were analysed (83%), the injured were not blamed.

iii. Questions 18 and 19: These questions are examining two different contexts within which investigators may be blaming people. It does integrate into question 20 (ii) above. Several leading human factors experts claim that blatant human errors still have roots in the organisational safety management system. Blaming people detracts from pursuing such roots (Rothblum, et al., 2002) (Reason, 2000). The respondents disagreed that people were to blame for failures in operational procedures and risk assessments by 40% and 37%, respectively.

During the validity discussion pertaining to the three contexts of blaming people, the direct and indirect blaming of people was referenced. Indirect blaming could possibly be masked by blaming people for poor risk assessments and non-conformance with procedures instead of gross negligence; 54% of respondents disagreed on direct blaming, but only 37% and 40%, respectively, did not blame people for poor risk assessments and non-conformance to procedures.

iv. Question 15: A total of 43% of respondents felt that they are preoccupied with operational responsibilities to the extent that the deadline or the quality of the investigation is influenced. When examining completed investigations, it was discovered that in almost 60% of cases the investigators missed the deadline. The organisational policy requires that investigators be freed from operational responsibilities to focus on the investigation. There is normally conflict between production and safety, but sacrificing safety has led to many disasters (Saleh, et al., 2010).

v. Question 27: It is important that investigators understand the entire investigation process. The organisation policy together with literature state that it is equally important to understand when an investigation begins as it is to understand when an investigation ends (IRCA Global, 2010) (Johnson, 1973) (Sklet, 2002) (U.S. Department of Energy, 2012). An investigation does not end when root causes are identified but ends when the effectiveness of the implemented action is validated (Le Coze, 2013), (Lundberg, et al., 2009) (Sweedler, 1995). Since this is a negatively phrased question, the higher the percentage who disagreed, the better. In this case, only 38% of investigators correctly disagreed with the statement that investigations are completed once root causes are identified.

It was discovered in completed investigations that the review of actions appeared to be a procedural formality rather than a comprehensive peer review process. If, as the survey implies, 62% of investigators fail to implement effective actions, then the entire investigation process is fundamentally flawed (Lindberg, et al., 2010). **This finding creates uncertainty as to whether investigators are adequately trained and knowledgeable on the investigation process.** A full understanding of the investigation process would have conveyed the importance of the review component. If this analysis is incorrect and the training was adequate, then **a lack of review of safety related actions may require further analysis in conjunction with the organisation's safety culture.**

vi. Question 1: Near-misses should be investigated with the same level of detail as a harm or loss-producing accident. Infamous failures such as the 1986 Space Shuttle Challenger explosion, 1997 Hindustan refinery explosion, 1999 Paddington train collision, and 1998 Morton explosion all displayed previous "near-miss" events that were not effectively investigated (Rothblum, et al., 2002). A notable 36% of the respondents state that near-misses are not being investigated with sufficient rigour to produce actions to prevent injury or loss. From the 12 investigations studied over a six-year period from 2010-2015, only one near-miss investigation was noted. The failure to investigate near-miss incidents could be due to poor reporting or a lack of concern about near-misses because there is often not a tangible consequence. It is ultimately the responsibility of the safety department to create a climate where workers feel safe to report and where management pursues reported near-misses and initiates investigations.

vii. Question 6: Certain investigation techniques such as the ECFC, MORT and SCAT require a diversity of technical and management systems specialists in the investigation team (Johnson, 1973) (Sklet, 2004). It was observed that the completed investigations which produced the lowest compliance ratings were those that lacked the external specialist involvement. 32% of respondents claim that external plant personnel are not involved in investigations. This has the potential to either influence the outcomes of the investigation or allow investigator biases to slip through.

Other observations in the survey

i. A substantial 27% of respondents did not receive training on the organisational policy. A further 9% remained neutral, possibly reflecting on the effectiveness of the training or refresher training. The survey indicated that more than a third of investigators were not trained on the policy. This result correlates with the fact that 83% of investigators who completed investigations were in fact not trained on the company policy. This finding shows that the organisation failed to enforce training as required by the policy and further permitted untrained persons to investigate.

ii. It was previously discussed that investigator training and knowledge were questionable. In that context, asking an investigator with inadequate knowledge of the investigation process to lead an investigation is ill-advised. It was found that 60% of investigators claimed to be experienced while claiming only 55% of their colleagues were experienced. Hence it is likely that 45% of investigators may not be experienced at all or may lack the experience necessary to investigate an incident. This finding was echoed in completed investigations and was found to be a major finding in the organisational policy.

iii. When examining the inclusion of Subject Matter Experts (SMEs), 58% of investigators indicated that these experts were included, 19% disagreed, and 23% remained neutral. The neutral number here could indicate that the respondents were either unsure or believed that experts were included sometimes and omitted at other times. A 51% non-compliance over 12 completed investigations fails to align with the 58% confidence by investigators that SMEs are included. It is expected that the inclusion of SMEs will promote a greater level of compliance. This may indicate a divergent finding and will be revisited later in Part D of this chapter.

iv. Since the survey was based on a 5-point Likert scale, the mode shows the rating most repeated in the survey.

a) A mode of "Strongly Agree" (score 5) appeared once in the survey, pertaining to "*training on investigation techniques such as RCAT, 5 Whys and CED*". This highlighted the fact that the organisation did focus on training and hence conformed to that specific training requirement in the organisational policy.

b) A "Neutral" (score 3) mode was noted on the question "Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures)".

c) Blaming people indirectly through non-conformance to a procedure was discussed previously: 40% disagreed, 33% remained neutral and 27% agreed (see question 10 in Table 4.7). The responses shown in Figure 4.3 to Question 18 (Incidents are caused by people and not a failure in a management procedure) raise an important issue. This shows elements of a blaming culture, which was not detected by the organisational policy or completed investigations.

One possible explanation is that the organisational policy requires the immediate manager to lead the investigation. It has been shown that these completed investigations were not reviewed and did not include external independent persons. Also, since the lead investigator is the manager, a possible conflict of interest is present despite the literature requiring independence or a good mix in the investigating team (Broadribb, 2012) (Mannan, 2014).

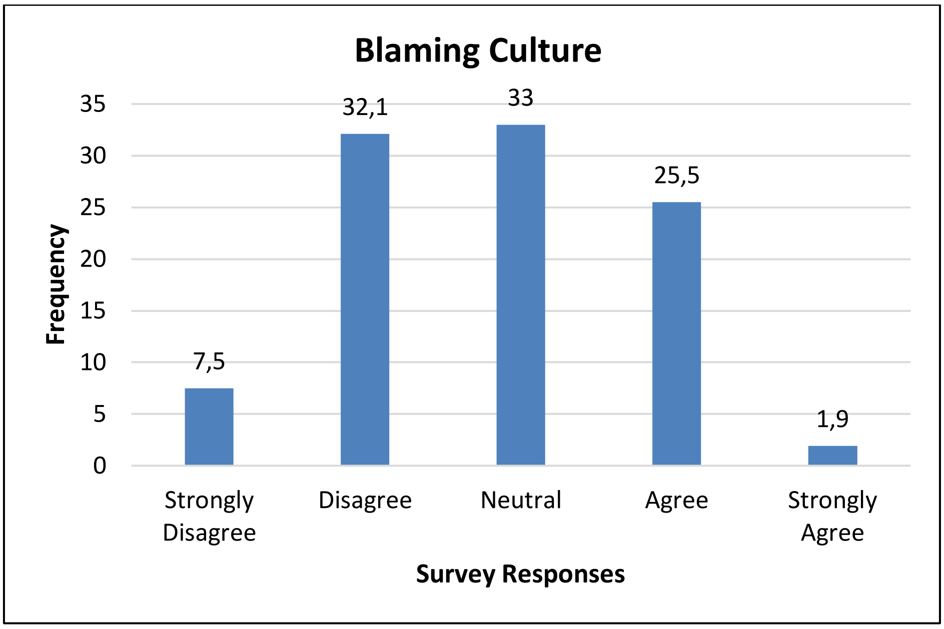

Figure 4.3 Frequency plot regarding blaming people

d) Completed incident investigations should be reviewed by experts on the organisational policy. Investigators were indecisive on this point, as 47% of respondents remained neutral. Considering that the completed investigations were ineffective, as discussed in section "*4.2.2.2 Discussion on the analysis of completed incident investigations*", it is evident that the majority of completed investigations were not reviewed by experts on the organisational policy.

This concludes the presentation of the analysis of the three streams. In the next section, the results are summarised before these are interpreted using the two variations of the triangulation method.

PART D

4.3 Consolidation of Findings Across All Three Streams

In order to study the effectiveness of the application of the investigation process, three streams were critically analysed in this chapter. The results are now summarised, before attempting to interpret the findings using triangulation.

4.3.1 Organisational policy

The organisational policy was largely compliant with the literature requirements for an effective investigation process. A 92% compliance was noted, with two deviations from the literature. The first deviation noted in the organisational policy was a failure to meet the review and approval requirements of the completed investigation report before actions were implemented. This is a key requirement which aims to determine factual accuracy of the investigation and ensure compliance to the investigation policy.

The second deviation in the organisational policy was the failure to stipulate any experience requirements in the investigation team. Literature requires that investigating teams should consist of members who are both knowledgeable and experienced in the investigation process. The organisational policy does cover the knowledge aspect requiring both training and a subsequent declaration of competency. However, the organisational policy failed to stipulate that investigators must be experienced and also failed to provide any guidelines on how such experience may be gained. Errors, omissions and non-compliance due to trained but inexperienced investigators may pass through the system unnoticed, as the previous deviation indicates investigations are often not reviewed. This can also impact the quality and accuracy of reporting and may also explain why human factors, in many cases, were not examined further.

4.3.2 Completed investigations

Following the examination of the organisational policy on incident investigations, 12 completed electrical arc flash incident investigations between 2010 and 2015 were studied. When compared to the literature requirements, 51% non-compliance was registered without a single investigation achieving more than 80%.

Major findings were noted in the following areas:

- A causal human factor regarding the use of personal protective equipment recurred in six of the incidents investigated.
- Actions were verified and signed off a day or two after implementation. The policy requires that actions be verified three months' post implementation.
- Investigators exceeded the investigation deadline in more than 60% of the completed investigations.
- The safety department generally failed to disseminate completed investigations and actions. In addition, investigators failed to reference similar historic incidents.
- In 67% of investigations the independent person was absent, while in 42% of investigations the correct mix of investigators was not present.
- 83% of investigators were not trained on the organisational policy. Although 58% of investigators were trained on an investigation technique, some of this training took place almost a decade ago. The investigators' level of experience could not be quantified through the completed investigations as this data was not available. Considering a 51% non-compliance, investigator experience is a notable finding.

The vast difference between the 92% compliance of the organisational policy and the 49% compliance of the completed investigations demonstrates a substantial level of non-compliance to the organisational policy by both investigators and management.

It was found that minor injury investigations recorded 38% compliance, first aid investigations recorded 45% compliance and lost time injury investigations recorded 70% compliance. The more serious incidents received wider attention and a better mix of experts. These findings require further examination to determine any possible links to the safety climate in the organisation.

4.3.3 Survey of investigators

A survey consisting of 31 questions was administered to investigators at the case study site. It was demonstrated that the data was statistically valid and reliable. The investigators indicated three major problem areas :

- Lack of communication of completed investigations (58%)
- Daily operational influences which hamper the investigation (43%), and
- Absence of independent external investigators on the investigation team (32%).

In addition, the survey results showed that 27% of investigators were not trained on the investigation policy whilst another 9% indicated that the training, refresher training or enforcement thereof were ineffective. This finding was further supported when 54% of investigators agreed with the statement that investigations are completed when root causes are identified. This goes against the investigation policy which stipulates that investigations can only be considered completed once actions are verified for effectiveness three months after completion.

The summary presented from the analysis of the three streams in this section is now interpreted using the two types of triangulation in the next section.

PART E

4.4 Triangulation of the Results

This section demonstrates the use of the between-method and within-method triangulation. If the results from each stream converge to a common finding, then reliability and validity of the study can be claimed. Divergent findings imply that either the approach is not working or that more thorough analysis is required.

An example demonstrating the successful working of a divergent finding is presented in Figure 4.4, using the "Subject Matter Experts (SMEs)" requirement. The results show that the instruction for using SMEs is vague in the organisational policy and is absent in almost 50% of completed investigations. However, survey results indicate that almost 60% of investigators believe that they *have* adequately addressed the use of SMEs, which is a divergent finding. A thorough analysis of literature, presented earlier in this chapter, shows that investigators are sometimes unaware of which SME to include. It is thus expected for the investigators to indicate (through the survey) that they are using SMEs, when this is not the case. A divergent finding would thus support this claim.

This example demonstrates the interactions between the three streams. It also demonstrates the mutual influence of a vague organisational policy on the investigators resulting in an unintended omission of SMEs, a finding echoed in more than 50% of completed investigation records. This divergent finding from the three streams demonstrates the between-method. In order to demonstrate the within-method, the qualitative analysis of the completed investigations is considered. Firstly, in 67% of completed investigations, maintenance management systems were not investigated. This is indicative of the absence of a "maintenance systems SME". Secondly, the review of completed investigation reports was not performed. This is indicative of the absence of an "investigation process SME" in the investigation. As discussed previously, successfully demonstrating the within-method and between-method also serve to support the reliability and validity of the study.

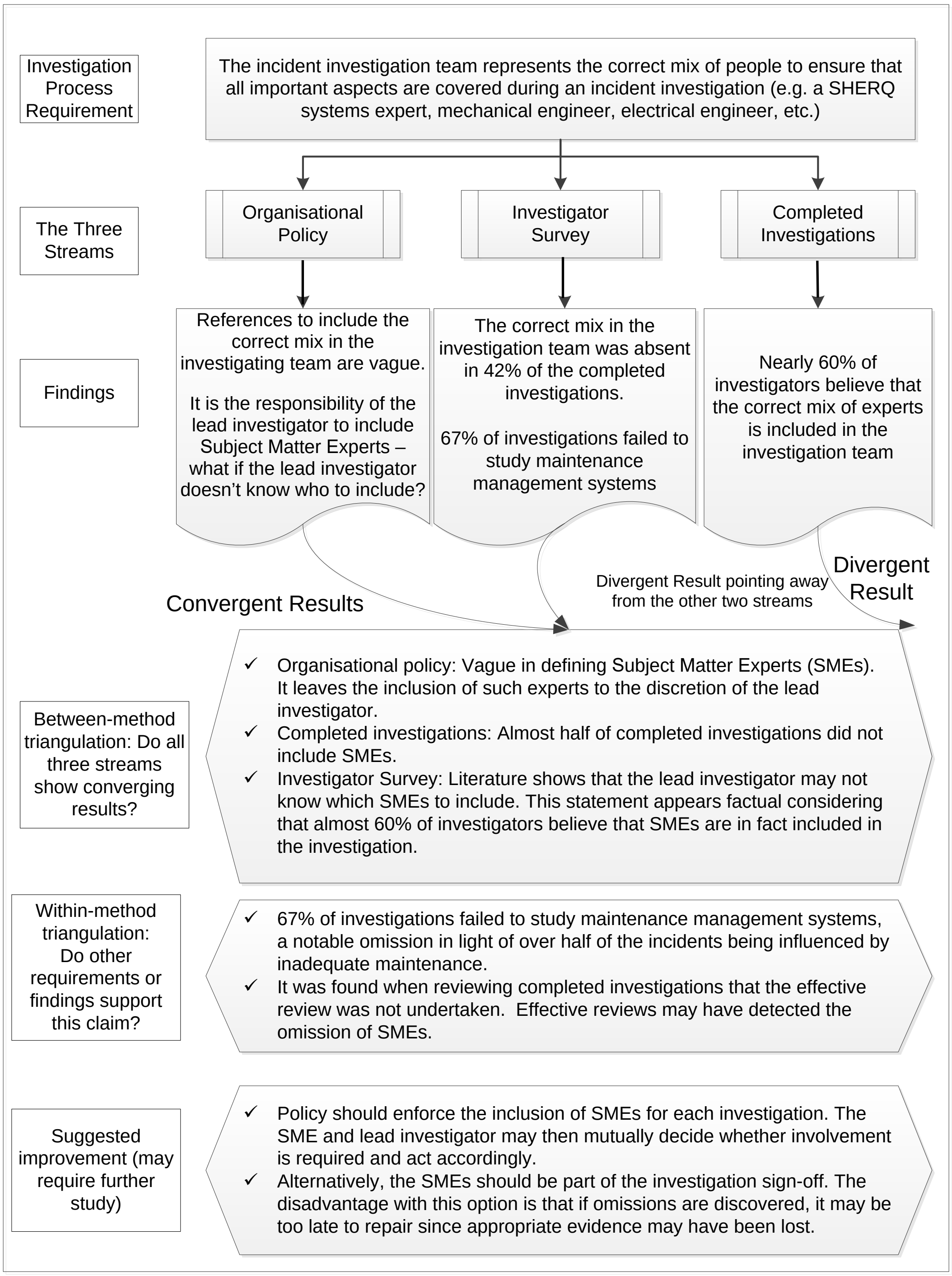

Figure 4.4 The omission of SMEs

Reviewing the literature and methodically identifying deficiencies allows for recommending corrective actions. This is not the aim of the research, but does offer a benefit to the industry end user. It was observed that identifying deficiencies specific to a plant is more beneficial than the generic findings offered in literature; as generic findings may or may not be applicable to a plant. Having identified a specific deficiency in the investigation process, combined with understanding the dynamic interaction and influences of the three streams, provides the plant with better information to resolve the deficiency. An example of this is demonstrated below:

To address the deficiency identified in Figure 4.4, the organisational policy could stipulate, for example, which SMEs should be used at the initiation of the investigation. The SME and lead investigator may then discuss the merit of such involvement and decide whether it is required or not. An alternative option is to get the SMEs to review and sign off on the final report. This approach may be less effective as the SME may require further work long after appropriate evidence has been lost or the investigation committee may have adjourned.

A summary of the findings regarding the SME shown in Figure 4.4 is that dynamic interactions between the three streams are present. These interactions were not considered random as they originated either in the organisational policy or stem from deficiencies in the management system that permitted non-compliance to policies. Meaningful results specific to the plant being studied were noted; these are considered more beneficial than generic findings from literature.

Two other examples with clear convergence, displaying both the between-method and within-method triangulation, are presented in Figure 4.5 and Figure 4.6. These findings are now briefly discussed.

In Figure 4.5, the dissemination of information requirement is discussed. The dissemination of information is imperative, as it leads to changes globally. This ensures that other operating units which may not be governed under the same management system also benefit. The organisational policy stated that the safety department should disseminate the investigation report. The policy also required that the report be distributed to plants with similar risks. Since 100% of completed investigations failed to reference any historical incidents, it is clear that the dissemination of previous arc flash incidents did not occur. The investigation team had no knowledge of the previous records, which also raises the question of access to such information. Fewer than 30% of investigators claimed that they were aware of completed investigations. Now, as an example to demonstrate this point, consider the fact that all twelve completed investigations had an arc flash component and in more than half of these, the absence of arc rated PPE was found in these cases over a five-year period. Effective dissemination of information after the first incident should have enforced the use of the correct PPE. The term “effective dissemination” indicates a need to provide the information reports in summarised manner. It was also noted that 83% of investigators were not trained on the organisational policy on incident investigations and were thus unaware of the need to disseminate, or were not aware that the safety department managed the incident investigation records and database.

The latter two observations from the completed investigation records demonstrate the within-triangulation method. In this example, both the between-method and within-method triangulation produced convergent results to support the hypothesis as shown in Figure 4.5.

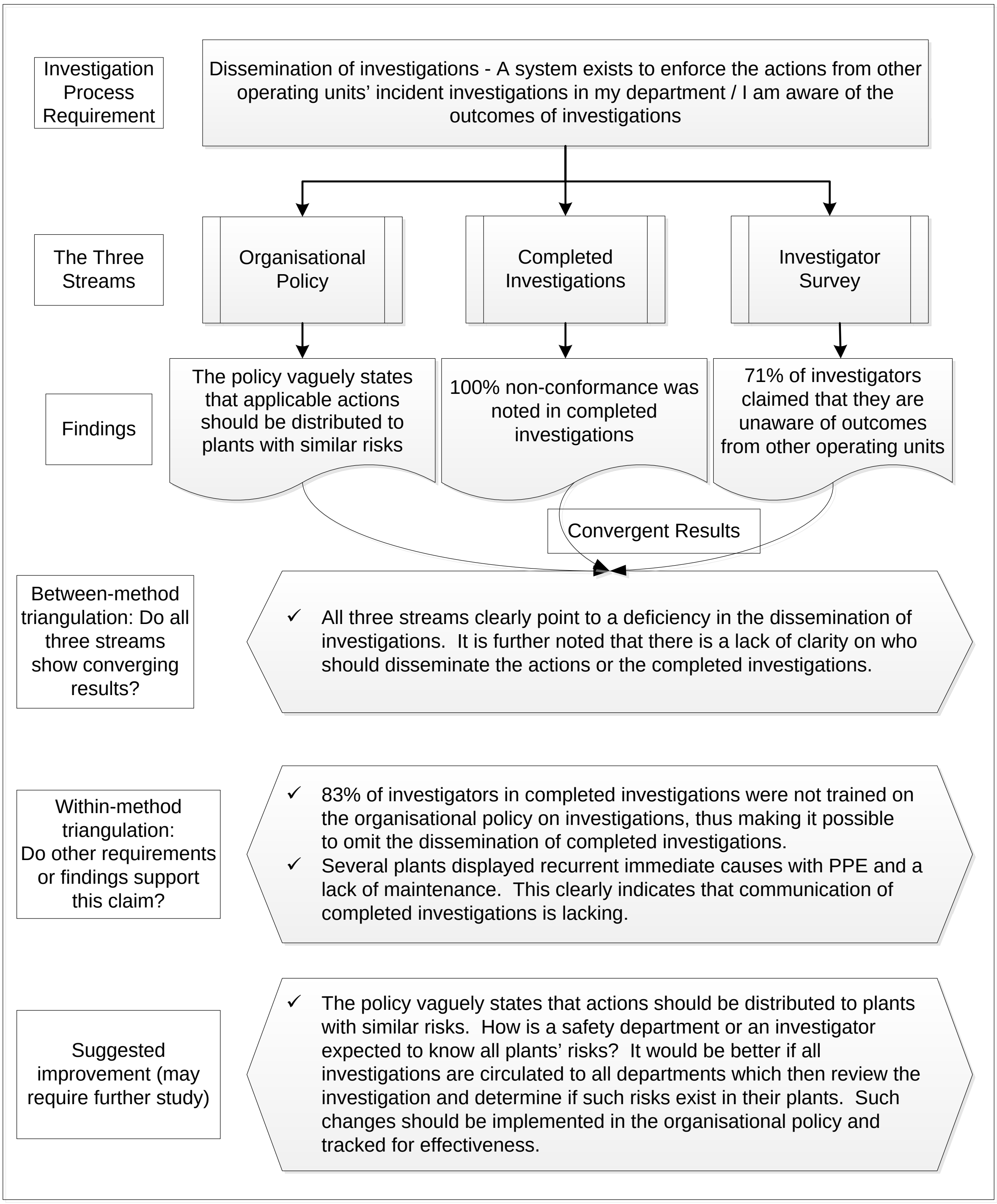

Figure 4.5 Absence of the dissemination of completed investigations and actions

Finally, the omission of the requirement for experienced investigators to undertake investigations also produced convergent findings across the three streams as shown in Figure 4.6.

The organisational policy failed to stipulate the need for experienced investigators. The lack of experienced investigators was echoed in the analysis of completed investigation records that demonstrated a mere 51% compliance to the investigation process requirements. Almost half of the investigators surveyed indicated that they are not experienced and believe that other investigators also lack experience. Clearly the three streams converge when the between-method is used to interpret the results.

In addition to the organisational policy failing to stipulate the need for experience, the verification of actions in the completed investigation records was found non-compliant. Instead of waiting three months to test for the effectiveness of remedial actions, investigators and management signed off on the verification task immediately after it was uploaded into the database. This was sometimes a day after the action was proposed. Clearly an experienced investigator would wait for action implementation, define a performance measure to determine if the action was successful, communicate with role players and then sign off on the verification task. Combining the two qualitative findings from the organisational policy supports the deficiency regarding the lack of experienced investigators in the plant. This finding demonstrates convergence using the within-method. The absence of experienced investigators is demonstrated in Figure 4.6.

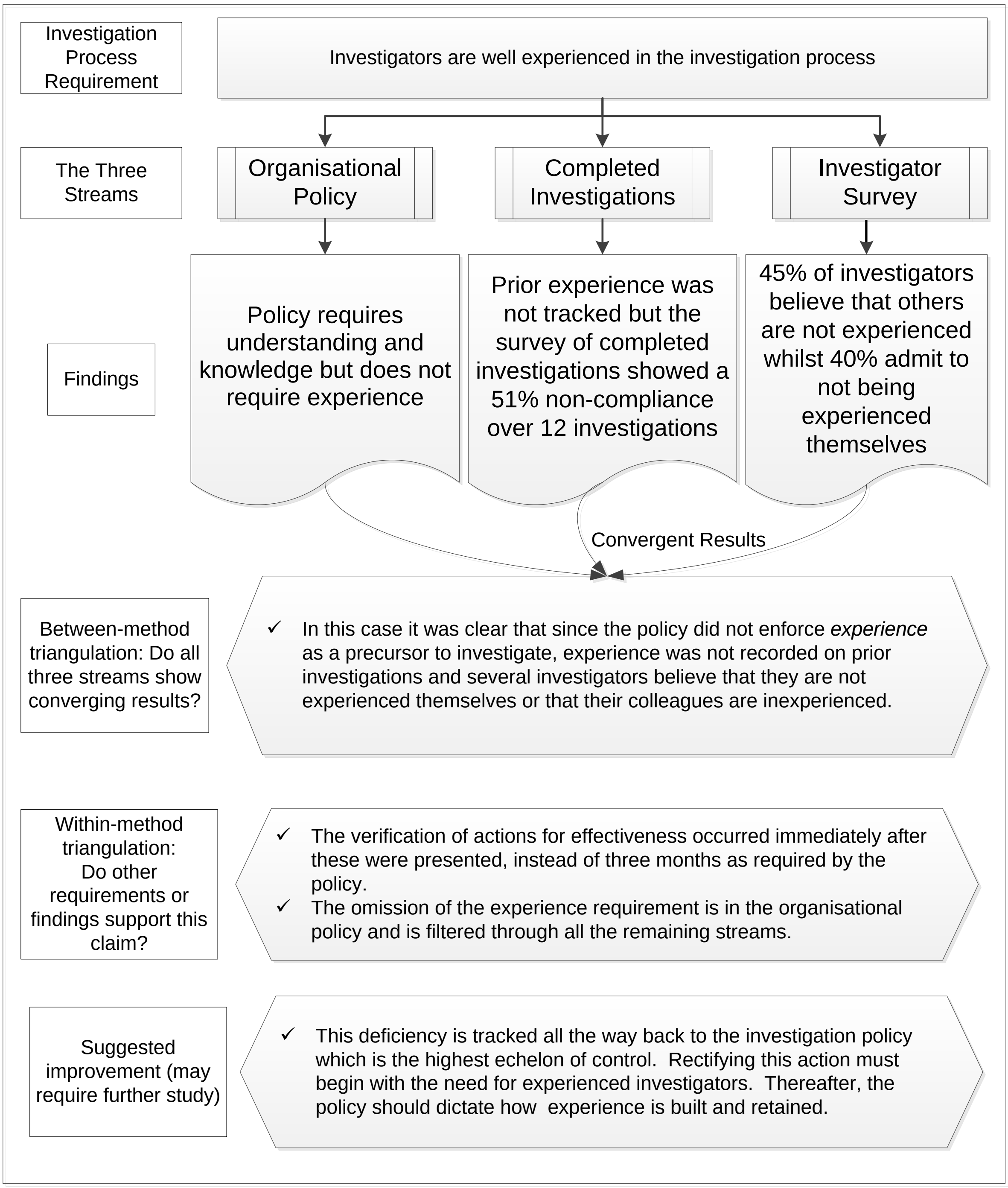

Figure 4.6 The lack of experienced investigators

4.5 Summary

The three streams of the investigation process were analysed to determine the compliance to the minimum requirements of the investigation process. The method proposed in chapter 3 was executed at a steel plant in South Africa to demonstrate that the approach was working and operationally ready to deploy in practice.

The organisational policy on incident investigations at the plant was compared to the investigation process requirements established in literature. If an investigation process requirement was found to have been addressed in the organisational policy, that requirement was indicated as compliant. Conversely, if a requirement was not found to have been addressed in the organisational policy, that requirement was indicated as non-complaint. Certain investigation process requirements did not apply to the organisational policy and were not used in the compliance scoring. The organisational policy was found to be 92% compliant with the investigation process requirements established from literature. The two deficiencies identified in the organisational policy at the plant were the omission to stipulate that 1) the investigator be experienced, and 2) that completed investigation reports be reviewed before actions are implemented.

A similar comparison was used for the analysis of the completed investigation records. In this instance, however, when a non-compliance was found, the organisational policy was also used to understand why such a deficiency existed. Twelve completed electrical arc flash incident investigations between 2010 and 2015 were studied and demonstrated 51% non-compliance, without a single investigation achieving more than 80%. This shows that none of the twelve completed investigations met all investigation process requirements established in literature. It was observed that the more serious incidents received higher compliances and were more regulated. Senior management were usually involved in these investigations.

The investigators at the plant were issued with an online survey and a total of 106 responses were received. The 31 survey questions were based on the investigation process requirements. Several observations were identified after the statistical analysis of the survey data. These include the lack of dissemination of completed investigation records, lack of experience of investigators and the influence of production on the investigators' availability to investigate.

The investigation policy and completed investigations were analysed qualitatively while the results from the survey of the investigators were analysed quantitatively.

Using two types of triangulation, between-method and within-method triangulation, inefficiencies in the application of the investigation process were identified. The major findings included:

- the omission of Subject Matter Experts in investigations,
- lack of experience of investigators, and
- lack of communication of investigation reports across all business units.

These results were used as examples to demonstrate convergent findings across the three streams, thus supporting the hypothesis. An example of divergent findings (using the SME deficiency in Figure 4.4) was presented to demonstrate how such findings should be evaluated in practise.

Several other important findings were presented in this chapter; however, only the above three were used to demonstrate the research method using triangulation. In other cases, it was found that the requirements of the organisational policy were largely not adhered to. Information established in the literature survey was used to provide recommendations to address certain findings. In other cases, the findings presented several possible influences and it was recommended that those be investigated further.

In summary, this chapter demonstrates that **combining the three streams and evaluating these against the investigation process requirements** allowed for understanding the interactions and mutual influence between the streams. This holistic approach successfully allowed industry to comment on the effectiveness of the *application* of their investigation process. Further, deficiencies specific to a plant are identified using this approach. This is considered a major benefit to industry when compared to the generic findings from literature.

The next chapter aims to synthesise the information and findings from the study. Certain limitations of the study are presented, followed by recommendations for future work. The study then concludes by answering the research question.

5 CONCLUSION AND RECOMMENDATIONS

In concluding this research, this chapter will present the answers to the research question, explain the limitations of the study and provide recommendations for future work.

5.1 Introduction

Electrical incidents are prevalent globally and have resulted in numerous disabling and fatal injuries. The affected organisation also suffers the loss of equipment and associated production interruptions. Learning from these incidents is of paramount importance, and learning can only be achieved through effective investigations (Saleh, et al., 2010). Literature has shown that there is sufficient information and existing knowledge on the taxonomy of the investigation process. The investigation process consists of steps such as evidence collection, describing the incident, analysing the incident, providing remedial actions, recommendations, reporting, review, testing for effectiveness and close-out (Ji & Zhang, 2012) (Jørgensen, 2011) (Ilie & Ciocoiu, 2010) (Lindberg & Hansson, 2006) (Blair, 2004). The *application* of the investigation process in industry is different. It occurs through three streams; these are the organisational policy on incident investigations, completed investigations performed by the organisation, and the investigators who perform the investigations. The investigation process is a theoretical model, while the application of the process in industry is a practical model.

5.2 Literature Survey and Methodology

A review of literature indicated that studies related to the three streams are available, but the focus of each study is limited to one stream only. One study focussed on eight organisational policies on incident investigations and evaluated these against the investigation process requirements (Lundberg, et al., 2009).

Another study focussed on a survey of 108 investigators with multidisciplinary organisational experience (Rollenhagen, et al., 2010). This study was partly based on the investigation process requirements by Lundberg (2009), but mainly examined the investigators' knowledge, experience, and preferences.

Several studies on the stream examining completed investigation records were found. Although the studies on completed investigations present valuable findings, these are very specific to the actual incident and include engineering and process control, maintenance management, and operational management (Jooma, et al., 2016b) (Le Coze, 2013) (Deepwater Horizon Study Group, 2011) (Pham, et al., 2010) (Saleh, et al., 2010) (Phimister, et al., 2003).

As can be seen, the existing studies in literature handle each stream individually. No study has combined these three streams to provide valuable findings on the complex interactions and mutual influences among the three streams. It was also observed that findings presented in literature are generic. These findings may or may not be applicable to each industry. Industry end users may not have the expertise to combine the three streams and address this gap. This study built on existing literature by combining the three streams.

It was hypothesised that combining and evaluating the dynamic interactions of the three streams in industry allows for evaluating the *effectiveness* of the *application* of the investigation process.

A steel plant in South Africa was used as a case study to test the hypothesis. The study began with the investigation policy of the steel plant, which was critically reviewed against the investigation process requirements from literature for compliance. Thereafter, 12 completed investigations were studied in detail. During this phase, the completed investigations were compared to both the investigation process requirements and the organisational policy requirements. The analysis of the organisational policy and completed investigations were performed qualitatively.

The investigation policy requirements were then used to develop a 31-question survey that was issued to the investigators. The Likert-item survey data was analysed quantitatively using descriptive statistics. The results demonstrated a good level of reliability with a Cronbach's Alpha of 0.878 and an acceptable validity as indicated by a Kaiser-Meyer-Olkin (KMO) measure of 0.734.

The results from the qualitative and quantitative studies were interpreted using triangulation (Guion, et al., 2014). Two variations of the triangulation method were used. The between-method was used to analyse the mutual influence of the three streams. The within-method was used to support findings either in the qualitative or quantitative analysis. These two variations of triangulation allowed for demonstrating that the qualitative study was valid and reliable, yielding meaningful results.

5.3 Discussion on Key Results

When the results from the three streams were interpreted using the between-method triangulation, some results were found to converge. Other results appeared divergent until the underlying reasons were examined and found to still converge to a common finding. An example of this can be seen in Figure 4.6, which examined the investigators' experience and is summarised in these points:

a) The organisational policy did not require experience as a precursor for investigators;
b) the study of the completed investigations failed to track or provide any evidence of experience; and
c) the survey indicated that 40% of investigators claimed no experience whilst 45% claimed that other investigators were not experienced.

Since all three streams converged to the same point, the approach successfully identified a lack of experienced investigators – a deficiency in the *application* of the investigation process. The analysis of qualitative and quantitative data to interpret results, as demonstrated in this example, is known as the between-method triangulation.

Divergent results could also imply a weakness in the application of investigations; these required further analysis to explain the findings (Jick, 1979). An example of this can be seen in Figure 4.4, which examined the use of Subject Matter Experts and is summarised in these points:

a) The organisational policy was vague on the requirement for the use of Subject Matter Experts;
b) completed investigations demonstrated that 67% of investigations failed to include Subject Matter Experts; and
c) contrastingly, the survey indicated that 60% of investigators believed that Subject Matter Experts were included.

The investigators' response diverged from the findings in the completed investigations. This divergent finding was explained in literature which stated that lead investigators may not know which SMEs to include. This implies that the investigators are unaware of this omission, supporting their belief of SMEs' inclusion. This is an example of a divergent finding using the between-method triangulation.

The within-method triangulation can be demonstrated in the example of SMEs as well. It was found that 67% of completed investigations failed to investigate maintenance management systems, indicative of the absence of a "maintenance systems SME". The review of completed investigation reports was not performed, indicative of the absence of an "investigation process SME". This shows convergent findings from two separate qualitative analyses. The findings obtained from the between-method and within-method triangulation demonstrate that the results of this study are valid and reliable.

The two examples presented above provide meaningful results demonstrating the success of the between-method triangulation and prove that the findings were reliable and valid. This is an important factor in demonstrating that this holistic approach is working (Nøkleby, 2011) (Denzin, 1978).

5.4 Addressing the Research Question

The research question was:

> **Can evaluating the three streams in which the investigation process is applied against a common set of requirements determine the effectiveness of the application of the investigation process?**

This research proposed a holistic approach to evaluate the effectiveness of the *application* of the investigation process. A comprehensive understanding of the established investigation process requirements is a prerequisite to executing this approach.

The approach used in this study is summarised as follows:

1. Undertake a qualitative study by comparing the organisational policy on incident investigations against the established investigation process requirements.
2. Continue with the qualitative study by comparing the completed investigation records against the established investigation process requirements. At this stage, however, include the organisational policy in the qualitative study.
3. Survey the investigators or investigating teams by using the investigation process requirements as the basis of the survey. Interpret the investigator responses quantitatively using descriptive statistics. This was demonstrated in section 4.2.3.2.
4. The findings from the qualitative study and quantitative study are now combined and interpreted using the two variations of the triangulation method.
5. The overall findings allow the organisation to identify deficiencies in the application of the investigation process and thus comment on its effectiveness, or lack thereof.

The approach suggested by this research was developed theoretically, but tested practically at a large steel plant in South Africa. Each of the qualitative and quantitative studies produced meaningful findings. When the qualitative and quantitative findings were combined, these findings converged into meaningful results. This demonstrates that the approach used in this study has a sound scientific basis and through the empirical results presented, shows that it can be deployed in practice.

The research question is answered in this research by demonstrating that the dynamic evaluation of the three streams allowed for determining the effectiveness of the application of the investigation process.

5.5 Limitations of the Study

Although the study aimed at promoting comprehensiveness in each aspect, certain limitations were noted. These limitations are now discussed.

a) The research methodology excluded interviews during the qualitative study. The review of documentation was undertaken without an interview, and, as a result, the researcher may not necessarily convey the intent of the authors of the organisational policy or the authors of the completed investigation reports. It is the researcher's belief that the documents should display a high level of comprehensiveness and thus should stand alone, without a need to engage with the author. The disadvantage is that the intent and logic of the authors and the circumstances around the investigations are unknown.
b) The triangulation method produced convergent findings amongst the three streams. During this analysis, however, it was noted that some "unconnected" deficiencies were identified. This may possibly indicate that the approach used in this study is producing additional outputs, which may require further analysis.
c) The investigation process requirements were not weighted, as each was considered equally important. It is possible, however, that certain process requirements may have a greater influence than others on the effectiveness of the application of the investigation process.
d) The investigation process requirements could have been grouped into constructs to outline broader areas where gaps or weaknesses may

exist. Although one of the white papers (Appendix D) alluded to these constructs, the idea was not developed further in this study. It is recommended that future work develop such constructs in order to define broader areas in the investigation, instead of focussing on singular investigation process requirements.

e) The literature examined for this work largely revolved around literature aimed at the industrial sphere. The work and the case study were thus limited to industry. In addition, the approach from this study was only tested at a single plant.

The recommendations for future work, which may address these limitations, are now discussed.

5.6 Recommendations

Since this work presents itself in the field of safety, continuation of this work has several benefits. The following recommendations aim to build on this study and realise such benefits.

a) The inclusion of interviews during the qualitative phase of document review may be considered in future work. This additional step should be included in the research methodology and tested to determine whether it adds value to the research.
b) Some deficiencies appeared “unconnected” because they were only present in a single stream. This indicated that the approach used in the study was producing results beyond the scope of this research. Such results may provide additional benefits to industry and it is recommended that this finding be further investigated.
c) The literature study focussed on organisations that are industrial. The application of this work outside that sphere may be possible. Future work may expand this scope to determine its applicability in other organisations.
d) It is recommended that this work be practically executed at more industrial sites. In addition, the use of more than one researcher and multiple case studies may provide improvements to this work.

5.7 Conclusion

It was shown that arc flash incidents caused harm to workers and damage to equipment. Incident investigations can reduce the prevalence of arc flash incidents, but only if such investigations are performed effectively. This created a need for evaluating the *application* of the investigation process. It was shown, however, that existing literature studied each stream of the application of the investigation process individually. Also, existing studies provided generic findings, which may or may not be applicable to all industry. Industry did not have a consolidated method to determine the effectiveness of the application of their investigation process and was resultantly unable to identify deficiencies specific to their investigation process.

This study built on the existing literature by combining the three streams and evaluating these against the investigation process requirements. This allowed for the understanding of the interactions and mutual influences among the streams. This holistic approach successfully allowed a steel plant to determine the effectiveness of the application of their investigation process. Further, deficiencies specific to a plant are identified using this study. This is considered a major benefit to industry when compared to the generic findings from literature. Apart from providing a common base to analyse the three streams, the investigation process requirements served as a due diligence checklist to industry that is developing an organisational policy on incident investigations.

In conclusion, it has been demonstrated that this research contributed to advancing knowledge in the field of incident investigations. It built on existing literature and provided a holistic approach that demonstrates the complex interactions of the three streams. This approach successfully determines the effectiveness of the *application* of the investigation process. Finally, demonstrating the success of this holistic approach empirically at a steel plant also confirms that it is operationally ready to be used by industry.

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APPENDIX

A PRESENTATION OF INVESTIGATION TECHNIQUES

This part of the appendices attempts to cover further information to support Chapter 2, the Literature Survey. Appendices covered in sections A1- A6 provide further details on specific investigation techniques. Appendix D contains the conference paper submission relevant to the Literature Survey chapter.

A.1 The Systematic Cause and Analysis Technique

In the Systematic Cause and Analysis Technique (SCAT) method an incident is defined as a potential loss producing event. If no loss is incurred the event stops at the incident phase and is termed a "near-miss" event. Incidents are the contact between an energy source and a target such as people, equipment or the environment. If the event results in a loss it is termed an "accident". Such loss or accidents result in harm to people, damage to equipment, legal or environmental liability or substandard quality of the end product (IRCA Global, 2010).

Immediate causes precede an incident and consist of substandard acts or substandard conditions. Substandard acts or conditions can be seen, heard, smelled, tasted or touched (Sklet, 2002) (IRCA Global, 2010) as shown in Table A1.

Table A1 SCAT substandard acts and substandard conditions (Sklet, 2002) (IRCA Global, 2010)

Substandard practices/acts	**Substandard conditions**
1. Operating equipment without authority	1. Inadequate guards or barriers
2. Failure to warn	2. Inadequate or improper protective equipment
3. Failure to secure	3. Defective tools, equipment or materials
4. Operating at improper speed	4. Congestion or restricted action
5. Making safety devices inoperable	5. Inadequate warning system
6. Removing safety devices	6. Fire and explosion hazards
7. Using defective equipment	7. Poor housekeeping, disorderly workplace
8. Using equipment improperly	8. Hazardous environmental conditions
9. Failing to use personal protective equipment	9. Noise exposures
10. Improper loading	10. Radiation exposures
11. Improper placement	11. High or low temperature exposures
12. Improper lifting	12. Inadequate or excessive illumination
13. Improper position for task	13. Inadequate ventilation
14. Servicing equipment in operation	
15. Horseplay	
16. Under influence of alcohol/drugs	

Immediate causes are a result of root causes (also referred to as basic causes). These root causes attempt to explain why substandard conditions or substandard acts were allowed and consist of either personal factors or job factors as shown in Table A2.

Table A2 SCAT basic or root causes (Sklet, 2002) (IRCA Global, 2010)

Personal factors	Job factors
1. Inadequate capability - Physical/physiological - Mental/psychological	1. Inadequate leadership and/or supervision
2. Lack of knowledge	2. Inadequate engineering
3. Lack of skill	3. Inadequate purchasing
4. Stress - Physical/physiological - Mental/psychological	4. Inadequate maintenance
5. Improper motivation	5. Inadequate tools, equipment, materials
	6. Inadequate work standards
	7. Wear and tear
	8. Abuse or misuse

Root causes set in motion the series of events which lead to an incident or loss; however, root causes exist due to inadequate management control systems. If the management systems are not altered, root causes will manifest in other situations and lead to incidents or losses. There are three drivers to a lack of control (IRCA Global, 2010):

- Inadequate Systems – A safety, health, environmental, risk and quality (SHERQ) system may be inadequate due to inadequate subsystems which aim to control activities. These may include the training, scoping, functional responsibilities and mechanisms to ensure that activities are executed effectively.

- Inadequate Standards – SHERQ standards may be vague by not clearly defining the who, what, where, when and how aspects of the subsystems which require control.
- Inadequate compliance with standards – Adequate systems and standards add no value if compliance is lacking. Clear roles, responsibilities, enforcement and auditing (amongst others) should be in place to ensure that compliance is achieved.

Sklet (Sklet, 2002) identifies in Table A3 the elements which should be in place to address the lack of control due to inadequate systems, standards and compliance.

Table A3 SCAT elements in a safety program (Sklet, 2002) (IRCA Global, 2010)

Elements in a safety program	
1. Leadership and administration	11. Personal protective equipment
2. Management training	12. Health control
3. Planned inspection	13. Program evaluation system
4. Task analysis and procedures	14. Engineering controls
5. Accident/incident investigation	15. Personal communications
6. Task observations	16. Group meetings
7. Emergency preparedness	17. General promotion
8. Organisational rules	18. Hiring and placement
9. Accident/incident analysis	19. Purchasing controls
10. Employee training	20. Off-the-job safety

The information provided in the tables is explained in detail in the method literature (Bird & Germain, 1986) allowing the investigator to ensure that the facts line up with the correct element throughout the investigation. Accidents identify multiple weaknesses in the lack of control of the systems, standards and compliance and each finding should be traceable to the incident or loss. Once improvements are recommended on the management system, a thorough risk assessment is required on each finding. The risk assessments are (IRCA Global, 2010):

- Baseline Risk Assessments – these are standing risk assessments which are reviewed at least annually
- Issue Based Risk Assessments – these are performed as required by the situation and usually linked to a change management system
- Continuous Risk Assessments – these are considered the most important as they address the day-to-day operational risks. They are typically performed by line management

A.2 Fault Trees and Event Trees

Rausand and Høyland (2004) present the fault tree as an analysis technique that was developed by Bell Laboratories in 1962 and improved by the Boeing Company. They introduced computer based quantitative analysis techniques. It is a deductive method that analyses the manner in which environmental factors, human factors, events and component failures contribute to an incident. The analysis is in a binary format (using logic gates) where an event either occurs or doesn't occur; there is no intermediary state. The binary analysis provides for the minimum cut set, that is, the minimum number of events which will lead to the incident. Simple trees may be analysed visually but more complicated trees require software analysis (Rausand & Høyland, 2004).

An event tree, like the fault tree, is a logic tree but rather provides a timewise representation of events. Each event can occur if the preceding event was allowed to occur and unlike the fault tree, events are allowed to partially occur (Sklet, 2002).

A hypothetical fire detection system failure, shown in Figure A1, is used to present the fault tree analysis. The start relay provides information regarding possible fire. If the start relay fails, one of three causes is possible (the OR gate). In this example, the signal from the detection system is absent. Expanding this cause it can be seen that all three inputs which make up the signal from the detection system must be present (AND gate). The absence of any of the three signals from the heat detection, smoke detection and human activation system will result in the failure of the start relay (Rausand & Høyland, 2004).

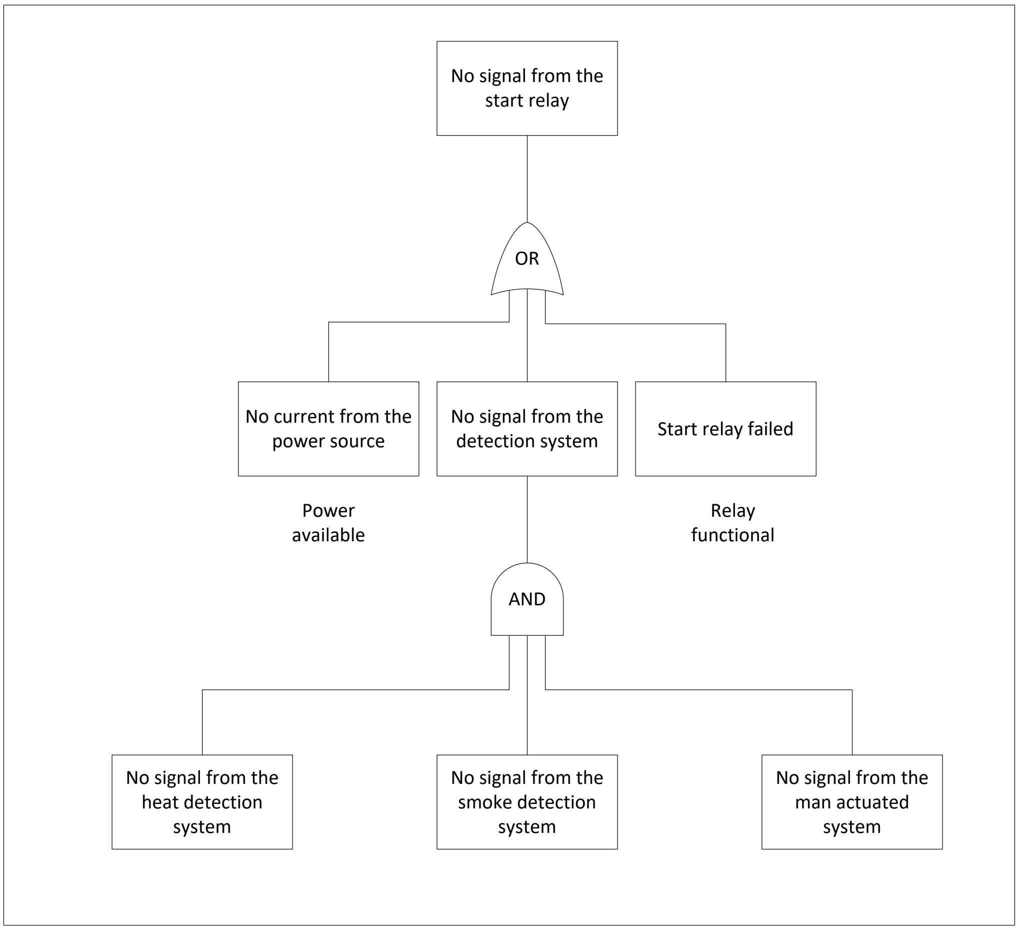


Figure A1 Fire system failure analysis using the fault tree technique (Rausand & Høyland, 2004)

An example of the event tree is demonstrated using the train collision on the Rørosbanen line at Åsta (Sklet, 2002).

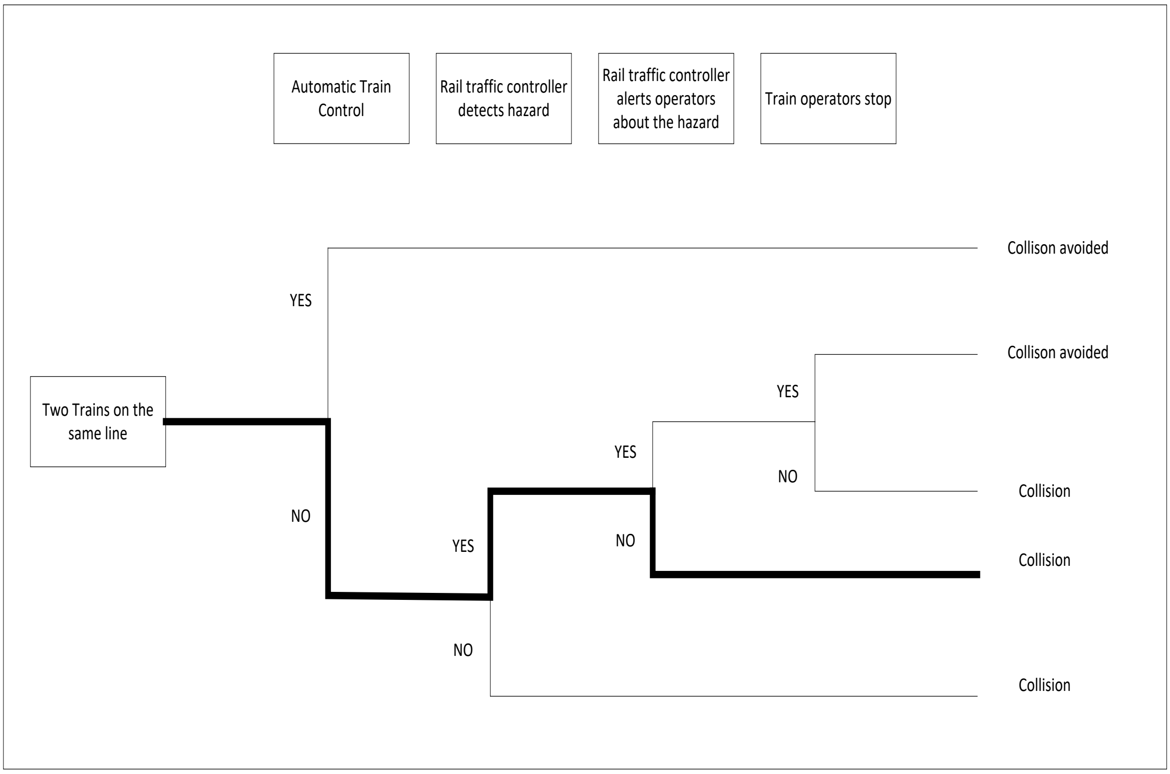


Figure A2 Simplified event tree of a train collision (Sklet, 2002)

The diagram shown in Figure A2 could be used to establish safety systems in undesirable events. In the example shown in this case, the dark line is used to trace the various events which led to the train collision.

A.3 Management Oversight and Risk Tree (MORT)

MORT, a third generation investigation technique plots a flow of energy and establishes the need to prevent it from causing harm to a target (someone or something). Energy can be kinetic, thermal, electrical, ionizing and non-ionizing radiation, acoustic, biological, exclusion of oxygen and exposure to elements. Weaknesses in management systems, specific oversights and omissions let the energy through to the vulnerable target (Johnson, 1973). The MORT technique was introduced as a report in 1973 by W. G. Johnson (Johnson, 1973). A condensed version of the MORT was published in 1992 and is shown in Figure A3 (Knox & Eicher, 1994) .

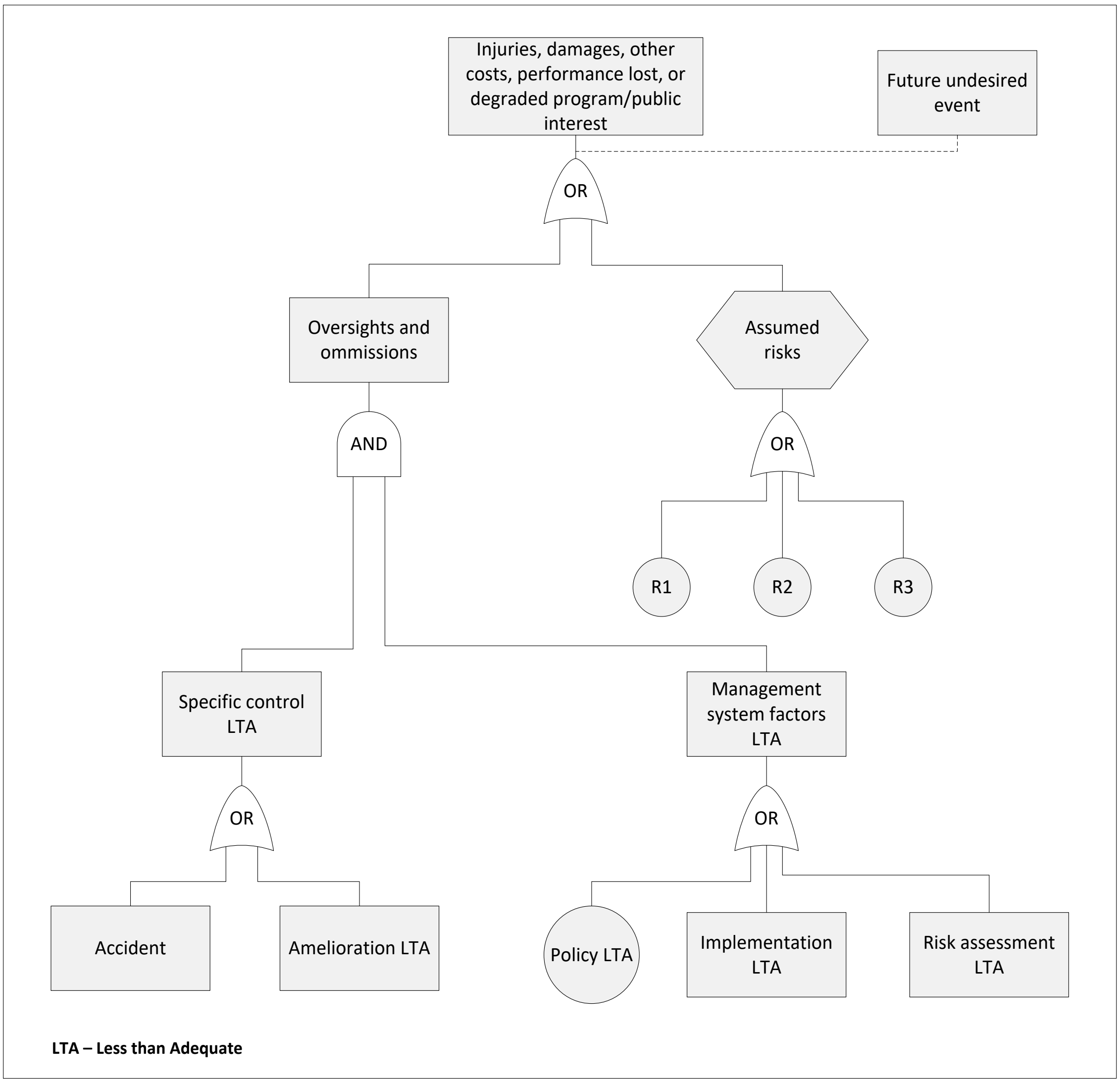


Figure A3 Summarised version of MORT (Knox & Eicher, 1994)

The summarised MORT diagram shown in Figure A3 is now explained using the MORT Users Guide (Knox & Eicher, 1994). Phrases in italics make direct references to blocks in the MORT diagram. The incident is shown at the top of the chart. Either *oversights/omissions* or *assumed risks* could have led to the incident. *Assumed risks* are those risks that have been analysed by experts, approved by management and deemed as tolerable risks. *Oversights and omissions* then branch into *specific control factors* and *management system factors*. At this point the MORT diagram splits and the investigator is guided into two distinct paths. Firstly, the investigator focusses on items and findings directly related to the incident through the *specific control factors*. The investigator is then instructed to consider such finding in the global context regulated by *management system factors*. An example to demonstrate the link between the *specific control factors* and *management system factors* is a Less Than Adequate (LTA) risk assessment by the worker. The LTA risk assessment is a finding in the *specific control factors* leading to the incident. The investigator must now address this specific finding through the *management system factors* and more specifically through the *risk assessment LTA*. This is also an embedded failsafe in the MORT diagram to focus on global improvements through management systems instead of blaming people or equipment.

The tip of the analytical tree (Figure A4) of the MORT Chart shows the final consequences of an adverse event. These are all events which resulted in harm to a person or damage to equipment. They could also refer to direct or indirect costs of operations and the adverse effects on quality or the quantity of production.

Three parallel paths consisting of the Specific Oversights & Omissions, Assumed Risks and Management Systems feed into the event block as shown in Figure A4. Items shown in italics are basic problem blocks appearing in the MORT chart.

LTA is only used in a block which could possibly be deficient and fail as preventing the flow of unwanted energy. The unfilled triangle represents an OR gate whilst a filled triangle represents an AND gate.

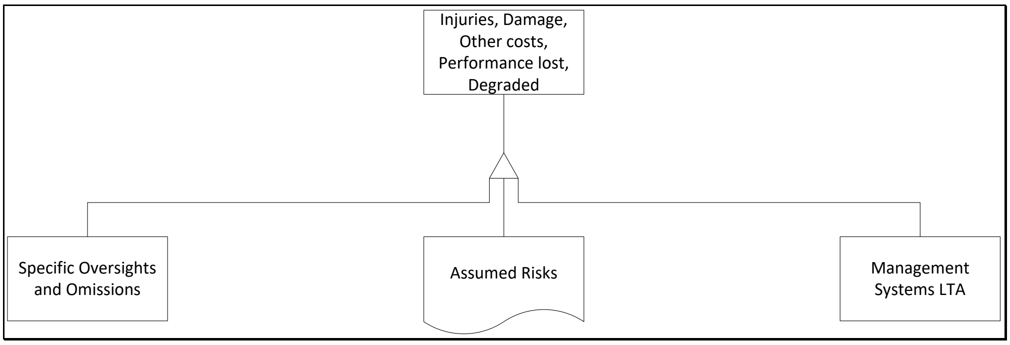


Figure A4 MORT top portion (Johnson, 1973)

a) Specific Oversight & Omissions

The *Specific Oversight & Omissions* branch is shown in Figure A5. These are then worked backwards or branched out until the source of the energy (as used in the MORT context) is discovered. In working backwards at each stage, the analyst could jump to the *Management System* by asking "why could it go wrong?"

In the Chart the term F/M represents a failure to monitor or measure whilst F/M & R represents both the failure to monitor or measure and review.

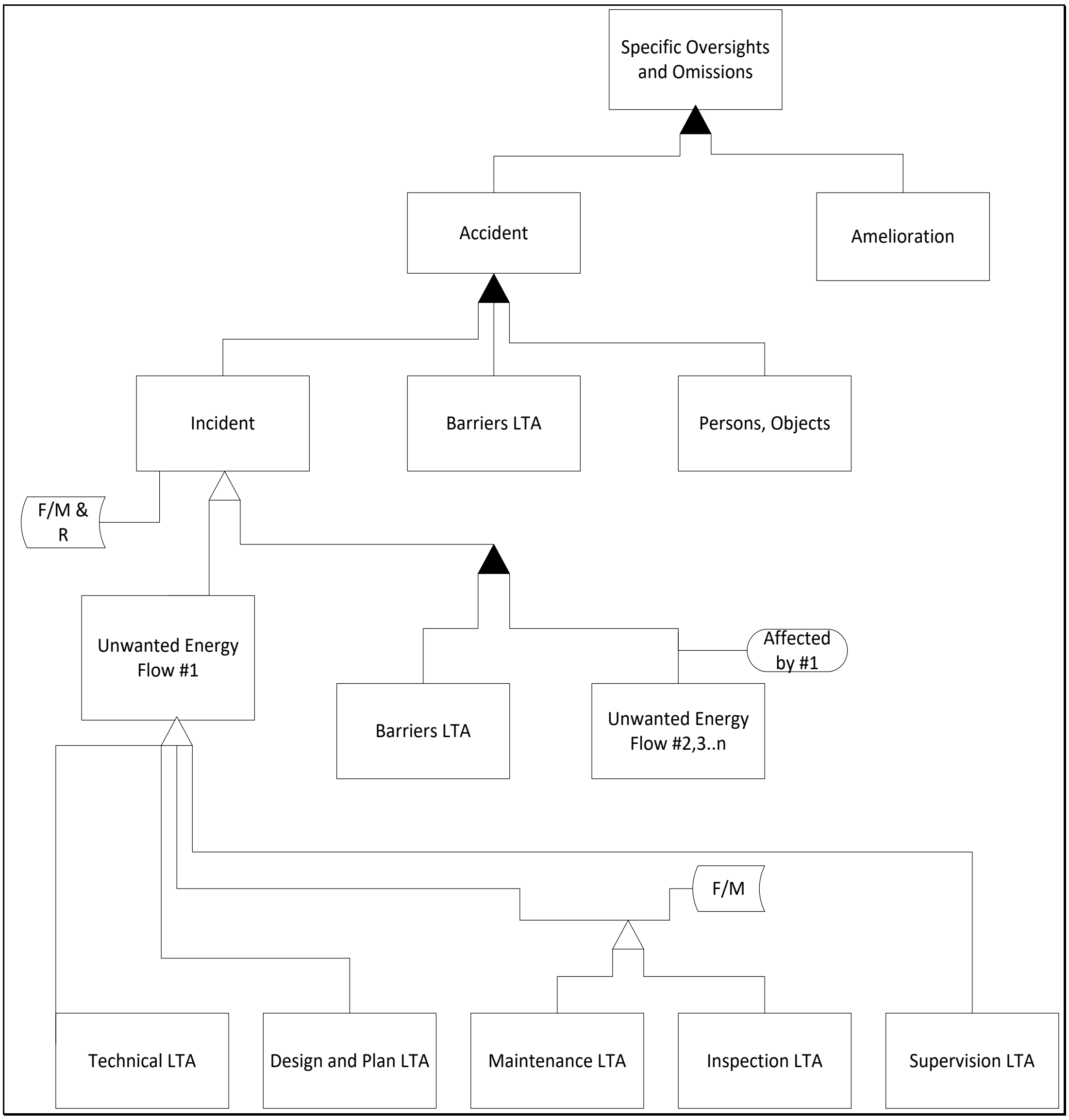


Figure A5 MORT Analytical Tree - Specific Oversight & Omissions (Johnson, 1973)

An *Accident* occurs when energy interacts with *Persons, Objects,* whilst an *Incident* is a near-miss event.

Amelioration is a term generally associated with improvements. In this context it refers to reducing the knock-on or secondary events. These could include the prevention of a second accident, firefighting, rescue, emergency medical services and rehabilitation.

Barriers are those measures that address the transfer of harmful energy. The 12 barriers include the limit of energy, prevention of build up or release, provision of slow released or channel release away (this includes the separation in time or space), inclusion of a barrier at the energy source or at the person or object, personal protection or protection on the object, raise the threshold of injury or damage, treat or repair and finally rehabilitate (Johnson, 1973). An example of the barrier type "raise threshold" is the use of damage resistant material.

Energy *Barriers* may typically link the specific event branch of the analytical tree to the Management System. An example would be an operational instruction in mining where explosives are only detonated at the end of a shift.

An important note regarding energy *Barriers* is that the greater the possible consequences the earlier the barrier should be initiated and redundancy provided (Johnson, 1973).

In Figure A5 a *Barrier* which is LTA in the presence of *Persons, Objects* and unwanted energy, as in the form of an *Incident,* will produce an *Accident*. Removing the deficiency in the *Barrier* or removing the *Person, Object* will prevent an *Accident*.

Unwanted Energy #1 is the energy which has the primary role in the *Incident*. A number of serious incidents experienced successive interactions from consequent sources of energy (Johnson, 1973). The primary energy can thus result in a secondary source of *Unwanted Energy Flow* if the Barriers in place for those energies are LTA. Johnson states that in 12 serious accidents four had two forms of energy while four had three forms of energy.

The bottommost branch under Specific Oversights and Omissions looks at the engineering aspects regarding *Technical Information LTA*, *Design and Plan LTA* and the maintenance management aspects of *Maintenance LTA, Inspection LTA and Supervision LTA.* Working backwards, these blocks then further expand into other pages of the MORT Chart. The Human Factor or Ergonomics are then inherently encompassed in those blocks. Importantly, in the wider branches (blocks further downstream) the analyst is cross referenced to the Management System LTA.

b) Management System LTA

Johnson describes safety as an organisational process which resides with top management further stating that "MORT puts the accident on managements' door step" (Johnson, 1973, pp. 136). Moving away from a person error, when an accident occurs it is a system that fails. The primary responsibility is at top management while operational, engineering, supervisory and middle management errors are subsidiaries. (Johnson, 1973).

It should also be noted that the context of the term 'management' does not only refer to a manager, but also refers to a 'system', i.e. a systematic approach to developing, implementing and improving safety. It is a role not exclusively associated with a manager, although the manager has a key role in the system. This is an important concept in understanding the MORT branch pertaining to Management System.

A safety Policy is seen as the first problem block which must be addressed. Top management must be clear in conveying that to achieve maximum profitability and efficient operation, damage to people and property must be avoided. Employees must be provided with a safe place to work and their welfare must be looked after. Many references are provided by Johnson (Johnson, 1973) where the cost of accidents and the direct correlation between managing safety and managing efficiency are discussed. The Management System LTA is shown in Figure A6.

Policy LTA requires that the management policy be written and updated. It should be comprehensive in dealing with major problems (e.g. social or economic) and major operational challenges (e.g. cost, efficiency, legal compliance).

Implementation LTA can be addressed by reducing high performance and high safety goals to procedures. Human performance improvements can start or improve from this point with literature referring to the use of rewards to gain acceptance. Job Safety Analysis and review of critical incident studies have led to improvements in performance and morale (Johnson, 1973).

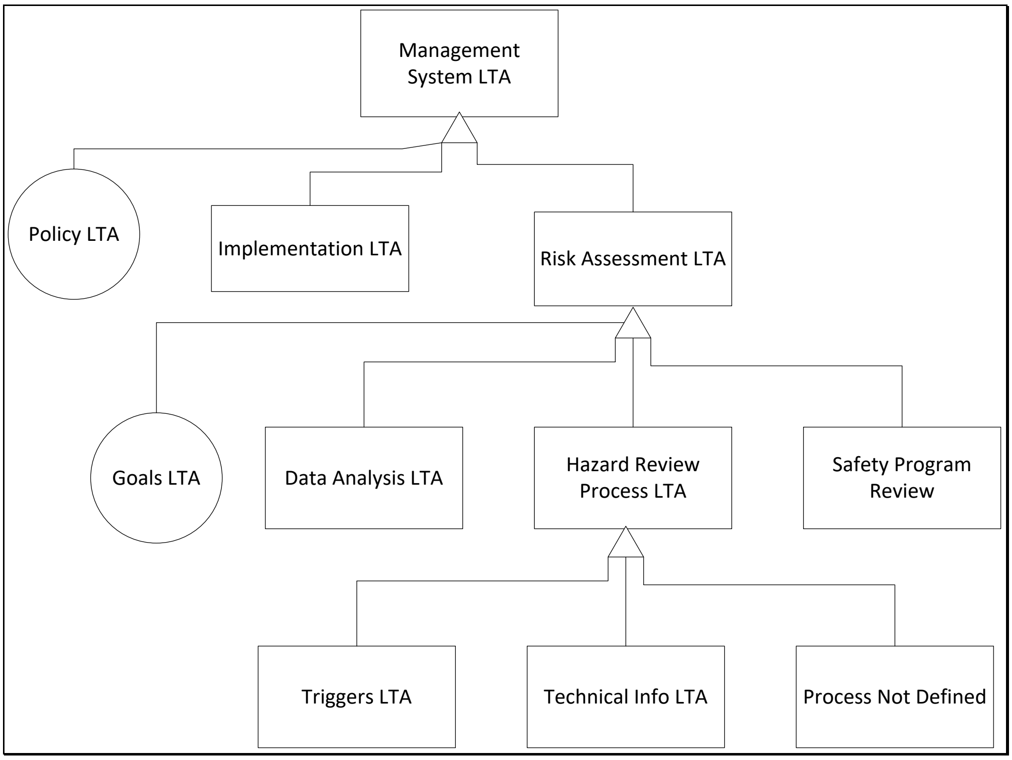


Figure A6 MORT Analytical Tree – Management System LTA (Johnson, 1973, pp. 149)

Implementation LTA according to Johnson (Johnson, 1973) requires attention to:

- Criteria and analysis – the criteria against which work or systems are designed, reviewed and executed. Analysis is a continuous yet methodical review of a system from concept to operation and includes independent review.
- Budgets – the influence on planned or available budgets.

- Delays – these can be built into assumed risks. The influence of postponement of safety related problems, especially in the early life cycle of the influence, should be investigated.
- Line management – clearly defined policies which are followed by the board of directors down to the line foreman. This point also considers outstanding work programmes and the appropriate allocation of tasks.
- Staff – the correct execution of given instructions combined with the clarity of roles and responsibilities. Also there is a need for independent review and cross departmental interfaces.
- Organisation and directives – the implementation of policies through detailed directives or procedures must be examined. Specific rules are required, but it is more important to convey the function or philosophy pertaining to a system. MORT research unintentionally discovered that the use of point-form functional objectives is generally better understood than a paragraph.
- Training – in addition to the specific task or functionary role of the person on the floor, line management must also be familiar with the work they supervise. Likewise, floor staff should be familiar with understanding certain management training.
- Accountability – although supervisors and managers are accountable, have the necessary training and tools been given to the supervisor?
- Feedback – MORT research revealed that pending safety related failures were only visible to senior management after an incident investigation. There is thus a need to evaluate the communication between line management and senior management and the role of the department in this function.
- Vigour and example – this aspect tests the top-down management structure in physically demonstrating what is stated on a policy. Is management leading by example, showing presence on the floor to

re-emphasize safety? Is safety a way of life to management which can positively influence the floor?

A Risk Assessment, like many other problem blocks, does not fail as such but rather its failure lies in the elements which constitute it (Johnson, 1973). The primary objective of the risk assessment system is to provide a measure of the residual risk and take appropriate action if required. The secondary objective is the comparison of similar risks and the use of improvements of the risk scheme as a tool to reduce risk. This is achieved by the *Risks Assessment LTA* consisting of the following elements:

- Goals LTA – goal setting theoretically states what level of excellence is required and the resources such as budgets, time frames and other resources used to achieve the goal. Goals must be set using available data to make them practical and thus acceptable.
- Experience Data analysis – This includes careful analysis of the rates of the different types of incidents, the causes and the circumstances around such causes.
- Hazard Review Process
    - Triggers – these are stimuli to warrant the initiation of the Hazard Analysis Process. Triggers can include planned or unplanned changes, high potential to cause harm or damage, critical incidents, new information and priority problem lists (Johnson, 1973).
    - Knowledge and Information – combination of technical data such as standards, manuals, best practise guidelines for known hazards and investigations or research for unknown hazards.
    - Hazard Analysis Process – a hazard analysis is required for every activity. The hazard analysis process must be able to capture all potential injury producing energies irrespective of the activity (Johnson, 1973).

The two processes required by MORT for the hazard analysis process are the Life Cycle Phase and the Safety Precedence Sequence (Johnson, 1973).

The Life Cycle Phase approach consists of the following steps:

- Conception (definitions and requirements),
- Design and development
- Installation of system components
- Operation (procedures, personnel, maintenance intervals)
- Disposal and renewal

The Safety Precedence Sequence consists of the following requirements:

- Design for minimum hazard (failsafe, redundancy and safety factors)
- Safety devices for hazards which cannot be eliminated
- Warning devices to allow for timely notification or detection
- Human factors review
- Procedures including emergency procedures
- Personnel aspects like supervision, selection, training and motivating
- Residual risk must be identified and communicated for further evaluation

Safety Program Review – the review of the safety program is a major aspect of the risk assessment model. The review can follow a general scheme outlined as follows:

- Define Ideals. These are tools used to improve or develop a safety program and can be based upon high risk materials, risk assessment system, hazard analysis process, safety precedence sequence, energy, error tolerances, supervision. Ideals are the basis from which ideas and improvements are generated.
- Descriptions or Schematics. The ideals of the safety program must be evaluated against actual performance and this requires

a physical system. On the specific side of an operational system, the omission of basic data should be reverse engineered or simply outlined if possible to achieve some basis to develop a safety program.

- Monitor, Audit and Compare. The monitoring of the systems indicates the level of success achieved which can be communicated to management. The audit portion is essential to evaluate the success of the system and implement improvements. The comparative aspect refers to the benchmark, internal or external, as a measure of success.
- Organisation by Scope, Integration and Management Committees. The scope of the safety program should encompass all forms of hazards. The internal resource should be integrated into one unit and then disseminated, rather than being distributed at satellite programs and then attempting to integrate. Safety management committees must be capable of independent review and should ideally report to top management.
- Professional Staff. The use of safety specialists with strong organisational, technical and behavioural knowledge.
- Staff Services. It is important that safety personnel are able to target research, exchange of information, analyse standards and recommendations, provide training and technical assistance and measure performance.

c) Assumed Risks

Most risks are addressed by the hazard analysis process or subsystems of the process. There are certain cases in which the solution to a problem is unavailable (albeit temporarily), is impractical or is delayed. These risks can result in an event without the failure of the Management System or Specific Oversights and Omissions. Assumed Risk requires additional study and effort to mitigate or reduce the risk (Johnson, 1973).

Risks which have not yet been analysed or risks with a level of uncertainty are not an Assumed Risk.

A.4 5 Whys

Toyota refers to the Japanese culture which aims to identify and eliminate every obstacle in the path to perfection in every activity. An obstacle or problem is seen as an opportunity and accepting this opportunity is the essence of solving the problem (Liker & Meier, 2006). The problem-solving method is broken into the following steps:

- Identify the problem
- Perform a root cause analysis
- Plan, Do, Check, Act Cycle [discussed later]
- Reflect and learn from this endeavour

The focus of this section is the root cause analysis step. It was developed internally (to Toyota) and focusses strongly on the effective use of the "5 WHYs" technique (Liker & Meier, 2006).

At first glance a literal inference of the 5 Whys may obscure the need to train or further understand this technique. It is for this reason that the *Toyota Way Fieldbook* (Liker & Meier, 2006) warns the user not to simply take 5 questions and provide 5 answers. The ease of using this technique masks the minute details which can easily lead the investigation team to apply it incorrectly. This can result in finding and addressing problems not related to the root cause of the incident (Rashid, et al., 2014). The 5 WHYs technique does not follow a predefined template or format and can branch at any level or provide unknown quantities (of answers) at each branch. If answering a question is improbable, it is very likely that a step or iteration was missed (Liker & Meier, 2006).

The *Toyota Way Fieldbook* discusses the 5 WHYs using an example. In this example the root cause as to the reason *why* production units are below target is determined. The answer to the *why* could consist of the machines breaking down, operators not present, lack of parts, lack of operator training or protracted setup times. These answers may be correct but are out of sequence which could lead to a dead end or create a missed branching-out opportunity.

The main goal when using the 5 WHYs is to focus exclusively on the question asked, which is “Why are the production units below target?”. The answer is “Because enough units are not produced each hour”.
Following the sequence and asking, “why are enough units not produced each hour”, one could default again to machines breaking down, operators not present, lack of parts, lack of operator training or protracted setup times. This would once again be out of sequence. The correct answer would be “opportunities to produce good units each hour are missed”.
Continuing on, why are "opportunities to produce good units each hour missed"? It may appear simple enough to understand that the time of either a person or a machine is used to convert material into a product. “Opportunities to produce good units each hour are missed” because of a loss of time or the loss of material (scrap or re-class). The sequencing up to this stage is shown in Figure A7.

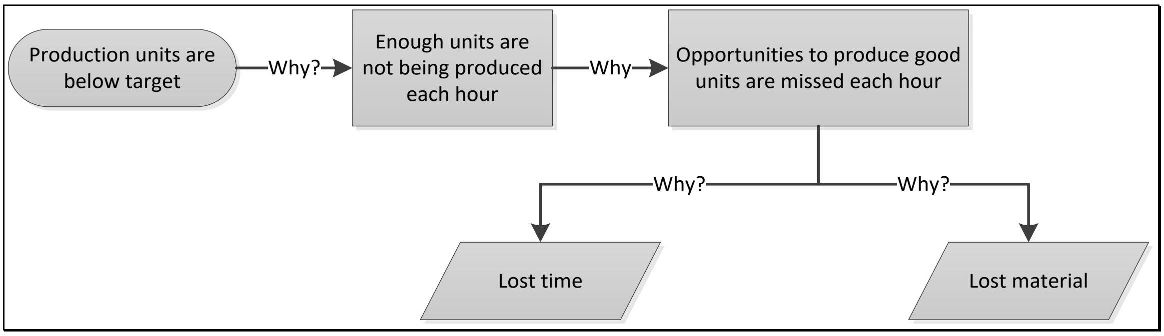


Figure A7 Initial 5 WHYs analysis (adapted from Liker & Meier, 2006)

At this stage, it should be mentioned that if multiple answers are presented higher in the sequence, the most significant causes can be masked by the many less significant or unrelated causes of the issue of production units being below target. A wide or long chain draws away from the focussed approach which a gradually developed sequence through effective questioning creates (Liker & Meier, 2006).
Continuing with the example presented by the *Toyota Way Fieldbook*, the production reports indicated that the scrap production was very low whilst reporting on time was inconclusive. This gives rise to an important concept in the 5 WHYs technique: *Genchi Genbutsu* , or “actual place, actual thing”;

that is, go and see the actual site which will allow understanding of the actual situation and fact-gathering (Liker & Meier, 2006).

In order to maintain the focussed approach, the term “therefore” should be used to cycle through the question and answer. Is the statement “Setting up the process takes too long” the most significant? Answer by using the word “therefore”. “Therefore the machine is not running for that period” and “Therefore time is lost”. During a visit to the site, the production cycle, the machine run and the scrap removal times were critically observed and recorded. It was noted that the production cycle time results in 75 minutes of losses, the machine run time results in 60 minutes of losses and scrap results in 20 minutes of losses. The most significant contributor is the cycle time and is therefore examined (questioned) further as shown in Figure A8.

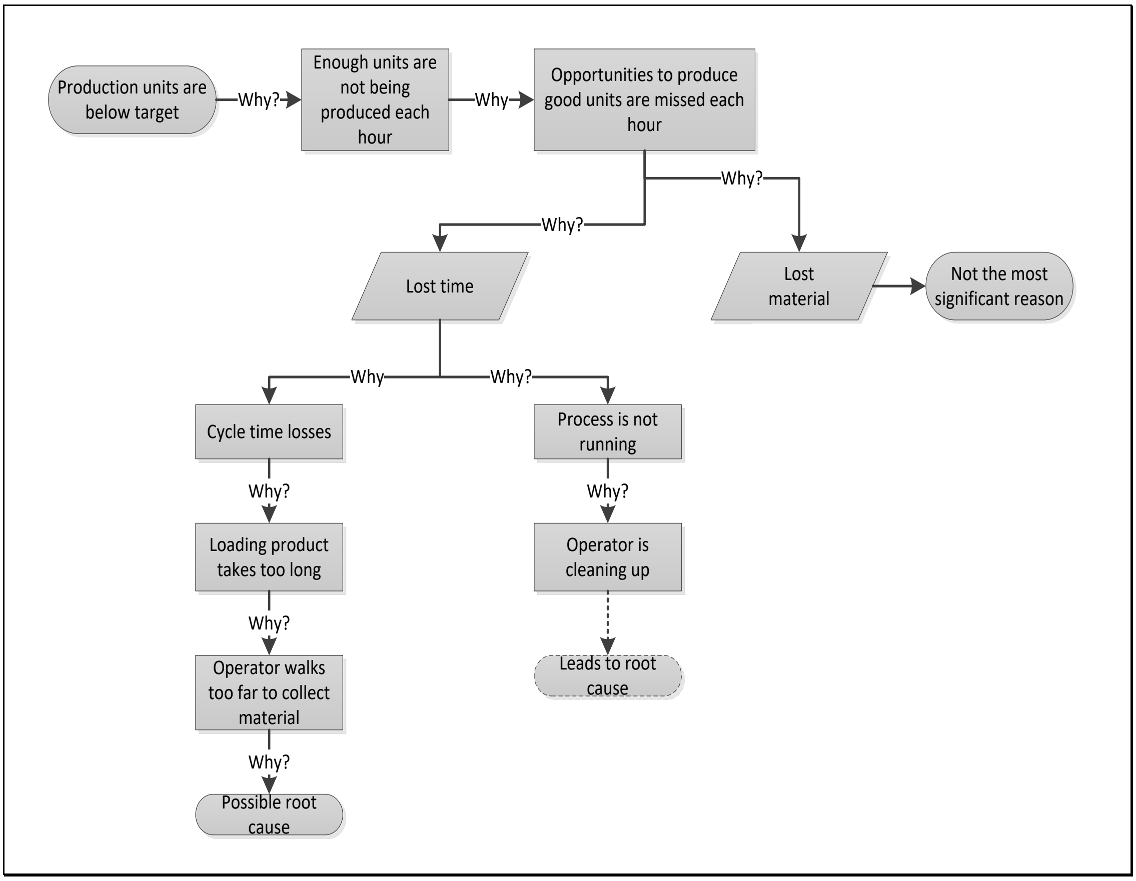


Figure A8 Extended 5 WHYs analysis (adapted from Liker & Meier, 2006)

Returning to the cycle time losses after the *Genchi Genbutsu* was completed and analysed (within the context of the problem and the control of the investigators), it is important to separate the value-adding versus non-value adding activities. A value-adding activity would be "the machine is processing". Non value-adding tasks are collecting raw material, loading the machine, unloading the machine and cleaning. In the example considered, the most significant finding was the time spent loading the machine as the operator walked a distance to collect material and then back to load the machine. This extended the cycle time losses as shown in Figure A8.

The root cause used in Figure A8 is not the end of the 5 WHYs technique. The *Toyota Way Fieldbook* (Liker & Meier, 2006) requires that after identifying the root causes, an appropriate and well defined solution should be proposed, implemented and then verified.

A.5 Cause and Effect Diagram

The Cause and Effect Diagram (CED) finds its roots in quality control. Dr Kaoru Ishikawa published the book titled *TQC towa Nanika - Nipponteki Hinshitsu Kanri* in Japanese. This book was translated into English by David J. Lu and titled *What is Total Quality Control? The Japanese Way* (Ishikawa & Lu, 1985). In this book the CED is used as an improvement tool within several stages of the "Plan, Do, Check, Action" (PDCA) cycle by Dr Frederick W. Taylor (Ishikawa & Lu, 1985) shown in Figure A9.

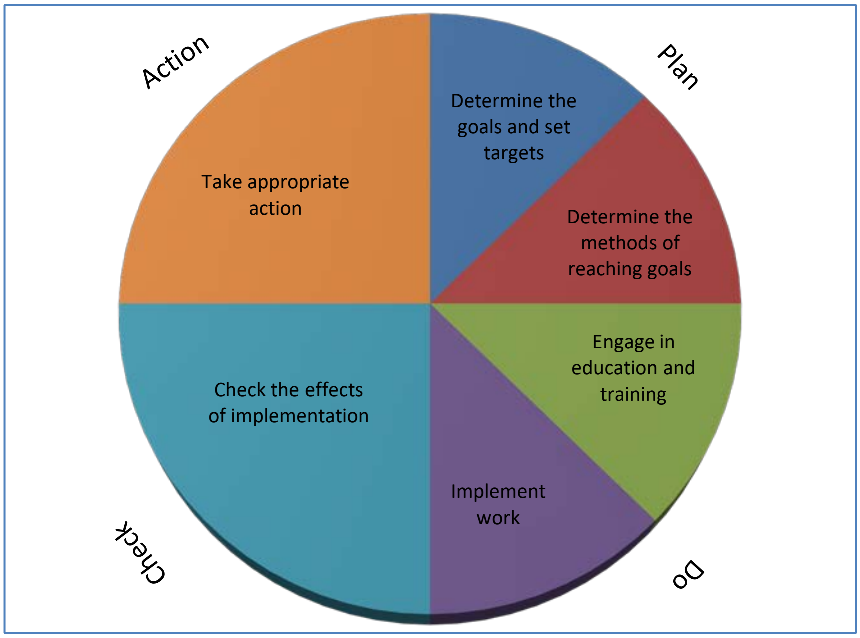


Figure A9 Dr Frederick W. Taylor PDCA model (adapted from Ishikawa & Lu, 1985)

The diagrammatic structure in Figure A10 shows the relationship between effects (events) and cause factors and so became known as the "Cause and Effects Diagram" (CED), which later became known as the Ishikawa or Fishbone diagram due to its shape which loosely resembles a fishbone (Ishikawa & Lu, 1985). The Effect shown on the right hand side can be an event, goal or any characteristic brought about as a result of a collection of Cause Factors. The Cause Factors in Figure A10 (on the branch tips) are factors such as man, machine, material, method and measurement. These Cause Factors can in turn be considered Effects and then have associated Cause Factors (shown by the unmarked arrows in Figure A10). Causal Factors can be extensive as there is no formal limit set; however, a consensus should be established by the investigating team using the Pareto Principle which states that 80% of the effects come from 20% of the causes (Ishikawa & Lu, 1985). This implies that by identifying and addressing 20% of the most significant Causal Factors the investigating team will address 80% of the most significant Effects (Schulmeyer, 2008).

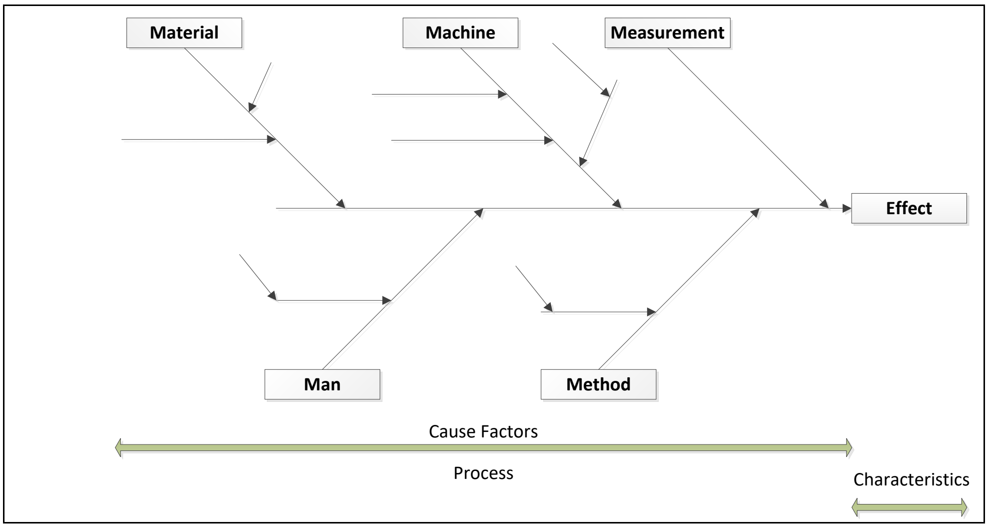


Figure A10 Cause and Effect Diagram (Ishikawa & Lu, 1985)

A practical example is presented in Figure A11. The event is "incorrect deliveries", the main cause "communication". If communication were the event, then the communication of the sales staff becomes the cause. If the communication of the sales staff then becomes the event, then the detail on the order form becomes the cause. The process continues until the most substantial causes are identified.

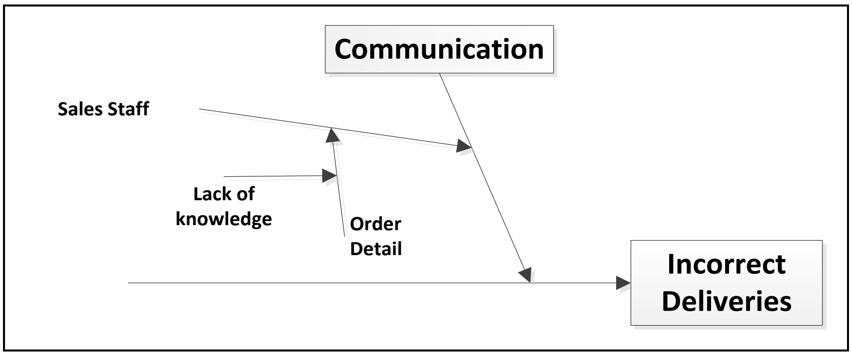


Figure A11 Cause and Effect Diagram (HCi, 2014)

A.6 Events and Causal Factors Charting

Blaming a worker for making the wrong decision does not explain why such a decision was made. People make decisions in the absence of hindsight and generally do not make decisions to intentionally harm themselves or to intentionally perform poorly (U.S. Department of Energy, 2012). Such decisions should be viewed in the same contextual circumstances by an investigator. The situation at the time may have required a worker to respond to different demands. Understanding why a particular action made sense at the time is the cornerstone of the ECF Chart (ECFC). It is important to identify the action, the decision which led to the action and context of such decisions. The context of the situation is used to highlight human performance, missed opportunities, organisational cultural attributes and latent weakness (U.S. Department of Energy, 2012). ECFC is an effective method to tackle accidents which resulted due to a breakdown of multiple systems as each event is expanded into actions, decisions, context and conditions.

ECF facilitates the graphical plotting of events, actions and decisions which trigger the investigation team to establish the conditions and context within which such decisions were made. The other analytical techniques such as barrier and change analysis together with safety systems and human performance analysis will support an identification of causal factors. By addressing the causal factors, possible recurrence can be prevented (U.S. Department of Energy, 2012).

The graphical representation of the Events and Causal Factors Charting is shown in Figure A12 as explained in the US DOE Handbook (U.S. Department of Energy, 2012) pages 2-50 to 2-52.

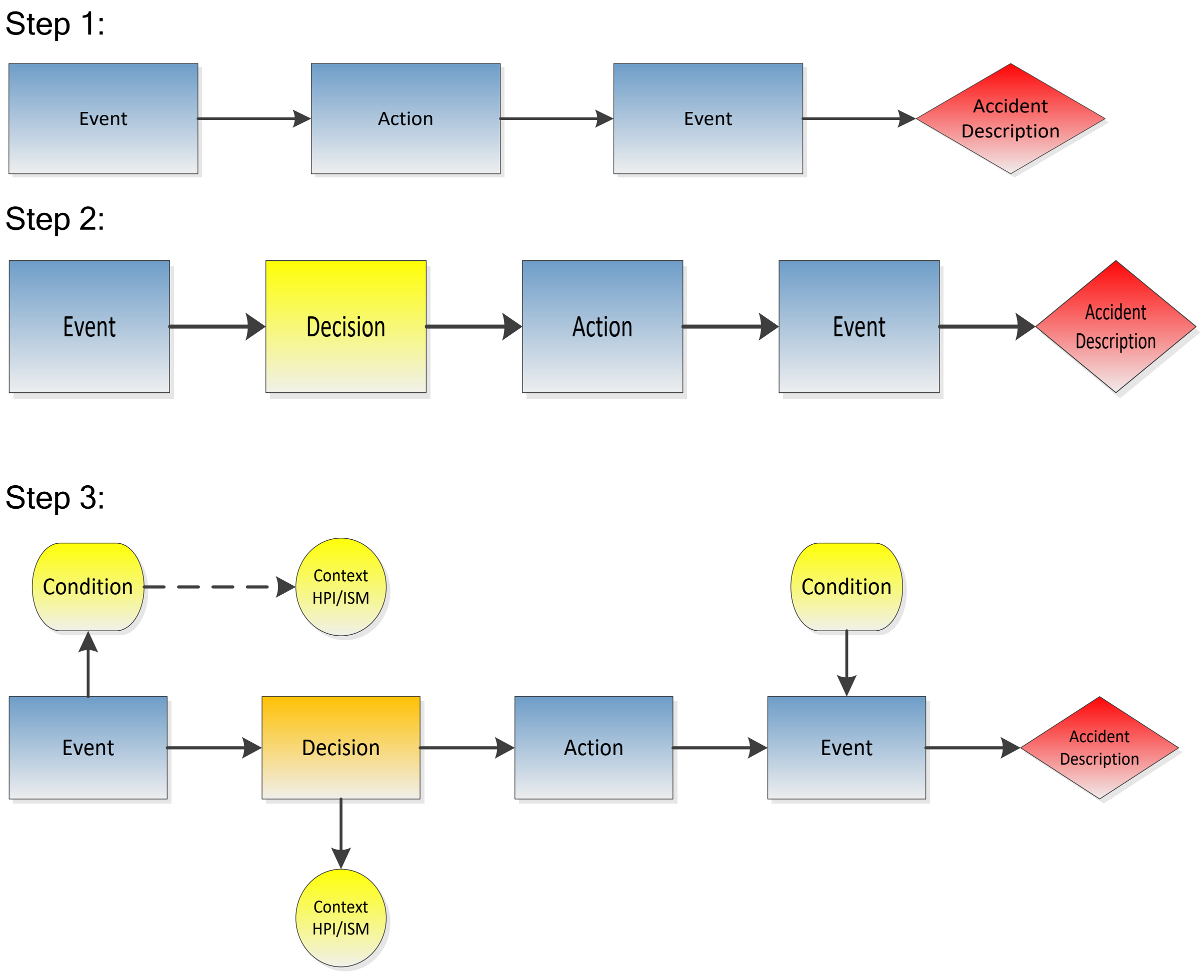


Figure A12 Events and Causal Factors Charting adapted from the DOE Accident Investigation Handbook (U.S. Department of Energy, 2012)

In Figure A12, the first step requires the plotting of the events leading up to the incident and the immediate occurrences after the accident such as emergency response and containment. The events can include actions, observations and changes in the process or system.

The second step evaluates the decisions made before events in an attempt to establish the basis of understanding how the worker's thought process unfolds in parallel with the situation developing.

The third step examines the context of human performance, safety management systems, culture analysis, the work environment and physical conditions which exist at that time. This step begins exploring deeper into the organisational culture and problems which may not be apparent.

Human performance analysis explores the organisational and human performance factors, which when combined with human actions produce undesirable events. The human performance factors are established in the Human Error Precursor Matrix (U.S. Department of Energy, 2012). The safety management system is a principle used by the U.S. DOE to ensure the safety of people and the environment. It is based on the Integrated Safety Management Five Core Functions (U.S. Department of Energy, 2012)) and Seven Guiding Principles (U.S. Department of Energy, 2012).

The reconstruction attempts to create understanding of exactly how the work was unfolding, the information available at the time and its influence on the decisions made. These are compared to how work was expected to proceed and an attempt is made to understand why deviations occurred. The Human Error Precursor Matrix, Integrated Safety Management Five Core Functions and Seven Guiding Principles are tools used to guide the investigation team (U.S. Department of Energy, 2012).

An example used in the DOE Handbook which brings all the information presented on the ECFC together is shown in Figure A13.

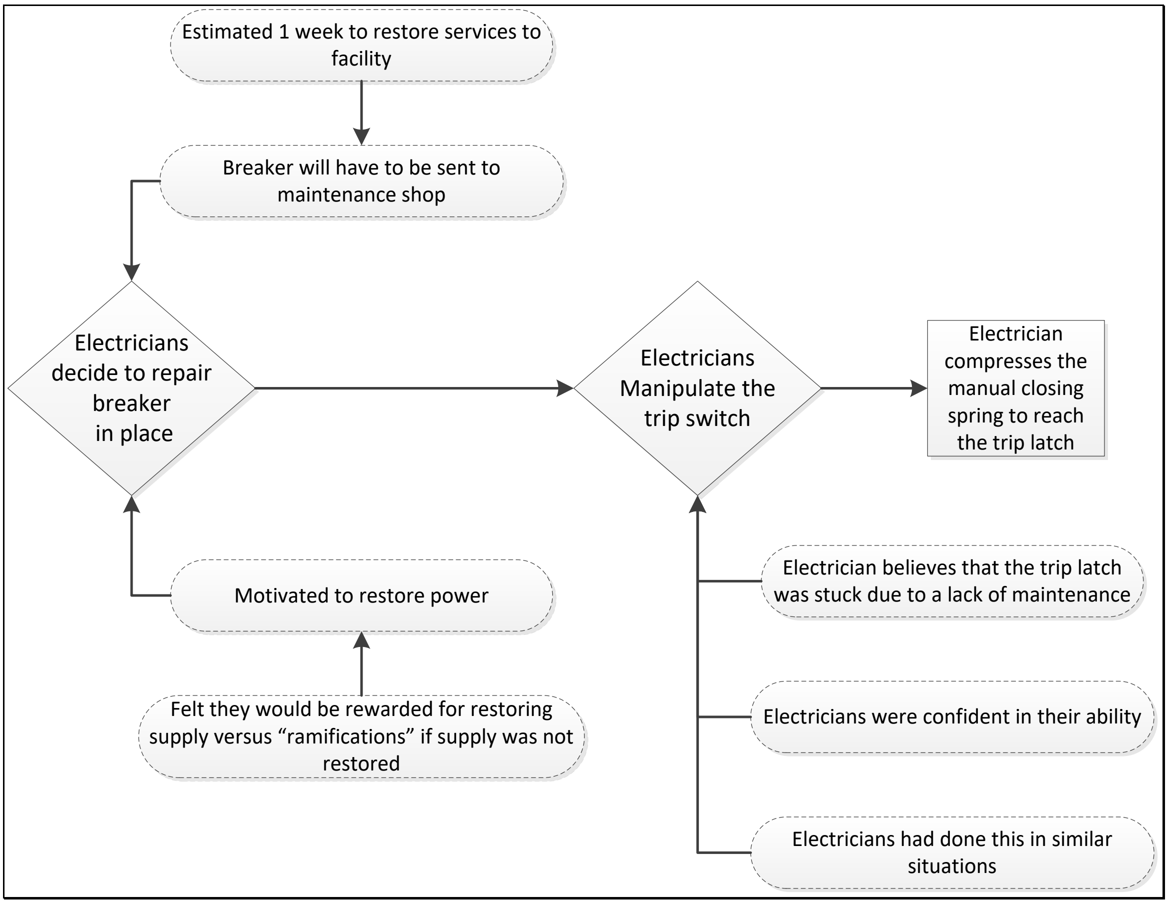


Figure A13 Excerpt from an Accident ECFC summarised from DOE Accident Investigation Handbook (U.S. Department of Energy, 2012)

The benefits of the ECFC have been summarised by the DOE (U.S. Department of Energy, 2012) as follows:

- Graphical representation of the accident using actual timelines
- Establishing relationships between persons and the organisation which may have previously been less apparent
- Graphically portraying information which is missing or which requires further analysis and verification
- Drives the resolution of causal factors to organisational systems and management issues
- Cross validation of results using other techniques
- Structure method for the collection and processing of data
- Highlighting multiple causes

- Facilitating discussion between investigators with all the latest information visible to all role players
- Graphical representation which will facilitate the drafting of the incident report
- Effective visual aid portraying the entire incident from before until after the incident

A.6.1 Barrier analysis

Barrier Analysis, as defined previously, studies the various physical and administrative barriers which aim to prevent a hazard from reaching a target. Once the ECFC is drafted the investigation team uses Barrier Analysis to further examine the influence of physical and administrative barriers in the accident. The investigation team firstly identifies the barriers, if present, which prevent the initiation or mitigates the harm. The team then evaluates the barriers in the context of the specific decision or organisational conditions which either weakened or strengthened a barrier (U.S. Department of Energy, 2012). An example to demonstrate this point would be a worker who, due to time constraints, fails to identify a hazard (administrative) or does not use the prescribed protective equipment (physical). It is recommended that the investigation team access the various means by which a hazard can reach a target and then list all barriers which prevent this situation from occurring.

Physical barriers may include guarding devices, personal protective equipment, drawings and distance. Administrative barriers may include the clear definition of roles and responsibilities, hazard analysis and risk assessments, training, supervision and safety programs. An example of a barrier analysis worksheet is provided in Table A4.

Table A4 Sample Barrier Analysis Worksheet from the DOE Accident Investigation Handbook (U.S. Department of Energy, 2012, pp. 2-64)

Hazard: Electrical Cable		Target: Pipefitter		
What were the barriers	How did the barrier perform	Why did the barrier fail	How did the barrier affect the accident	Context • Human Error Precursor Matrix • Integrated Safety Management System, and • Seven Guiding Principles
Engineering Drawings	Failed to indicate cable	Final drawings not procured Preliminary design drawings used No as-built drawings	Failed to identify cable	Inaccurate mental picture (Human Nature) Inaccurate risk perception (Human Nature) Limited perspective (Individual Capabilities) Hazard Identification lacking (Guiding Principles)

The barrier analysis must examine organisational concerns, management systems and line management oversight to ascertain if the causal factors originated in these areas. The top down management structure must be evaluated without focussing on individuals (U.S. Department of Energy, 2012).

It is also important at this stage that the investigation teams search for past incidents which indicate similar barrier failures or similar incidents.

The furthermost right column in Table A4 covers the Human Performance, Safety Management Systems and Culture Analysis. Depending on the evaluation of the final ECFC, these factors may be classified as causal factors.

A.6.2 Change Analysis

Following the barrier analysis, the investigation team considers the effects of change on the accident. Although change is essential to an organisation, change which is not managed well can lead to unwanted or unintentional consequences. The context of change is not only limited to change in refurbishments or new projects but is applicable to staff turnover or retirement. (U.S. Department of Energy, 2012).

Change analysis consists of six steps. The comparison of the accident and accident-free situations produces a list of differences. The analysis of the differences in the context of finding causal factors produces results. These results are captured in the ECFC as shown in Figure A14.

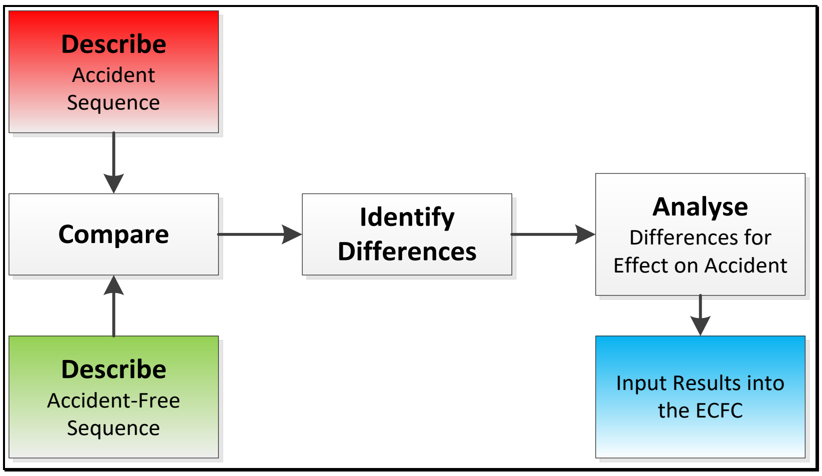


Figure A14 The Change Analysis Process from the DOE Accident Investigation Handbook (U.S. Department of Energy, 2012)

In order to create a baseline, the investigation team requires detailed information of the accident-free situation or the design philosophy. Failure to ensure that the baseline is established in sufficient detail may not only jeopardise the effectiveness of the analysis but may result in missed causal factor identification. A baseline or the accident situation may not be modelled accurately at the beginning of the investigation due to a lack of information. It is suggested that the ECFC and barrier analysis be performed and as information of the actual situation unfolds, the investigation team can perform the change analysis (U.S. Department of Energy, 2012). A challenge of the change analysis method is that of compounding changes. An example would be a change in the training policy from several years ago compounded by another change in the same system recently. It is suggested that multiple baselines be utilised if such a situation is suspected (U.S. Department of Energy, 2012).

When evaluating an accident, various subsets of change are possible e.g. change in the physical location versus a change in the person performing the task. It is thus recommended that the six steps shown in Figure A14 be evaluated in terms of the what, when, where, who and how method. This leads to the tabular representation of the six steps as shown, using an example, in Table A5.

Table A5 Sample Change Analysis Worksheet as adapted from the DOE Accident Investigation Handbook (U.S. Department of Energy, 2012)

Factors	Accident Situation	Accident-Free Situation	Difference	Evaluation of Effect
WHAT **Conditions, occurrences, activities, equipment**	1. Design and Safety reviews were not performed. 2. Established review process was bypassed. 3. Hazards associated with the work being performed were not identified. No review of as-built drawings. No excavation permits. No underground utility survey.	1. Project design and ES&H review are performed by appropriate groups to ensure adequate review and the safety and health of employees. 2. Construction packages are approved by facilities project delivery group. 3. A preliminary hazard analysis is performed on all work.	1 Environmental Group assumed design role and removed ES&H review from task. 2. Environmental Group approved work packages. 3. No preliminary hazard analysis was performed on construction task.	1. Design and ES&H reviews were not performed, contributing to the accident. 2. Construction packages were not approved by facilities group. 3. Hazards were not identified, contributing to the accident.
WHEN **Occurred, identified, facility status, schedule**	Insert date or description of the accident situation	Insert date or description of the accident-free situation	No information required in this space	No information required in this space

Table A5 Sample Change Analysis Worksheet as adapted from the DOE Accident Investigation Handbook (Continued)

Factors	Accident Situation	Accident-Free Situation	Difference	Evaluation of Effect
WHERE **Physical location, environmental conditions**	Sump location was placed above a 13.2 kV electrical line.	Sump is placed in a non-hazardous location.	Inadequate design allowed sump to be located above a 13.2 kV line.	Sump location was placed above an electrical line, which was contacted by a worker jack- hammering in the area.
WHO **Staff involved, training, qualification, supervision**	Environmental Group assumed line responsibility for project.	Environmental Group serves as an oversight/support organisation to assist line management in project.	Support organisation took responsibility of line function for project management.	Lack of oversight on project.
HOW **Control chain, hazard analysis**	Management allowed Environmental Group to oversee construction tasks.	Management assures that work is performed by qualified groups.	Hazard analysis was not conducted.	Hazards were not identified, contributing to the accident.

A.6.3 Causal Factors

Once the ECFC is constructed and analysed using the barrier and change analysis, the Causal Factors Analysis may be applied. The causal factor analysis entails the identification of causal factors and the classification of such into direct causes, contributing causes and, most importantly, root causes.

Direct causes are the precedents to the accident and can be summarised by a single sentence; e.g., the direct cause of the accident was the contact between the tool and the energised conductor. Another example could be: The direct cause of the accident was the inadvertent energising of the circuit which released CO_2 gas into an occupied area (U.S. Department of Energy, 2012).

Contributing causes may not have directly led to the accident but had to be present to facilitate or increase the likelihood of the accident occurring. Contributing causes are also seen to favour the recurrence of accidents if left unaddressed; e.g., failure to erect barricading or warning signs contributed to the accident. Another example would be: The failure to implement safety procedures for the project contributed to the accident (U.S. Department of Energy, 2012).

A.6.4 Root Cause Analysis

The events and causal factors charting, barrier analysis and change analysis have thus far provided a sequential graphical layout of the accident, answering such questions as the what, when, who, where and how. Root cause analysis examines and answers the why portion of the investigation. Root cause analysis is not an exact science and the investigators use the exhaustive list of facts and results presented up to this stage of the investigation to select the higher organisational system failures which led to the accident (U.S. Department of Energy, 2012).

Unlike direct causes, which may be limited to certain operations, root causes are deficiencies in the higher management system which expose all operations to the risk of accidents. As such, root causes are often broad statements lacking the specifics which must be provided by the operational units. Identifying root causes aims not only to prevent a recurrence of the accident being investigated, but also addresses line management oversight and the organisation's overarching integrated safety management system deficiencies. Such deficiencies have the ability to cause or contribute to other accidents (U.S. Department of Energy, 2012).

B SUPPLEMENTARY READING FROM THE RESEARCH METHODOLOGY CHAPTER

B.1 Data Analysis

This section presents the validity and reliability considerations for the statistical analysis of the survey which was issued to the investigators of the case study plant. Validity: To demonstrate the validity of the data, Principal Component Analysis (PCA) was used. PCA is used to reduce or summarise the total number of items explaining a construct (Yong & Pearce, 2013). The Laerd website (Lund & Lund, 2013) summarises the aim of PCA as follows:

(i) Remove superfluous/unrelated items: reduction of items which are not measuring the construct or do not relate to other variables measuring the construct

(ii) Reduce redundancy in a set of variables: if multiple items are measuring the construct in an identical manner, these items can be reduced

The PCA was determined through the Kaiser-Meyer-Olkin (KMO) index, shown in Table B1, and a correlation matrix, shown in Table B2. The correlation matrix produced a correlation coefficient which is the measure of linearity between two variables. It measured the degree to which a change in one variable predicts the change in the other (Ratner, 2015). A correlation coefficient greater than 0.3 showed correlation whilst values greater than 0.7 showed a strong correlation (Yong & Pearce, 2013). KMO is another linear correlation index (Kaiser, 1974).

Table B1 KMO Index of sampling adequacy (Lund & Lund, 2013)

KMO Measure	Meaning	No of Items
KMO ≥ 0.9	Marvellous	0
0.8 ≤ KMO < 0.9	Meritorious	3
0.7 ≤ KMO < 0.8	Middling	19
0.6 ≤ KMO < 0.7	Mediocre	5
0.5 ≤ KMO < 0.6	Miserable	2
KMO < 0.5	Unacceptable	2

KMO measures above 0.6 can be considered adequate whilst values above 0.9, although strong, start showing multicollinearity (linearity with multiple items) which is not desired in this study (Yong & Pearce, 2013).

All items in the survey, except two, had at least one correlation coefficient greater than 0.3 (Lund & Lund, 2013). Table B2[8] demonstrates an extract of the 31X31 correlation matrix.

The two items which did not have a correlation coefficient greater than 0.3 consisted of the following questions:

(a) In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.

(b) Incident investigators blame people for incidents

These two questions are linked to another item which is:

[8] The correlation matrix is a large 31x31 matrix excluding headings and only part of the table is shown for demonstration.

(c) Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).

The same two questions [(a) and (b)] had a KMO measure of less than 0.5 (unacceptable). Looking at these three items, it is evident that all three are testing whether investigators are blaming people for accidents. These questions were paraphrased to test whether the investigators perceived themselves or others as blaming people during investigations.

The context of this focus area was based on literature which described blaming as a common occurrence (Reason, 2000) (IRCA Global, 2010) (U.S. Department of Energy, 2012).

The overall KMO measure was 0.734 and the individual KMO measures are shown in Table B3. The majority of items were greater than 0.7, classifications of 'middling' to 'meritorious' according to Kaiser (Kaiser, 1974) as shown in Table B3.

Two other questions displayed a KMO measure of less than 0.6 (miserable); however, these items showed multiple correlation coefficients greater than 0.3 and thus have linear relationships with other items.

The PCA did not justify the reduction of the 31 questions based on the KMO. Thus all questions were used in the analysis of the survey data.

Table B2 Extract of the 31 x 31 correlation matrix

Correlation Matrix	Near-misses investigated in detail	Structured guideline…	Investigation begins as soon…	Statements collected…	Incidents which require investigation	Independent person…	Correct mix…
Near-misses are investigated in detail	1.000	.388	.337	.289	.344	.425	.253
A structured guideline exists, …need investigating	.388	1.000	.181	.251	.235	.237	.136
The incident investigation process begins…	.337	.181	1.000	.404	.412	.235	.213
Statements are collected …	.289	.251	.404	1.000	.424	.210	.258
Incidents which require investigation are being investigated	.344	.235	.412	.424	1.000	.226	.396
Independent persons are included…	.425	.237	.235	.210	.226	1.000	.474

Table B3 Individual KMO measures on the 31 investigation process requirements

No.:	Item	KMO Measure
1	Near-misses are investigated in detail	.821[a]
2	A structured guideline exists, which outlines what type of incidents need investigating	.749[a]
3	The incident investigation process begins as soon as the incident becomes known	.644[a]
4	Statements are collected as soon as the incident becomes known	.670[a]
5	Incidents which require investigation are being investigated	.772[a]
6	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	.761[a]
7	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	.753[a]
8	At this company, I have received formal training on an incident investigation technique (e.g. RCAT, CED, 5 WHYs etc.)	.712[a]
9	I have received formal training on my company's incident investigation policy	.800[a]
10	I am well experienced in incident investigation techniques	.675[a]
11	Other investigators are well experienced in incident investigation techniques	.548[a]
12	An incident investigation team is provided with clear roles and responsibilities	.776[a]
13	Time frames are specified for the completion of incident investigation reports	.761[a]
14	If time frames are specified, these times are adhered to	.741[a]
15	Investigators are somewhat protected from operational responsibilities and are allowed to focus on a thorough incident investigation	.734[a]
16	Investigators are given adequate time to complete a thorough incident investigation	.698[a]
17	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	.741[a]

Table B3 Individual KMO measures on the 31 investigation process requirements (Continued)

No.:	Item	KMO Measure
18	Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).	.547[a]
19	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.	.305[a]
20	Incident investigators blame people for incidents	.451[a]
21	Incident investigators probe human behavioural management systems (e.g. individual development plan)	.826[a]
22	Incident investigators probe engineering management systems (e.g. change management)	.780[a]
23	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	.763[a]
24	Incident investigators probe operational management systems (e.g. safe operating procedures)	.736[a]
25	I am aware of the outcomes of incident investigations, which occur at other operating units. (Please note that this point does not refer to a 24 hour or 1-pager report of the incident, but rather to the detailed accident investigation)	.720[a]
26	A system exists to enforce the actions from other operating unit's incident investigations in my department	.782[a]
27	An incident investigation is considered to be completed once the root causes are established	.645[a]
28	A system does exist to ensure that the implementation of all actions are effectively completed	.759[a]
29	A system exists to ensure that incidents are investigated thoroughly	.714[a]
30	Completed incident investigations are audited against the company policy	.766[a]
31	Completed incident investigations are reviewed by experts on the company's incident investigation policy.	.789[a]

a. Measures of Sampling Adequacy (MSA)

Reliability: Cronbach's Alpha was used to measure the reliability of the data as it is widely used when working with Likert scale items (Lund & Lund, 2013).

The 106 survey responses were entered into SPSS to perform a reliability study. Table B4 shows that a further 15 responses were omitted due to insufficient information which influenced the reliability of the study. Table B5 presents the reliability data.

Table B4 Case Processing Summary

		N	%
Cases	Valid	91	85.8
	Excluded[a]	15	14.2
	Total	106	100.0

a. Listwise deletion based on all variables in the procedure.

Table B5 Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.878	0.887	31

The 31 questions deployed to determine the effectiveness of the application of the incident investigation process showed a high measure of reliability, as determined by a Cronbach's alpha α = 0.878. Values above 0.7 are considered a good level of reliability (DeVellis, 2003) (Kline, 2005).

B.2 Ethical Considerations, Information, Consent and Clearance

This section presents a copy of the Participant Information Sheet that was provided to each of the investigators who was issued a survey. In addition, each participant was required to complete a consent form before taking the survey. Finally, the clearance certificate from the human research ethics committee from the University of the Witwatersrand is attached. The survey was issued and all responses were attained within the validity period of this clearance.

PARTICIPANT INFORMATION SHEET

Good day and thank you for your valuable time. My name is Zarheer Jooma (employee [redacted]) and I am both an Electrical Engineer and the [redacted] Manager at the Engineering Department at [redacted]. I have registered as a student at the University of Witwatersrand for a Master's Degree in Electrical Engineering (100% research based) and I would like to invite you to participate in this research work by answering the attached questionnaire.

In my role at [redacted], I am responsible for writing policies, standards and procedures. When a failure or incident occurs (including near-miss events), I consider it a learning experience and an opportunity to make things better by preventing recurrences. In line with this thinking, my Masters research aims at understanding the effectiveness of incident investigations as a tool to improve safety at [redacted]. Findings from the research will benefit [redacted] and the industry as a whole by identifying the salient (yet critical) requirements to perform an effective investigation which will prevent recurrences.

As a specialist or manager you have (*or* are likely to) undertake an investigation. You may also be required to implement recommendations based on incidents or accidents which occurred outside of your plant. As such, you have been selected to participate in this research. Your details were gathered from our previous work interaction, recommendations by the SHERQ department as well as information (role and position) gathered from our internal [redacted] directory ([redacted]).

It will be greatly appreciated if you could complete this questionnaire within the next two weeks. Participation in the questionnaire is entirely **voluntary** and your participation or refusal will not affect remuneration, material reward, overtime, special treatment, penalty or loss of benefits in any way whatsoever. Permission to undertake this survey as well as to invite you to participate has received the necessary and applicable clearances from the University of Witwatersrand, Johannesburg and [redacted]. Your confidentiality is guaranteed as your name, designation, role, location or any other details will not be published or made available to any person. You will be provided with a code so as to protect your information and ensure your anonymity. Your information will only be made available to myself and my supervisors from the University of Witwatersrand, Johannesburg. You are free to abstain from answering questions which you may feel uncomfortable answering; however, there are no questions of a personal nature in the questionnaire. You are welcome to withdraw or refuse from being part of this research at any time.

The results from this questionnaire will be analysed in a Masters dissertation and if successful for the purposes of a degree, may be published on the internet. None of your individual information will be published so there is no trace back to what you have answered. The information will be reported on for the group and specific questions highlighted. Again this reassures you that your information will be strictly confidential. If you would like the results of the questionnaire or require assistance in answering any question, please feel free to contact me using the details below. If the need arises, you may also contact my supervisor from the University of Witwatersrand, Johannesburg using the details below.

Please answer as accurately as possible using your present knowledge and experience without attempting to research answers. There are no right or wrong answers in this questionnaire. Once completed, you are welcome to contact me or alternatively await my follow up visit.

CONSENT FORM

I, (Full Name)

____,

understand that the research has been explained to me and that the role of the questionnaire in order to meet the aims of the research is clear. I understand the explanation and contents of the Participation Information Sheet and can contact the researcher for further clarity if so required.

I further understand that I am involved in this research by completing the attached questionnaire and that my anonymity is guaranteed. I may withdraw from this research at any time and there is no favour or reward for the completion of this questionnaire.

The Participation Information Sheet, will be retained by me. The Consent Form and Questionnaire will be returned to the researcher. The Consent Form will be separated from the Questionnaire as a further step to protect my anonymity. Your initials and number of years of service will generate a unique PIN which you may use to follow up on the results of the research.

Signed: _______________________

Date: __________________________

HUMAN RESEARCH ETHICS COMMITTEE CLEARANCE

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R 14/49 Jooma

CLEARANCE CERTIFICATE	PROTOCOL NUMBER H14/07/17
PROJECT TITLE	The effectiveness of the application of the Incident Investigation Process for Electrical Accidents
INVESTIGATOR(S)	Mr Z Jooma
SCHOOL/DEPARTMENT	Electrical & Information Engineering
DATE CONSIDERED	18 July 2014
DECISION OF THE COMMITTEE	Approved Unconditionally
EXPIRY DATE	29/07/2016

DATE 30/07/2014 **CHAIRPERSON** E.M. Tal pp (Professor T Milani)

cc: Supervisor: Prof I Jandrell & Ms J Hutchings

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10000, 10th Floor, Senate House, University.

I/We fully understand the conditions under which I am/we are authorized to carry out the above mentioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to completion of a yearly progress report.**

Signature

2014 / 07 / 21
Date

C SUPPLEMENTARY INFORMATION FROM RESULTS AND DISCUSSION CHAPTER

C.1 Analysis of Completed Investigations – Optimising the Questions

The minimum requirements of the investigation process covered all three streams. It was noted during the study that some requirements were only applicable to certain streams. This phenomenon of applicability was expected and discussed in the study. This section extracts the requirements that were exclusively applicable to the analysis of the completed investigations. The table shown in Table C1 assesses each of the 31 requirements for its applicability to analyse completed investigations.

All requirements which were not applicable to the analysis of completed investigations were removed and a cleaned-up table showing only the applicable 19 requirements is presented in Table C2.

Table C1 Requirements to analyse completed investigations

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
1	Near-misses should be investigated in detail as the root causes of a near-miss could produce serious and catastrophic accidents	Not Applicable	It is not possible to determine which near-misses were not reported or investigated by reviewing completed investigations. One near-miss investigation was analysed but its effectiveness will be determined via the other investigation process requirements.
2	Structured guidelines should outline what type of incidents require investigating	Not Applicable	The structured guideline is established in the investigation policy.
3	The incident investigation process should begin as soon as the incident becomes known	Yes	Incident date, 24 hour report dates and PIVOT investigation dates are available from the reports
4	Statements and other information from the scene should be collected promptly	Not Applicable	It is not possible to gauge when statements were collected from the written report. No statements were uploaded for any of the investigations.
5	Incidents which require investigation should be investigated	Not Applicable	No records of incidents which were not investigated was available at the case study plant
6	Independent Subject Matter Experts (technical and safety system related) should be included in the incident investigation group to prevent biased outcomes	Yes	This can only be gauged when the investigating team is listed and their plant is known

Table C1 Requirements to analyse completed investigations (Continued)

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
7	The incident investigation team should be represented by the correct mix of people to ensure that all important aspects will be covered during the investigation (e.g. Safety, Health, Environment, Risk and Quality (SHERQ) systems experts, technical Subject Matter Experts)	Yes	This can only be gauged when the investigating team is listed and their role is known
8	Investigators should have received formal training on incident investigation techniques used by the company (e.g. RCAT, CED, 5 WHYs, etc.)	Yes	The case study plant provided the investigating teams training reports for the purpose of this study.
9	Investigators should have received formal training on the company's incident investigation policy	Yes	The case study plant provided the investigating teams training reports for the purpose of this study.
10	The lead investigator should be experienced in the incident investigation process	Not Applicable	It was not possible to gauge experience from the written report.
11	Other investigators or supporting investigators should be well experienced on investigation techniques	Not Applicable	It was not possible to gauge experience from the written report
12	The incident investigation team should be provided with clear roles and responsibilities	Yes	Detailed investigations reports may indicate roles and responsibilities
13	Time frames should be specified for the completion of incident investigation reports	Not Applicable	The investigation policy requires a 24 hour report, safety investigations completed within 7 days and other investigations completed within 14 days

Table C1 Requirements to analyse completed investigations (Continued)

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
14	When time frames are specified, these times should be strictly adhered to	Yes	Incident date and investigation close-out dates are available from the reports
15	Investigators should be somewhat protected from operational responsibilities and allowed to focus on a thorough incident investigation	Not Applicable	It is not possible to gauge external influences from the written report; however, if investigators are continuously missing deadlines one reason could be operational influences. This aspect will be examined in the investigator survey results.
16	Investigators shall be offered adequate time to complete a thorough incident investigation	Yes	Incident date and investigation close-out dates are available from the reports. Deviations may highlight areas requiring further examination (e.g. operational influences)
17	Where human error is a factor, investigators should be provided with a sound guideline or matrix detailing the human error causal factors and working environment factors	Yes	Examine human factors analysis in the investigation
18	People should not be blamed for incidents caused by a failure in a management procedure (such as safe working or safe operating procedures)	Yes	Examine the reports to detect blaming

Table C1 Requirements to analyse completed investigations (Continued)

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
19	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, investigators should study the HIRA management systems for root causes instead of concluding that the root cause was a task initiator error (blaming people)	Not Applicable	This item is addressed in question 18. The reason for separation is to examine the investigators perception during the survey in this study. Hence it is marked as not applicable
20	Incident investigators should avoid blaming people for incidents (investigate beyond the blame culture)	Not Applicable	Same reasoning as stated in question 19
21	Incident investigators should probe human behavioural management systems (e.g. individual development plan, training matrices)	Yes	Through examination of the investigation report
22	Incident investigators should probe engineering management systems (e.g. change management)	Yes	Through examination of the investigation report
23	Incident investigators should probe maintenance management systems (e.g. maintenance strategies)	Yes	Through examination of the investigation report
24	Incident investigators should probe operational management systems (e.g. safe operating procedures)	Yes	Through examination of the investigation report
25	Incidents that occur at other operating units should be communicated across the company's global operations. (This does not refer to a 24-hour flash or 1-page report of the incident, but rather to the completed investigation report)	Yes	Since 12 arc flash incidents were evaluated, it is possible to observe historical data in the investigation report

Table C1 Requirements to analyse completed investigations (Continued)

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
26	A system should exist to enforce actions from other operating units' incident investigations across all departments or sections in a company	Yes	Since 12 arc flash incidents were evaluated, it is possible to observe historical action implementation or the effectiveness of such actions
27	The investigation should only be considered as completed when actions are verified for successful implementation. An investigation cannot be completed upon establishing root causes	Yes	Investigations are completed after actions are closed out. Examine whether risk assessed actions were proposed and subsequently closed out.
28	A system should exist to ensure that all actions are implemented and verified for effectiveness	Yes	Investigations are only completed after a three month audit to examine the effectiveness of the action. Are the actions verified after completion?
29	A system should exist to ensure that incidents are investigated thoroughly	Yes	Commentary on the effectiveness of the investigation will be provided
30	Completed incident investigations should be audited against the company policy	Not Applicable	It is not possible to gauge external audits from the written report. Such audits are filed elsewhere.
31	Completed incident investigations shall be reviewed by experts on the company's incident investigation policy	Not Applicable	It is not possible to gauge external audits from the written report. Such audits are filed elsewhere and PIVOT does not provide functionality for the review of accidents.

The items marked “not applicable” in the previous table are removed and a “clean” table is presented in Table C2.

Table C2 Requirements applicable to the analysis of completed investigations

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
1	The incident investigation process should begin as soon as the incident becomes known	Yes	Incident date and 24-hour report dates are available from the reports
2	Independent Subject Matter Experts (technical and safety system related) should be included in the incident investigation group to prevent biased outcomes	Yes	This can only be gauged when the investigating team is listed and their role and plant is known
3	The incident investigation team should be represented by the correct mix of people to ensure that all important aspects will be covered during the investigation (e.g. Safety, Health, Environment, Risk and Quality (SHERQ) systems experts, technical Subject Matter Experts)	Yes	This can only be gauged when the investigating team is listed and their role and plant is known
4	Investigators should have received formal training on incident investigation techniques used by the company (e.g. RCAT, CED, 5 WHYs, etc.)	Yes	The case study plant provided the investigating teams training reports for the purpose of this study.
5	Investigators should have received formal training on incident investigation techniques used by the company (e.g. RCAT, CED, 5 WHYs, etc.)	Yes	The case study plant provided the investigating teams training reports for the purpose of this study.
6	The incident investigation team should be provided with clear roles and responsibilities	Yes	Detailed investigation reports may indicate roles and responsibilities

Table C2 Requirements applicable to the analysis of completed investigations (Continued)

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
7	When time frames are specified, these times should be strictly adhered to	Yes	Incident date and investigation close-out dates are available from the reports
8	Investigators shall be offered adequate time to complete a thorough incident investigation	Yes	Incident date and investigation close-out dates are available from the reports. Deviations may highlight areas requiring further examination
9	Where human error is a factor, investigators should be provided with a sound guideline or matrix detailing the human error causal factors and working environment factors	Yes	Examine human factors analysis in the investigation
10	Incident investigators should avoid blaming people for incidents (investigate beyond the blame culture)	Yes	Examine the reports to detect blaming
11	Incident investigators should probe human behavioural management systems (e.g. individual development plan, training matrices)	Yes	Through examination of the investigation report
12	Incident investigators should probe engineering management systems (e.g. change management)	Yes	Through examination of the investigation report
13	Incident investigators should probe maintenance management systems (e.g. maintenance strategies)	Yes	Through examination of the investigation report
14	Incident investigators should probe operational management systems (e.g. safe operating procedures)	Yes	Through examination of the investigation report

Table C2 Requirements applicable to the analysis of completed investigations (Continued)

No:	Investigation Process Requirements	Applicable to completed incidents	Comments
15	Did the investigator reference previous incident investigations?	Yes	Since 12 arc flash incidents were evaluated, it is possible to observe historical data in the investigation report
16	Did the investigator consider the effectiveness of historical actions?	Yes	Since 12 arc flash incidents were evaluated, it is possible to observe historical action implementation or the effectiveness of such actions
17	Are actions risk assessed and implemented?	Yes	Investigations are completed after actions are closed out. Examine whether risk assessed actions were proposed and subsequently closed out.
18	Are completed actions verified for effectiveness?	Yes	Investigations are only completed after a three-month audit to examine the effectiveness of the action. Are actions verified?
19	A system should exist to ensure that incidents are investigated thoroughly	Yes	Commentary on the effectiveness of the investigation will be provided

C.2 Summary of the analysis of the completed investigations

Although all 12 records of completed investigation were analysed, only one of each type (two for LTI) was presented in the body of this report. The remaining investigations are presented in Table C3 below.

Table C3 Completed investigation 2 – Inv 2:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 2	16 July 2014	19:00	The automation circuit failed to reset. The injured was forced to look for a fault with millwrights on shift. The injured walked into the control room to do fault finding and saw that the motor room vent fan panel was open. After looking inside the panel, it was noted that the 220V control breaker was not made. The injured then decided to switch on the breaker for this might have been the reason for the PLC not resetting. In the process a flash occurred on the 525V incomer end of the main breaker. The injured sustained burns to the right hand.	MI	Short	1	Switch on controls in order to start the motor room fan	Investigation to determine root cause	When doing switching always treat equipment as LIVE! Always do the continuous risk assessment

Table C3 Completed investigation 2 – Inv 2 (Continued)

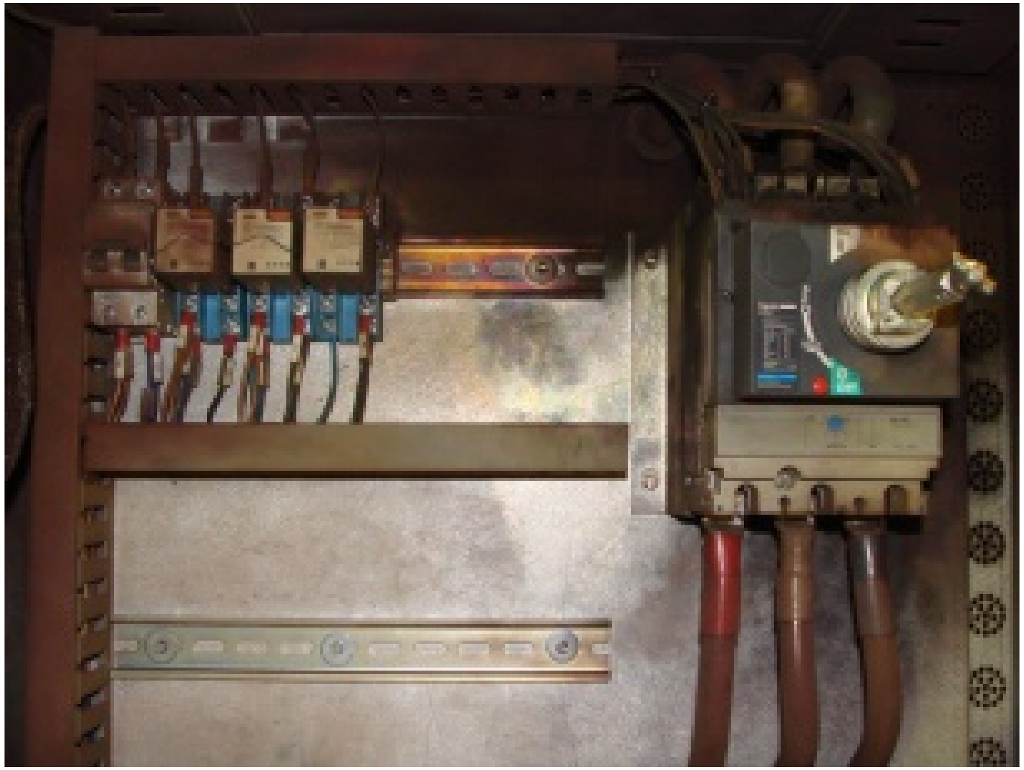


Table C4 Analysis of completed investigation 2 – Inv 2:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	No	Incident registration on PIVOT VBD110-201407 (>24 hours)
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Only plant personnel involved
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	SHERQ specialist; senior engineer
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Trained on investigation techniques on 01 November 2013
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate no training received on the investigation policy

Table C4 Analysis of completed investigation 2 – Inv 2 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
6	An incident investigation team is provided with clear roles and responsibilities	Yes	Roles and responsibilities assigned
7	If time frames are specified, these times are adhered to	No	Investigation completed after 8 days
8	Investigators are given adequate time to complete a thorough incident investigation	No	The investigator missed the investigation timeline
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator detected that the risk assessment required Personal Protective Equipment (PPE) when switching but failed to examine human factors when the injured did not use PPE.
10	Are investigators blaming people?	No	Employee was not blamed
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	The employees were re-trained on the task procedure
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	The plant revised the old type breakers with modern “intelligent” equipment

Table C4 Analysis of completed investigation 2 – Inv 2(Continued):

No:	**Investigation Process Requirements**	**Yes / No**	**Comments**
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	Yes	A maintenance plan for the testing of similar equipment was created
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	A new risk assessment was written and the safe operating procedure was revised
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “no” should count as compliance.

(f) Commentary on Inv 2:

(i) The investigation displayed 53% compliance and 47% non-compliance.

(ii) The investigation process was handled superficially as no investigation technique was used. The investigation consisted of a sequence of events only. This highlights the need to review the preliminary investigation. The reasons and root causes for the 525V breaker failing were not established. It was easy to overlook this aspect as the investigation provided 10 comprehensive actions. These actions were diverse and addressed aspects such as operations, engineering, maintenance and safety.

(iii) The policy required human performance analysis, which was not done in the investigation. What was the context within which the employee switched on a supply without the relevant PPE? In this case, the employee was not formally disciplined (compared to Inv 1). The absence of the human performance analysis does not establish further root causes and hence does not meet the requirements of the incident investigation policy.

(iv) The investigation was completed in 8 days instead of the required 7 days. Similar investigations were completed in the allotted timeframe. Three possible reasons for delays are external influences (operational responsibilities), lack of commitment to the investigation or awaiting forensic information. Since no forensic analysis was required in this case, external influence or a lack of commitment are possible.

(v) Lack of review of the completed investigation was again a finding.

(vi) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced. Also, no completed historical actions were discussed.

(vii) The opportunity to discover latent organisational gaps or unsafe behaviour was lost since the human factors analysis was omitted. In fact, not identifying human factors is a clear gap in this investigation, as the worker did operate without PPE. Why was such a decision made when PPE is required by the organisational electrical safety policy (as mentioned in the investigation)?

Table C3 Completed investigation 5 – Inv 5:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 5	25 September 2013	14:15	The injured was servicing (cleaning) electrical panels at the control room breaker. Although a plant shutdown was underway, certain services were still running, implying that the entire board could not be shut down. The injured was "hired" from central services to clean and tighten connections. After a detailed risk assessment, the injured was left alone to continue working. The injured touched a live 525V busbar with a screw driver, receiving superficial burns to the hand. The injured believed that a plant shutdown meant that all supplies are isolated.	FA	Full	1	The breaker was isolated and completely locked out, but its feeding busbars were still live at the stage that electrician touched them	General rule that electrician should test for zero potential before commencing work Warning signs on back of panel stating "LIVE BUSBARS"	The plant electrician stated that they did not realise that the busbars at the back of the breaker were still dangerous even though the breaker was locked out Unqualified persons working on electrical panels should not be allowed to contact live parts

Table C3 Completed investigation 5 – Inv 5 (Continued):

Table C4 Analysis of completed investigation 5 – Inv 5:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	Yes	Incident registration on PIVOT VDB096-201309 within 24 hours
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Plant personnel
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	SHERQ specialist and immediate supervisor
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Prior record of training was provided
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate no training received on the investigation policy
6	An incident investigation team is provided with clear roles and responsibilities	Yes	As described in investigation report

Table C4 Analysis of completed investigation 5 – Inv 5 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
7	If time frames are specified, these times are adhered to	No	Investigation completed after 1 day, using a full reporting format. This is not in line with expected time frames
8	Investigators are given adequate time to complete a thorough incident investigation	No	Unlikely that the investigator was given adequate time if the investigation was completed in one day
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator failed to examine why a person working exposed to electricity did not understand the electrical layout and energised electrical equipment
10	Are investigators blaming people?	No	Employees were not blamed
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	No	No human performance improvements were recommended
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Modified panels to facilitate locking out of LIVE sections

Table C4 Analysis of completed investigation 5 – Inv 5 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	No references to maintenance were made in the investigation records.
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	Changes to the lockout procedure were implemented
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(g) Commentary on the Inv 5:

(i) The investigation process displayed 47% compliance and 53% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. The opportunity to examine the skill level of persons exposed to electrical hazards was not pursued.

(iii) The investigation was completed in 1 day.

(iv) No investigation technique was used. The following opportunities were missed:

- The electrical worker was moving through the 525V busbar connection points sequentially cleaning and tightening. Why was every bolt being tightened? An infrared thermography report should identify exactly which bolts require tightening. This is once again pointing to the correct mix of maintenance and engineering skills involvement.
- It was claimed that the isolation procedure was lacking. The investigation failed to examine why the lockout procedure was lacking
- The equipment did not facilitate lockout, hence the worker was exposed to LIVE 525V busbars. Lockout in South Africa is governed by law as well as the organisational electrical policy. Why then was the non-compliant panel not identified previously?
- The electrical worker was brought in from a central maintenance department. Should the risk assessment not have covered the need for supervision? Why was an unqualified person allowed to work unsupervised? Surely this deviation should be investigated further for gaps in the organisation's safety management system.
- It was claimed that the hazards were communicated to the worker. The investigation failed to examine whether there was

a lack of understanding on the worker's part or poor communication from the plant side.

- In summary, the above findings are indicative of:
    a) not having the correct mix of expertise,
    b) not involving outside persons to benefit from a different perspective,
    c) not using an investigation technique and relying on a sequence of events,
    d) the absence of an investigation technique resulting in missed root cause identification,
    e) failure to undertake a preliminary investigation review,
    f) failure to probe engineering and maintenance aspects, and
    g) failure to reference historical events

(v) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

Table C3 Completed investigation 6 – Inv 6:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 6	11 June 2013	07:50	The injured was tasked to do fault finding on a 380V AC fan that did not switch off from the remote selector switch. The contactor was stuck due to some of the contactor tips that burnt together. The night before the operator had changed the plant configuration. The injured closed the knife switch (links) under load conditions. When an arc occurred the injured rapidly tried to open the link. This action resulted in an explosion and burns to the face and right hand.	LTI	Full	1	Operated a knife switch under load conditions	The task was stopped and the incident was communicated to all employees	Low risk routine task creates complacency and needs to be addressed with mini risk assessments

Table C3 Completed investigation 6 – Inv 6 (Continued):

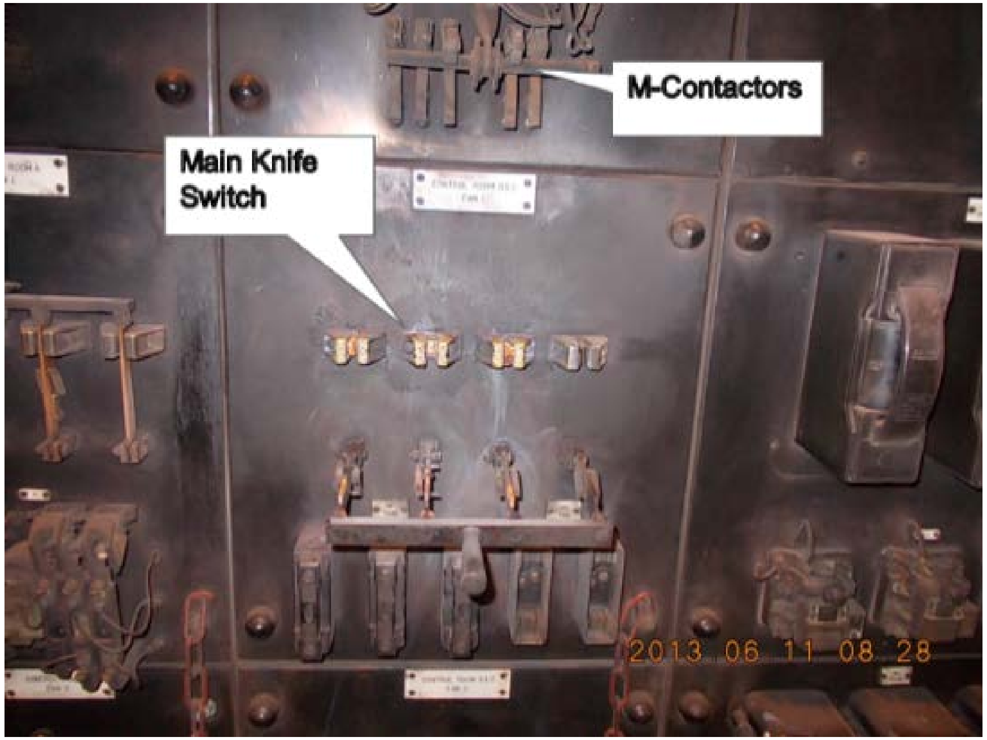


Table C4 Analysis of completed investigation 6 – Inv 6:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	Yes	Incident registration on PIVOT VBD132-201306 (<24 hours)
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	Yes	Independent SHERQ specialist involved
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	Yes	Plant SHERQ, senior engineer, maintenance specialist
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Trained on investigation techniques 10 October 2004 & 26 February 2003
5	Investigators are trained on the investigation policy	Yes	Lead investigator's training record available
6	An incident investigation team is provided with clear roles and responsibilities	Yes	As described in the investigation report

Table C4 Analysis of completed investigation 6 – Inv 6 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
7	If time frames are specified, these times are adhered to	No	Investigation completed after 8 days
8	Investigators are given adequate time to complete a thorough incident investigation	No	The investigator missed the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	Yes	Human factors analysed comprehensively and in accordance with the investigation policy
10	Are investigators blaming people?	No	Employee was not blamed
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	Yes	Action: review the electrician training program across the organisation
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Engineering intervention to review and address the problem Specification of PPE

Table C4 Analysis of completed investigation 6 – Inv 6 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	Yes	Action: re-evaluate maintenance program for these type of equipment
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	Action: review and implement an effective communication program Action: Emphasize task observations
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 "Are investigators blaming people?" is negatively phrased. A "yes" should count as a non-compliance.

(h) Commentary on the Inv 6:

(i) The investigation process was handled systematically and displayed 74% compliance and 26% non-compliance.

(ii) The human performance analysis was effectively completed. It was established that human error was inadvertent and the root cause was identified as a "lack of experience" and "lack of training". The investigation further identified gaps in the management system:

- Injured read and signed the safety policy which required PPE but failed to comply with the requirements
- Management allowed transgression of PPE for similar "low risk tasks"
- Management allowed transgressions in operating procedures (it was common practise to operate the knife switches locally instead of remotely)
- The status of the system had changed the night before (the main contactor refused to open so that knife switch or link switches were opened). When the electrician closed the links, the motor was started direct on-line through the links. Had the change in the plant status been communicated, the injured may not have attempted to operate the link switch.

(iii) The investigation took over a month to complete as specialised arc rated PPE, which had a long delivery time, was to be ordered.

(iv) The effects and causal factors charting, 5 Whys, and the human performance analysis techniques were used in this investigation.

(v) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

(vi) Special comments are required on the effectiveness of action implementation:

- The failed piece of equipment had demonstrated the same symptoms a week before. The investigation did not focus on (a) the technical reasons for such failure; (b) other areas (in the plant and in the organisation) where similar risks are prevalent; and (c) possible upgrade or replacement of this outdated technology

- The investigation on paper produced seven remedial actions. The PIVOT system responsible for the tracking of the implementation only contained four actions. The following three actions were not transferred from the paper to the PIVOT system:
    a) Review training of electricians and millwright's artisans across the organisation
    b) Further investigate the plant culture of (a) not wearing PPE; (b) switching locally instead of remotely; and (c) switching under load
    c) Review training intervals with regards to safe operating practises and safe working practises

Table C3 Completed investigation 7 – Inv 7:

No:	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 7	23 May 2013	17:20	The injured employees were busy changing a faulty magnet. While in the process of loosening the bolts on the magnet cover, the cover suddenly popped open due to the build-up of gasses that was the result of electrical cables that burnt. Debris and suspected electrical flash injured the two employees. The supplier of the magnet was unable to ascertain the cause of the explosion.	MI	Short	2	Build-up of gasses that was the result of electrical cables that burnt	To be determined after final investigation	Always expect the unexpected when working with faulty magnets

Table C3 Completed investigation 7 - Inv 7 (Continued):

Table C4 Analysis of completed investigation 7 – Inv 7:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	No	Incident registration on PIVOT VDB323-201307
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Plant personnel only
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	No	Plant supervisor investigated
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	Yes	Trained on investigation techniques 31 March 2009
5	Investigators are trained on the investigation policy	No	Training records provided for investigators indicate no training received on the investigation policy

Table C4 Analysis of completed investigation 7 – Inv 7 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
6	An incident investigation team is provided with clear roles and responsibilities	Yes	Only one investigator. An external was included for the forensic investigation
7	If time frames are specified, these times are adhered to	No	Investigation completed after two weeks, but registered on PIVOT after 5 weeks
8	Investigators are given adequate time to complete a thorough incident investigation	No	The investigator missed the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator identified embedded particles in one victim's eye and burns on the hand of the second victim. Standard PPE would require safety glasses and gloves. The opportunity to investigate human error or management gaps was missed.
10	Are investigators blaming people?	No	No employees were blamed
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	No	The opportunity to train workers on taking a safe position or emergency preparedness was missed

Table C4 Analysis of completed investigation 7 – Inv 7 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	The supplier of the magnet was contacted and undertook a forensic investigation
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	Maintenance was not examined
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	No	Operational procedures were not examined
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	No	No findings were established from the investigation
18	Are completed actions verified for effectiveness?	No	No findings were established from the investigation
19	A system exists to ensure that incidents are investigated thoroughly	No	Review takes place after all actions are completed. No findings were established from the investigation

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(i) Commentary on the Inv 7:

(i) The investigation process displayed 16% compliance and 84% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. The opportunity to examine the human performance in terms of using the minimum PPE and the management gap in the safe working procedure was not pursued.

(iii) The investigation was completed in just over two weeks.

(iv) No investigation technique was used. The following opportunities were missed:

- The development or revision of the safe working procedure. It is unclear whether the correct isolation procedures were followed.
- The investigator was completely dependent on the supplier of the equipment. The supplier failed to identify the reason for the failure. This led to the investigation being closed out on the basis of the evidence being "inconclusive."
- It is unknown whether maintenance was adequate on this piece of equipment since this avenue was not explored.
- The correct mix of investigators could have led to research on failure modes of such equipment. This was not done.
- In summary, the above findings are indicative of:
    a) not having the correct mix of expertise,
    b) not involving other plant personnel from different perspectives,
    c) not using an investigation technique and relying on a sequence of events,
    d) the absence of an investigation technique resulting in missed root cause identification,
    e) failure to undertake a preliminary investigation review,
    f) failure to probe engineering and maintenance aspects, and

g) failure to reference historical events

(v) Factors such as:

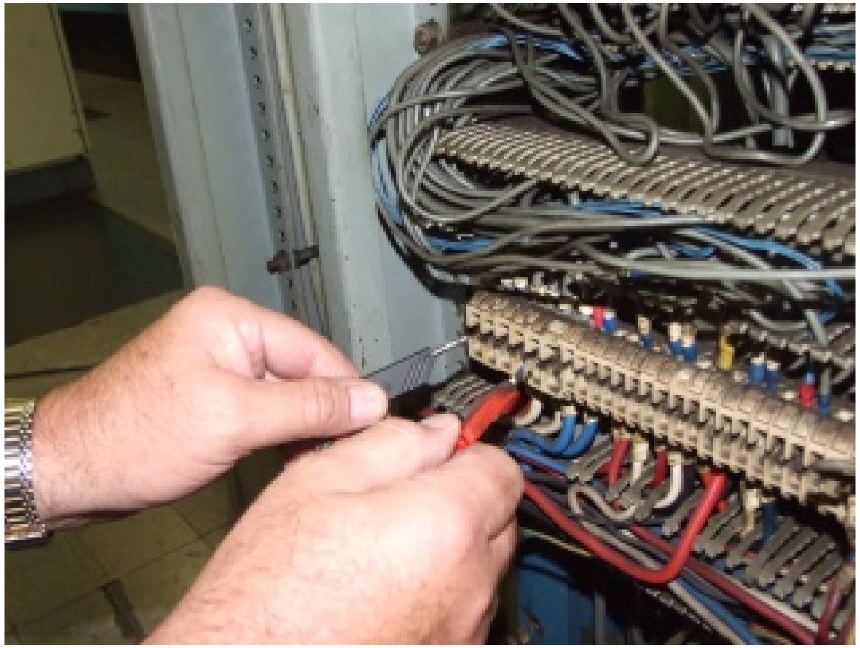
- Starting this investigation more than a week late,
- Stopping at the first failed attempt at solving the failure mechanism, and
- Taking two weeks to close the incident

Indicates that all avenues were not pursued persistently in establishing a thorough investigation. Several possible reasons could be explored to understand this end result.

Table C3 Completed investigation 8 – Inv 8:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 8	19 April 2013	14:05	Following a plant trip, the injured went to the control room and found that a 48V power supply was off. The injured proceeded to measure all supplies. While measuring on old terminals, two phases on a 380V supply were accidentally shorted. Gloves were not worn due to the difficulty in handling the measuring equipment. Correct measuring probes were not available. No risk assessment was done before fault finding commenced due to start-up pressure and fatigue. Terminals that were being measured did not have an insulating divider between phases. The employee is a qualified competent person.	MI	Short	1	Will be determined during the formal investigation	Millwrights and electricians to be issued with 8 cal and 40 cal gloves and safety probes to do fault finding on 110V and higher	Observe and be cautious of position and measuring points

Table C3 Completed investigation 8 – Inv 8 (Continued):



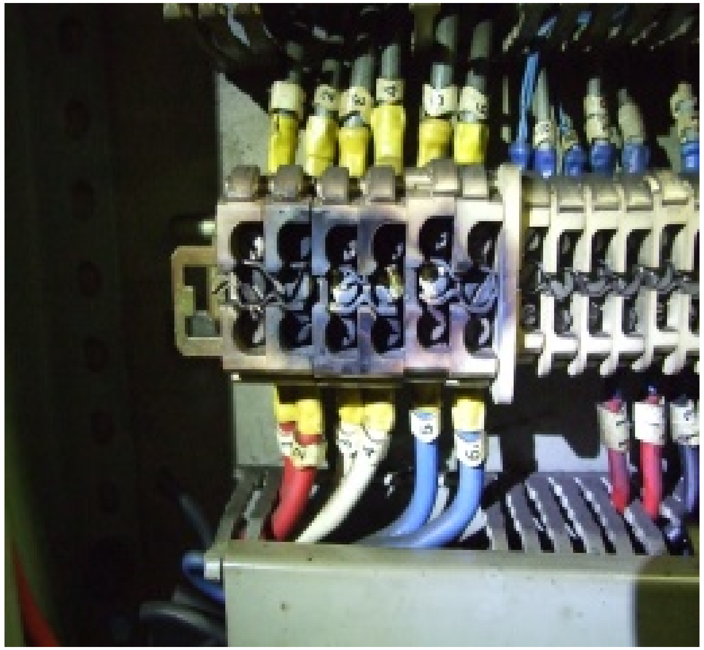


Table C4 Analysis of completed investigation 8 – Inv 8:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	No	Incident registration on PIVOT VDB308-201304
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Plant personnel investigated
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	No	Immediate manager investigated the incident
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	No	Training records provided for investigator indicate no training received on the investigation techniques
5	Investigators are trained on the investigation policy	No	Training records provided for investigator indicate no training received on the investigation policy
6	An incident investigation team is provided with clear roles and responsibilities	No	There was a single investigator with no defined roles

Table C4 Analysis of completed investigation 8 – Inv 8 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
7	If time frames are specified, these times are adhered to	Yes	Investigation completed after 5 days
8	Investigators are given adequate time to complete a thorough incident investigation	Yes	The investigator was within the allowed timeline
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator claimed "fatigue", "ergonomics" and "stress" but failed to provide any useful finding from these human factors influences.
10	Are investigators blaming people?	No	Employee was not blamed
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	No	Opportunity to assist the worker with human factors related development was missed
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Terminal blocks were replaced

Table C4 Analysis of completed investigation 8 – Inv 8 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	The electrician was investigating a loss of supply. The investigator failed to examine the reason for this situation and attempt to improve the maintenance philosophy.
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	No	The investigator failed to examine the effectiveness of the existing safe operating and safe working procedures
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(j) Commentary on the Inv 8:

(i) The investigation process displayed 32% compliance and 68% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. During the investigation the investigator claimed "stress", "ergonomics" and "fatigue". These are considered as important challenges to industry (Salehi, et al., 2014) (IRCA Global, 2010). The opportunity to examine these human performance factors was missed.

(iii) The investigation was completed in 5 days.

(iv) No investigation technique was used. The following opportunities were missed:

- It is unclear whether the short circuit was created by bridging different phases using a single probe or whether the meter was set incorrectly for the parameter being tested (e.g., testing voltage but meter is on current scale). Does the investigator have an electrical background to detect this? If not, why was an electrical specialist not in the investigation mix? If the investigator does have an electrical background why was this aspect not discussed?
- The investigator failed to examine the effectiveness of a safe working and safe operating procedure for this task.
- The investigator mentions "old" terminal blocks without spacers. If these presented additional risks, why was it not identified through engineering systems (such as plant based risk assessments)? Subsequent to this incident, it was identified as a risk; however, the corrective action was limited to this plant only. No controls were established to manage this risk across the organisation (direct contradiction of the investigation policy)
- The investigator claims that due to space constraints the electrician was unable to use gloves. An important corrective

action calls for the supply of arc rated gloves. There is a clear deficiency between the action and the findings.

- It is also unclear why the plant allowed the use of the non-compliant test probes. This was another missed opportunity to examine human factors influence on this incident.
- The investigator failed to discuss why the supply had fallen away in the first place. This avenue would have led to the exploration of engineering and maintenance routines as improvement actions.
- In summary, the above findings are indicative of:
    - i. not having the correct mix of expertise,
    - ii. not involving other plant personnel from different perspectives,
    - iii. not using an investigation technique and relying on a sequence of events,
    - iv. the absence of an investigation technique resulting in missed root cause identification,
    - v. failure to undertake a preliminary investigation review and failure to probe engineering and maintenance aspects.

Table C3 Completed investigation 9 – Inv 9:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 9	17 January 2013	11:55	The injured was working in a Motor Control Centre (MCC) where a Variable Speed Drive (VSD) had to be installed into one of the electrical panels. While drilling a hole into the back plate to fit the VSD the drill went through the plate and onto the busbar. A flash occurred resulting in both hands getting burnt.	MI	Short	1	Drill touched live bus bar.	No drilling or any construction work will be done on electrical panels. Back plate to be removed and work done outside the MCC.	Employees to be made aware of the dangers of working on panel in MCC. SWP to be in place and updated.

Table C3 Completed investigation 9 – Inv 9 (Continued):

Table C4 Analysis of completed investigation 9 – Inv 9:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	Yes	Incident registration on PIVOT VDB110-201301 within 24 hours
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Plant personnel only
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	No	SHERQ specialist and immediate manager
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	No	Training records provided for investigator indicate no training received on investigation techniques
5	Investigators are trained on the investigation policy	No	Training records provided for investigator indicate no training received on the investigation policy

Table C4 Analysis of completed investigation 9 – Inv 9 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
6	An incident investigation team is provided with clear roles and responsibilities	No	There was a single investigator with no defined roles
7	If time frames are specified, these times are adhered to	No	Investigation completed after three weeks
8	Investigators are given adequate time to complete a thorough incident investigation	No	The investigator missed the investigation timeline
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigator failed to examine why the injured was not using gloves during a drilling operation
10	Are investigators blaming people?	No	Employee was disciplined for not using PPE but not blamed for the incident
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	No	No human factors influences were investigated and hence no improvements were established
12	Incident investigators probe engineering management systems (e.g. change management)	No	No engineering interventions examined

Table C4 Analysis of completed investigation 9 – Inv 9 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	No maintenance interventions examined
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	Yes	A new operational procedure was registered to modify panels
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(k) Commentary on Inv 9:

(i) The investigation process displayed 26% compliance and 74% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. During the investigation it was found that the injured sustained minor (<5%) burns to both hands. Standard issue leather working gloves would have prevented such burns which raises the issue of why mechanical work was being conducted without any PPE. The opportunity to examine this human factor was missed.

(iii) The investigation was completed within 3 weeks.

(iv) No investigation technique was used. The following opportunities were missed:

- A proper engineering design should have been performed to modify the electrical panel. One aspect of an engineering modification is that drawings would have to be provided. The drawings should indicate tolerances. Failure of the inclusion of electrical persons in the investigation appears to be reason for this oversight.
- The investigator stated that the injured "*was in a hurry and didn't realise that the live busbars were 50mm from the back-plate*". Clearly the rushing aspect in this statement warrants further human factors analysis.

(v) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

Table C3 Completed investigation 10 – Inv 10:

No.	Date	Time	Description	Type	Report	No. of people	Immediate Causes	Counter-measures	Lessons learned
Inv 10	27 September 2012	15:50	The pump gave a false high level alarm. The injured discovered the alarm switch was faulty. The control circuit was switched off to replace the part but the 525V system was live. A tool fell over two phases of the 525V system resulting in a flash. The risk assessment was done and all PPE was used except for gloves which were determined as impractical to wear.	MI	Short	1	The reason for the short circuit will be determined during the investigation Panel and the wiring is of such a nature that gloves can't be used to execute the job	Job was stopped and injured taken to medical station. The situation and circumstances were re-evaluated before the job continued The incident and consequences were communicated and discussed with all relevant personnel	Be alert when doing fault finding on live equipment PPE is there for a reason. The safety glasses that were worn during the incident protected the eyes

Table C3 Completed investigation 10 – Inv 10 (Continued):

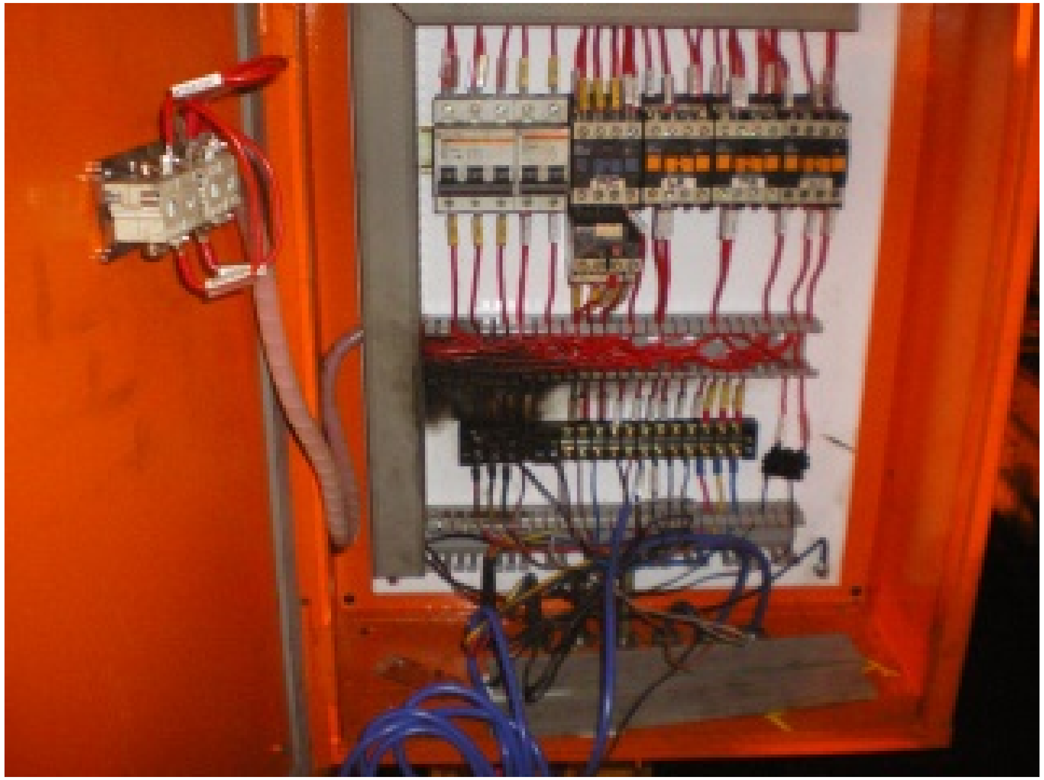


Table C4 Analysis of completed investigation 10 – Inv 10:

No:	Investigation Process Requirements	Yes / No	Comments
1	The incident investigation process begins as soon as the incident becomes known	Yes	Incident registration on PIVOT VDB324-201209 (< 24 hours)
2	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	No	Plant personnel only
3	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	No	Injured person and immediate manager undertook the investigation
4	Investigators are trained on investigation techniques (e.g. RCAT, CED, 5 WHYs etc.)	No	Training records provided for the investigator indicate that no training was received on investigation techniques
5	Investigators are trained on the investigation policy	No	Training records provided for the investigator indicate that no training was received on the investigation policy

Table C4 Analysis of completed investigation 10 – Inv 10 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
6	An incident investigation team is provided with clear roles and responsibilities	No	There was a single investigator with no defined roles
7	If time frames are specified, these times are adhered to	Yes	Investigation completed after 4 days
8	Investigators are given adequate time to complete a thorough incident investigation	Yes	The investigator adhered to the investigation timeline.
9	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	No	The investigation report stated that a tool fell by accident onto the live bus bars and also stated that gloves were not used due to space constraints. Human factors analysis could have provided improvements in the safety management system
10	Are investigators blaming people?	No	Employee was disciplined for not using PPE but not blamed for the incident
11	Incident investigators probe human behavioural management systems (e.g. individual development plan)	No	The employees were re-trained on the task

Table C4 Analysis of completed investigation 10 – Inv 10 (Continued):

No:	Investigation Process Requirements	Yes / No	Comments
12	Incident investigators probe engineering management systems (e.g. change management)	Yes	Stipulated changes to tools used around electricity
13	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	No	No maintenance interventions examined
14	Incident investigators probe operational management systems (e.g. safe operating procedures)	No	No changes to the safe working procedure were noted.
15	Did the investigator reference previous incident investigations?	No	No references to prior incidents were noted.
16	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.
17	Are actions risk assessed and implemented?	Yes	Actions were risk assessed
18	Are completed actions verified for effectiveness?	Yes	Actions were verified after implementation
19	A system exists to ensure that incidents are investigated thoroughly	Yes	Review takes place after all actions are completed

Note: Question 10 “Are investigators blaming people?” is negatively phrased. A “yes” should count as a non-compliance.

(l) Commentary on Inv 10:

(i) The investigation process displayed 37% compliance and 63% non-compliance.

(ii) The investigation policy required human performance analysis, which was not done in the investigation. During the investigation it was found that the injured sustained minor burns to both hands. The investigator accepts that space limitation prevented the use of safety gloves. The picture of the panel, however, indicates more than enough space to work. Why did the investigator fail to probe this point further? Can the stance to not use PPE reside in technical reasons or human factors?

(iii) The investigation was completed in four days.

(iv) No investigation technique was used. The following opportunities were missed:

- It was stated that the injured claimed that no gloves were used and the investigator accepted this point. The reason was a lack of finger dexterity. An external person or electrical safety specialist may have found otherwise.
- Why was the work done with the circuit live? This was either a transgression of the operation lockout procedure or a deficiency in the safe working procedure. Neither of these operational aspects was investigated.
- One of the findings calls for installing crimp sleeves around tools used around electricity. Firstly, such in-house modifications are not allowed and electrical insulating tools tested according to local statute are required. Secondly, this action (supposedly illegal) was verified and closed out. This single action casts questions on the level of control over actions, implementations and verifications of incident actions. Once again, the lack of engineering and maintenance expertise in the investigation is highlighted.

- In summary, the above findings are indicative of:
    a) not having the correct mix of expertise,
    b) not involving other plant personnel from different perspectives,
    c) not using an investigation technique and relying on a sequence of events,
    d) the absence of an investigation technique resulting in missed root cause identification,
    e) failure to undertake a preliminary investigation review,
    f) failure to probe engineering and maintenance aspects

(v) The investigation was handled in an isolated manner in the sense that no previous arc flash investigations were referenced.

C.3 Results of the survey issued to the investigators

The results of the survey are presented in Table C5. In certain cases, a respondent may have not answered a question; this is indicated as a "Missing". The descriptive statistics are then determined using the remaining number of valid responses. The standard error of means attempts to explain the sample mean approaching the population mean; the lower the value, the closer the population and sample means correlate.

Table C5 Survey Results

No.	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
1	Near-misses are investigated in detail	105	1	2.99	.107	3.00	4	1.096	1.202	10.5	25.7	21.0	40.0	2.9
2	A structured guideline exists, which outlines what type of incidents need investigating	104	2	3.61	.091	4.00	4	.929	.862	1.9	12.5	21.2	51.9	12.5
3	The incident investigation process begins as soon as the incident becomes known	106	0	3.80	.087	4.00	4	.899	.808	1.9	8.5	15.1	56.6	17.9

Table C5 Survey Results (Continued)

No.	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
4	Statements are collected as soon as the incident becomes known	106	0	3.92	.069	4.00	4	.713	.509	0.0	1.9	23.6	54.7	19.8
5	Incidents which require investigation are being investigated	106	0	3.73	.079	4.00	4	.811	.658	0.0	9.4	21.7	55.7	13.2
6	Independent persons are included in the incident investigation group to prevent biased outcomes (e.g. an engineer from another plant)	106	0	3.10	.105	3.00	3	1.086	1.180	5.7	26.4	30.2	27.4	10.4

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
7	The incident investigation team represents the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g. a SHERQ systems expert, mechanical engineer, electrical engineer etc.)	105	1	3.49	.095	4.00	4	.972	.945	1.9	17.1	22.9	46.7	11.4
8	At this company, I have received formal training on an incident investigation technique (eg RCAT, CED, 5 WHYs etc)	103	3	4.029	.1290	4.000	5.0	1.3095	1.715	9.7	7.8	1.9	31.1	49.5

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
9	I have received formal training on my company's incident investigation policy	104	2	3.54	.130	4.00	4	1.329	1.765	10.6	16.3	8.7	37.5	26.9
10	I am well experienced in incident investigation techniques	103	3	3.43	.116	4.00	4	1.177	1.384	9.7	12.6	17.5	45.6	14.6
11	Other investigators are well experienced in incident investigation techniques	103	3	3.51	.097	4.00	4	.989	.978	2.9	12.6	29.1	40.8	14.6
12	An incident investigation team is provided with clear roles and responsibilities	106	0	3.56	.081	4.00	4	.829	.687	0.0	12.3	29.2	49.1	9.4

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
13	Time frames are specified for the completion of incident investigation reports	105	1	3.79	.076	4.00	4	.781	.610	1.0	6.7	17.1	62.9	12.4
14	If time frames are specified, these times are adhered to	105	1	3.12	.076	3.00	3	.781	.610	1.0	20.0	46.7	30.5	1.9
15	Investigators are somewhat protected from operational responsibilities and are allowed to focus on a thorough incident investigation	106	0	2.80	.094	3.00	2	.970	.941	6.6	36.8	28.3	26.4	1.9
16	Investigators are given adequate time to complete a thorough incident investigation	106	0	3.69	.076	4.00	4	.785	.616	.9	6.6	25.5	56.6	10.4

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
17	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	105	1	3.30	.088	3.00	4	.900	.810	1.9	17.1	36.2	38.1	6.7
18	Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).	106	0	2.82	.094	3.00	3	.964	.929	7.5	32.1	33.0	25.5	1.9

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
19	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.	106	0	2.92	.087	3.00	2	.891	.794	1.9	34.9	34.9	25.5	2.8
20	Incident investigators blame people for incidents	106	0	2.62	.102	2.00	2	1.046	1.094	11.3	42.5	22.6	19.8	3.8
21	Incident investigators probe human behavioural management systems (e.g. individual development plan)	106	0	3.52	.078	4.00	4	.807	.652	.9	11.3	28.3	53.8	5.7
22	Incident investigators probe engineering management systems (e.g. change management)	105	1	3.52	.079	4.00	4	.810	.656	1.0	11.4	27.6	54.3	5.7

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
23	Incident investigators probe maintenance management systems (e.g. maintenance strategies)	106	0	3.57	.077	4.00	4	.793	.629	.9	9.4	28.3	54.7	6.6
24	Incident investigators probe operational management systems (e.g. safe operating procedures)	106	0	3.75	.071	4.00	4	.728	.530	.9	4.7	21.7	63.2	9.4

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
25	I am aware of the outcomes of incident investigations, which occur at other operating units. (Please note that this point does not refer to a 24 hour or 1-pager report of the incident, but rather to the detailed accident investigation)	106	0	2.56	.115	2.00	2	1.180	1.392	18.9	39.6	13.2	23.6	4.7
26	A system exists to enforce the actions from other operating unit's incident investigations in my department	104	2	3.490	.1085	4.000	4.0	1.1060	1.223	5.8	13.5	24.0	39.4	17.3
27	An incident investigation is considered to be completed once the root causes are established	106	0	3.24	.114	4.00	4	1.176	1.382	4.7	33.0	8.5	41.5	12.3

Table C5 Survey Results (Continued)

No.:	Question	N		Mean	Std. Error of Mean	Median	Mode	Std. Deviation	Variance	Frequency Percentage (%)				
		Valid	Missing							1	2	3	4	5
28	A system does exist to ensure that the implementation of all actions is effectively completed	102	4	3.79	.092	4.00	4	.926	.858	2.9	6.9	16.7	54.9	18.6
29	A system exists to ensure that incidents are investigated thoroughly	105	1	4.00	.074	4.00	4	.760	.577	1.0	4.8	8.6	64.8	21.0
30	Completed incident investigations are audited against the company policy	104	2	3.37	.090	3.00	4	.914	.836	2.9	13.5	35.6	40.4	7.7
31	Completed incident investigations are reviewed by experts on the company's incident investigation policy.	104	2	3.16	.088	3.00	3	.893	.798	3.8	15.4	47.1	27.9	5.8

D PAPERS PUBLISHED OR PRESENTED FROM THIS STUDY

Four papers originated from this study. Two papers were published in the Institute of Electrical and Electronics Engineers (IEEE) Transactions on Industry Applications Journal. One paper was approved and is pending publication, and the fourth paper is in the peer review process. All four papers were presented at various IEEE Industry Applications Society Conferences in the United States of America between 2015-2017.

The first paper was titled “The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents”. It is based on the literature survey and the development of the questions in the research instrument for this study.

The second paper was titled “The Analysis of an Incident Investigation System”. This paper focussed on applying the research instrument to the organisational policy and completed investigations.

The third paper was titled “Case History: Arc flash incident on a locked out (LO/TO) 3.3kV fused contactor”. This paper presented the engineering, maintenance and human factors considerations from one of the 12 completed investigations that were reviewed.

The fourth paper was titled “A method to measure the application of the incident investigation process for electrical incidents”. This paper presented the process to survey investigators to identify gaps in the investigation process. It discussed the quantitative methods used to analyse the survey data and presented the top findings from the survey and recommendations for improvements.

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The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents

Zarheer Jooma, Jessica Hutchings, and Hugh Hoagland, *Senior Member, IEEE*

***Abstract*—Electrical incidents occur globally, providing valuable opportunities for practical-knowledge-based learning and improvements. The underlying root causes of an incident are not always apparent, and an incident investigation method or a loss causation model is required to analyze the facts gathered from an incident. It is important that an incident investigation is effectively executed in order to add value. An ineffective investigation may lead to recurrent incidents and the wastage of resources. Investigators performing an incident investigation can be biased and subjective. Incident investigation methods can be also subjective. Adequately resolving root causes is another subjective area. In order to mitigate subjectivity and biases, various models such as the cause and effect diagram, the five whys method, the sequential cause analysis technique, the management oversight and risk tree, effects and causal factor charting, change analysis, barrier analysis, and casual factor analysis are examined. This aims to improve knowledge on the application of a technique and to establish a review method to determine the effectiveness of an incident investigation process. The review method consists of the development of survey-type questions that can be applied to industry, and this serves as the aim of this research paper.**

***Index Terms*—Accident investigation, cause and effect diagram (CED), five whys, incident investigation, loss causation, management and oversight risk tree (MORT), root cause analysis, systematic cause analysis technique (SCAT).**

I. Introduction

FOR the purposes of this paper, the term incident refers to an event in which an injury or a fatality occurred (sometimes referred to as an accident) or could have occurred (sometimes referred to as a "near miss," a "near hit," a "close call," or a "dangerous occurrence").

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Electrical incidents result in harm and equipment damage that various studies attempt to quantify. The reported data by the U.S. Mine Safety and Health Administration show 1926 electrical incidents, including 75 fatalities for the period of 1990–1999 [1]. The medical costs of such electrical injuries are estimated at $20 800 per incident, whereas the lifetime medical costs for severe cases could reach $12.8 million [2]. Electrical incidents are occurring globally, with incident details and statistics provided from Dhaka, Bangladesh [3]; Iran [4]; France [5]; and South Africa [6], [7], among others.

Understanding the events of the past provides valuable and, in certain cases, previously unknown information that can be used to prevent similar events in the future [8], [9]. These also provide a tool to determine whether systems are suitable for use by improving the way in which risk assessments are performed within a safety management system [10].

An effective mechanism is required to exactly determine what learning can be deduced from past events and then to incorporate such learning into future safety planning.

Chua *et al.* explained a loss causation model as a feedback mechanism to facilitate learning from past events and to implement improvements within a safety management system [11]. As shown in Fig. 1, a gap in a safety management system may result in an incident. An incident investigation provides for learning that is used to improve a safety management system. The removal of the incident investigation, or ineffective investigations, will then compromise improvements in a safety management system.

The importance of incident investigations is highlighted by the fact that a multinational motor vehicle manufacturer included it as a key element to achieve an effective safety culture. The company further required that the investigation tool be used to identify underlying causes to incidents and not as a tool to assign blame to people [12].

In order to improve a safety management system, an effective incident investigation is required. Biases and subjectivity have the ability to produce ineffective incident investigation outcomes [13]–[16]. This paper studies incident investigation models used in the industry as a guideline to identify requirements that mitigate biases and subjectivity. In the following sections, various incident investigation models will be discussed, and the key requirements are presented. These findings will lead to the development of questions that can be used in future work to determine the effectiveness of the incident investigation process.

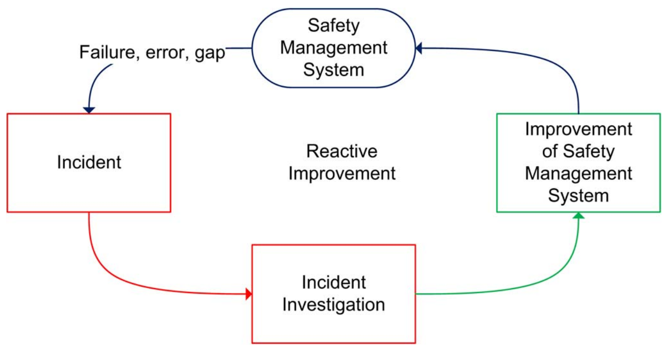

Fig. 1. Incident investigations as a feedback mechanism to improve safety management systems, as adopted from the work in [11].

II. Commentary on Incident Investigation Models Used in Industry

Investigator biases can influence the effectiveness of investigations. Mark Twain wrote that "the very ink with which all history is written is merely fluid prejudice" as a generalization that written history is inherently biased [17]. Incident investigations can be similarly subjective and biased.

- One such bias is blaming people. It was found while analyzing aerospace incidents that most reports stopped after assigning blame to a person and failed to identify the root causes [13]. When performing an incident investigation, it is easier to separate an individual's action from the organization. Such actions are biased toward the company's reputation and are likely to mitigate legal exposure and further claims [15]. In certain fields, human error as a result of following a self-established work practice rather than a specified work practice is reported to have caused 70%–80% of incidents [13]. These 70%–80% of incidents are not the root causes but are the symptoms of a failing management system. This claim is described by cases in which 87% of root causes were found in management system deficiencies [14]. Although it is known that there are more systematic management factors that can be identified as root causes, it is rarely practiced in actual incident investigations [18]. It is suggested that, in addition to the operator or the technician who is directly involved in the incident, engineers and managers should be also included [19] in the investigation. In fact, there is literature that proposes the need for engineers to receive incident investigation and safety systems courses for a semester [16].
- Another bias is presuming the outcome before investigating. Presuming an outcome sets precedence on the focus of an investigation. If an investigator assumes the root cause, he or she will work backward to try and match the presumed cause to the event [20]. A presumption can also influence the team; thus, it is important to remain neutral and explore all possible scenarios [19].
- Event-based loss causation models consider the transfer of energy, component failure, or human error in a chronological sequence. The events have a direct or linear link. This makes the implementation of nonlinear causes such as feedback or compounding states difficult to include into the model [10].
- Apart from physical events, the choice of contributory events and the conditions used to explain these are subjective [10] and are thus not repeatable. Since there is no clear definition of the initiating event that ultimately led to the incident, any remotely linked previous event could be added. Due to the sequential structure of the investigation, these could alter the root causes. [10].
- Rasmussen [21] stated that the continuous need to be more productive and less costly can result in a normal change in the behavior, which can lead to incidents. If such a root cause was addressed through a safety barrier, an incident would likely manifest itself in a different form at a different time in a different place. This implies that there are shortcomings by exclusively explaining an incident in terms of events, acts, and errors.

The shortcomings, biases, and subjectivity discussed in this section will be used as a resource to identify mitigating actions in the incident investigation process. The next section will present various incident investigation methods used in the industry, including nuclear and mining.

III. Incident Investigation Methods

Sklet provided an expanded list of incident investigation models consisting of events and causal factors, charting and analysis, barrier analysis, change analysis, root cause analysis, fault tree analysis, event tree analysis, the management and oversight risk tree (MORT), and the systematic cause analysis technique (SCAT), among others [22]. Lundberg categorized investigation methods into three major categories [23], i.e., a simple linear system [cause and effect diagrams (CEDs)], complex linear systems (epidemiological models such as SCAT), and complex interactions (such as the failure resonance accident model). Boraiko *et al.* presented a CED and an analytical tree [12], whereas Lehto and Salvendry discussed MORT, change analysis, analytical trees, and an updated domino theory [24].

Various other methods are discussed in the referenced literature. The investigation methods discussed in this paper are neither exhaustive nor representative of all method types. The methods selected for discussion in this section represent a variety of concepts, such as analytical trees, sequential models, and complex linear systems. Future research aims to expand on the number of methods examined. For introductory purposes, the CED, five whys, SCAT, MORT, effects and causal factor charting, change analysis, barrier analysis, and casual factor analysis are presented.

A. *CED*

The CED was developed by Dr. Kaoru Ishikawa, and it is also known as the fishbone diagram or the Ishikawa diagram [25]. The structure of the CED is similar to a fishbone, as shown in Fig. 2. The effect shown on the right-hand side can be an event or a goal.

The cause factors in Fig. 2 (on the branch tips) are factors such as man, machine, material, method, and measurement [26]. These cause factors can in turn be considered effects and then

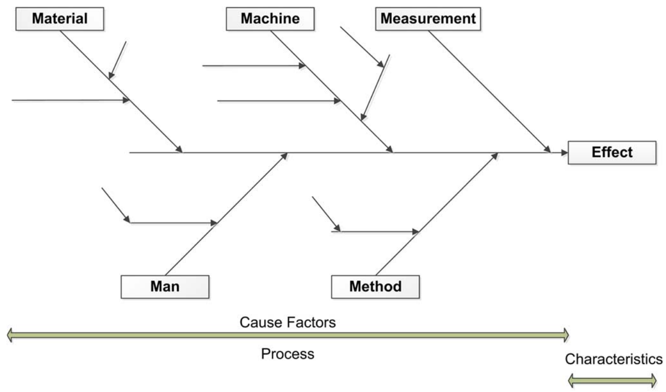

Fig. 2. CED [25].

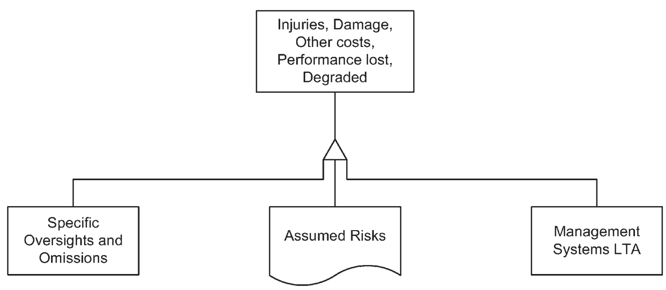

Fig. 3. Top portion of MORT [27].

have associated cause factors (as shown by the unmarked arrows in Fig. 2). Causal factors can be extensive as there is no formal limit set; however, Ishikawa and Lu recommended that a consensus be established by the investigating team using the Pareto principle that states that 80% of the effects come from 20% of the causes [25]. This implies that, by identifying and addressing 20% of the most significant causal factors, the investigating team will address 80% of the most significant effects [26].

B. MORT

MORT was proposed and largely finalized as an analytical tree diagram in its fourth revision by Johnson in a technical report presented to the U.S. Atomic Energy Commission in 1973 [27]. Although it was developed for investigation purposes, similar to many investigation systems, it can be also used to design or evaluate safety systems without an incident as a precursor [27].

In the technical report, Johnson refers to a flow of energy and the need to prevent it from causing harm to a target (someone or something). At the top of the analytical tree is either a past event that must be investigated or a future event that must be prevented. Three parallel paths consisting of specific oversights and omissions, assumed risks, and management systems feed into the event block, as shown in Fig. 3, i.e., they contribute to the incident.

At each branch of the risk tree, an investigator should ascertain the intermediate source of energy and branch off wider for the initial source of energy.

The term LTA in the chart refers to less than adequate. It is only used in a block that could be possibly deficient and that could fail in preventing the flow of unwanted energy. In the third revision, the unfilled triangle represented an OR gate, whereas a filled triangle represented an AND gate. An update of the third revision (the 1973 version) of the tree was presented, as shown in Fig. 4.

In the technical report, Johnston presented eight pages of MORT charts and discussed the requirements of each block, i.e., the various contributors in each block. The information is presented in the form of a checklist that allows an investigator to focus on aligning the facts to the method [28]. MORT is an extensive exercise that considers all factors in safety management systems, and due to this complexity, it is recommended for investigating major events [27].

C. Five Whys

The five whys technique was developed by Toyota as a root cause analysis tool [30]. The technique requires the iterative questioning of why an event was allowed to occur until the root causes are determined. At first glance, the literal inferences of the five whys may obscure the need to train investigators or to further understand this technique. It is for this reason that *The Toyota Way Fieldbook* [30] warns a user not to simply take five questions and provide five answers. If the questioning deviates from the contributory factors of an event, it can result in finding and addressing organizational issues not related to the root cause of an incident [14]. The five whys technique does not follow a predefined template or format and can branch at any level or provide unknown quantities (of answers) at each branch. If answering a question is nearly improbable, it is very likely that a step or an iteration was missed [30].

The Toyota Way Fieldbook discusses the five whys technique using an example shown in Fig. 5. In this example, the root cause as to the reason *why* production units are below target is determined. The answer to the why question could consist of the machines breaking down, operators not present, lack of parts, lack of operator training, or protracted setup times. These answers may be correct, but they are out of sequence, which could lead to a dead end or create a missed branching out opportunity.

In the Toyota context, the root cause analysis using the 5 whys technique is just one portion of the incident investigation. The data collection, the plan–do–check–act cycle, the reflecting, and the acting used with the root cause analysis form the complete Toyota incident investigation process [30].

D. SCAT

The concept of SCAT evolved from the domino model proposed by Heinrich [31] and was later refined by Bird and Germain [32]. It is a bidirectional model that sequentially examines an accident from a loss, an incident, immediate causes, basic causes, and a lack of control [33]. The bidirectional reference is made to the sequence progressing in an incident causation model and working backward in a problem solving model [34], as shown in Fig. 6.

A loss refers to any incident that results in harm to people, damage to equipment, or any negative effect to production, quality, the environment, or legal liability. Immediate causes

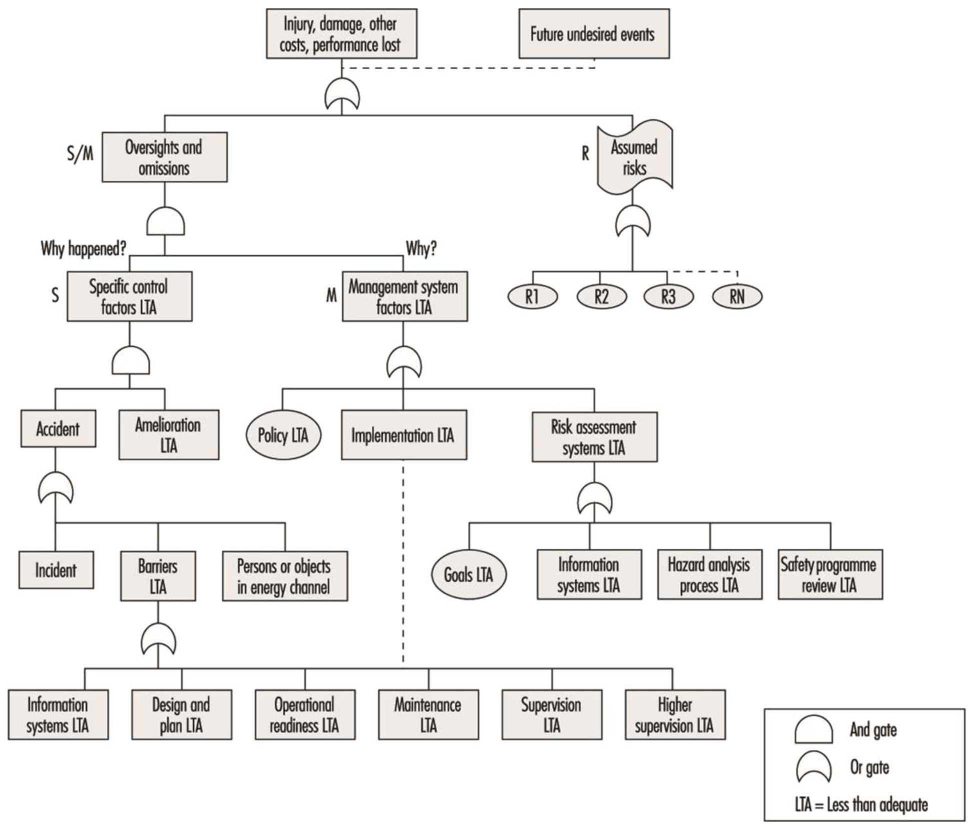

Fig. 4. Updated version of MORT from Kjellén [29].

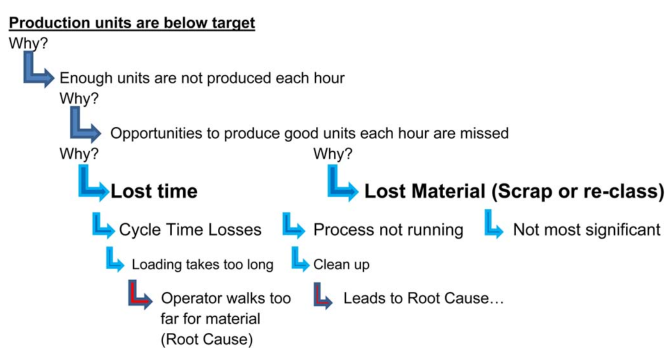

Fig. 5. Extended five whys analysis adapted from Liker and Meier [30].

precede an incident and consist of substandard acts or substandard conditions. Substandard acts or substandard conditions can been seen, heard, smelt, tasted, or touched [28], [34].

Examples of substandard acts are the removal of safety devices, operating equipment without authority, or a failure to secure. Examples of substandard conditions are inadequate guards or barriers; defective tools, equipment, or materials; and fire or explosion hazards.

Substandard acts or substandard conditions are allowed due to root causes consisting of either human factors or workplace factors. Examples of human factors include inadequate capability, lack of knowledge, lack of skill, stress, or improper motivation. Examples of job factors include inadequate leadership, inadequate engineering, inadequate maintenance, or inadequate work standards [28], [34].

Root causes exist due to inadequate management control systems. If management systems are not altered, root causes will manifest in other situations and lead to incidents or losses. There are three drivers to a lack of control [34], and these are inadequate systems, inadequate standards, and inadequate compliance to standards. Sklet provided examples of the elements that can address root causes and improve an organization safety program [28]. These include leadership, administration, personal protective equipment, management training, planned inspection, engineering controls, program evaluation systems, task analysis, and procedures or incident investigations [34].

Once improvements are recommended on a management system, a thorough risk assessment is required on each finding. The risk assessments are as follows [34].

- Baseline Risk Assessments: These are standing risk assessments that are reviewed at least annually.
- Issue-Based Risk Assessments: These are performed as required by the situation and usually linked to a change in the management system.
- Continuous Risk Assessments: These are considered the most important as they address the day-to-day operational risks. These are typically performed by line management.

E. ECFC

The effects and causal factors charting (ECFC) method is described in the U.S. Department of Energy (DoE) handbook *Accident and Operational Safety Analysis Vol. 1: Accident Analysis Techniques* [20]. The handbook states that a single

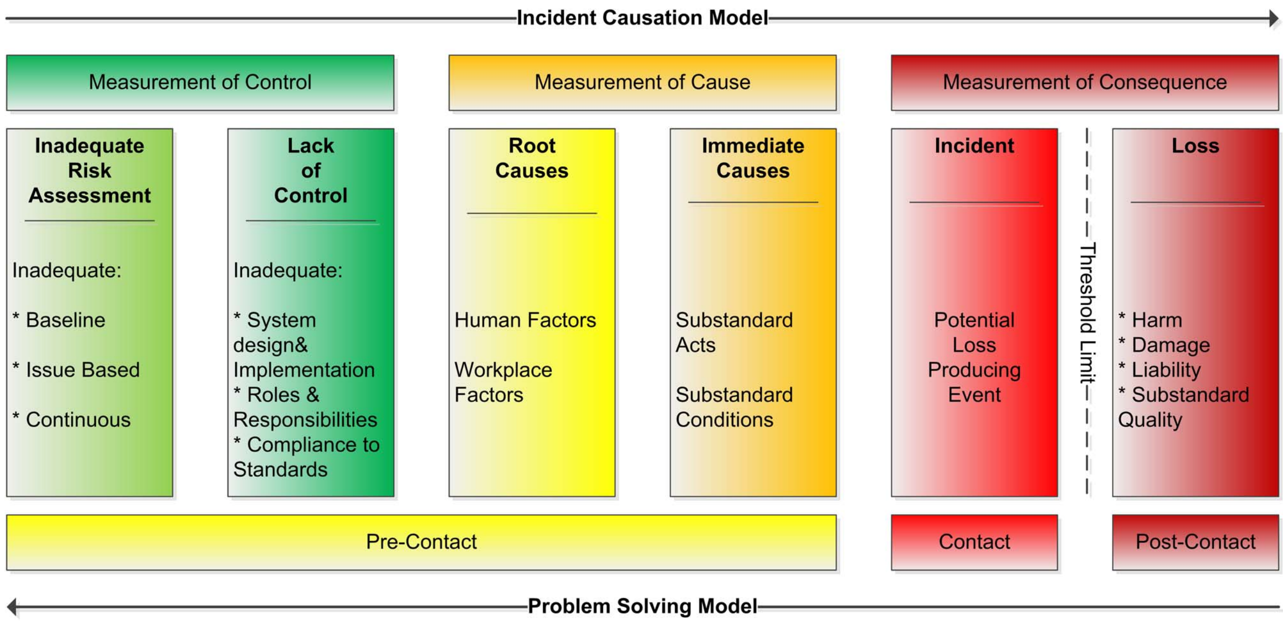

Fig. 6. SCAT [8], [32], [34].

method to evaluate complex incidents is ineffective and that multiple methods are preferred that can allow for ease of cross checking [20]. The handbook recommends the following five methods:

- ECFC and analysis;
- barrier analysis;
- change analysis;
- root cause analysis;
- verification analysis.

Understanding why a particular action made sense at the time is the cornerstone to ECFC. It is important to identify the action, the decision that led to the action, and the context of such decisions. The context of the situation is used to highlight human performance, missed opportunities, organizational cultural attributes, and latent weakness [20]. ECFC is an effective method to tackle incidents that resulted from a breakdown of multiple systems as each event is expanded into actions, decisions, contexts, and conditions. The chronological sequencing is shown in Fig. 7. Step 1 provides the chronological representation of the facts (actions and events) and the description of the incident, whereas step 2 investigates the decisions that led to such actions. Step 3 then examines the context of such actions in terms of human performance, safety management systems, culture analysis, the work environment, and the physical conditions that existed at the time.

Step 3 begins exploring deeper into the organizational culture and problems that may not be that apparent. The handbook provides the human error precursor matrix, the integrated safety management five core functions, and the seven guiding principles as tools that will guide the investigation team in identifying the causal factors [20]. By addressing the causal factors, possible recurrence can be prevented [20].

1) Barrier Analysis: Upon the development of the ECFC method, barrier analysis is used to further examine the influence of physical and administrative barriers in an incident. The barrier analysis studies hazards, targets (such as people or objects of such hazards), and the barriers that prevent a hazard from reaching a target [20].

Physical barriers may include guarding devices, personal protective equipment, drawings, and distance. Administrative barriers may include the clear definition of roles and responsibilities, hazard analysis, risk assessments, training, supervision, and safety programs. A worksheet is provided for the investigation team to implement the barrier analysis. An example of a barrier analysis worksheet is provided in Table I.

The worksheet shown in Table 1 requires the investigation team to identify the barriers and then determine the performance of the barrier. The investigation team then identifies why and how the barrier failed. This information is then used with the human error precursor matrix, the integrated safety management five core functions, and the seven guiding principles to develop the context of the condition of the event being examined.

2) Change Analysis: Following the barrier analysis, the effects of a change are considered. The context of a change is not only limited to a change in refurbishments or new projects but is also applicable to all facets of the organization, such as staff turnover or retirement.

A change can be also implemented by comparing an incident-free scenario and an incident scenario. The difference between the two scenarios is a form of change analysis [20]. The systematic implementation of this comparison is incorporated into the ECFC method, as in Fig. 8.

A challenge of the change analysis method is that of compounding changes. An example would be a change in the training policy from several years ago compounded by another change in the same system recently. It is suggested that multiple incident-free scenarios be utilized if such a situation is suspected [20].

When evaluating an incident, various subsets of a change is possible, e.g., a change in the physical location versus a change

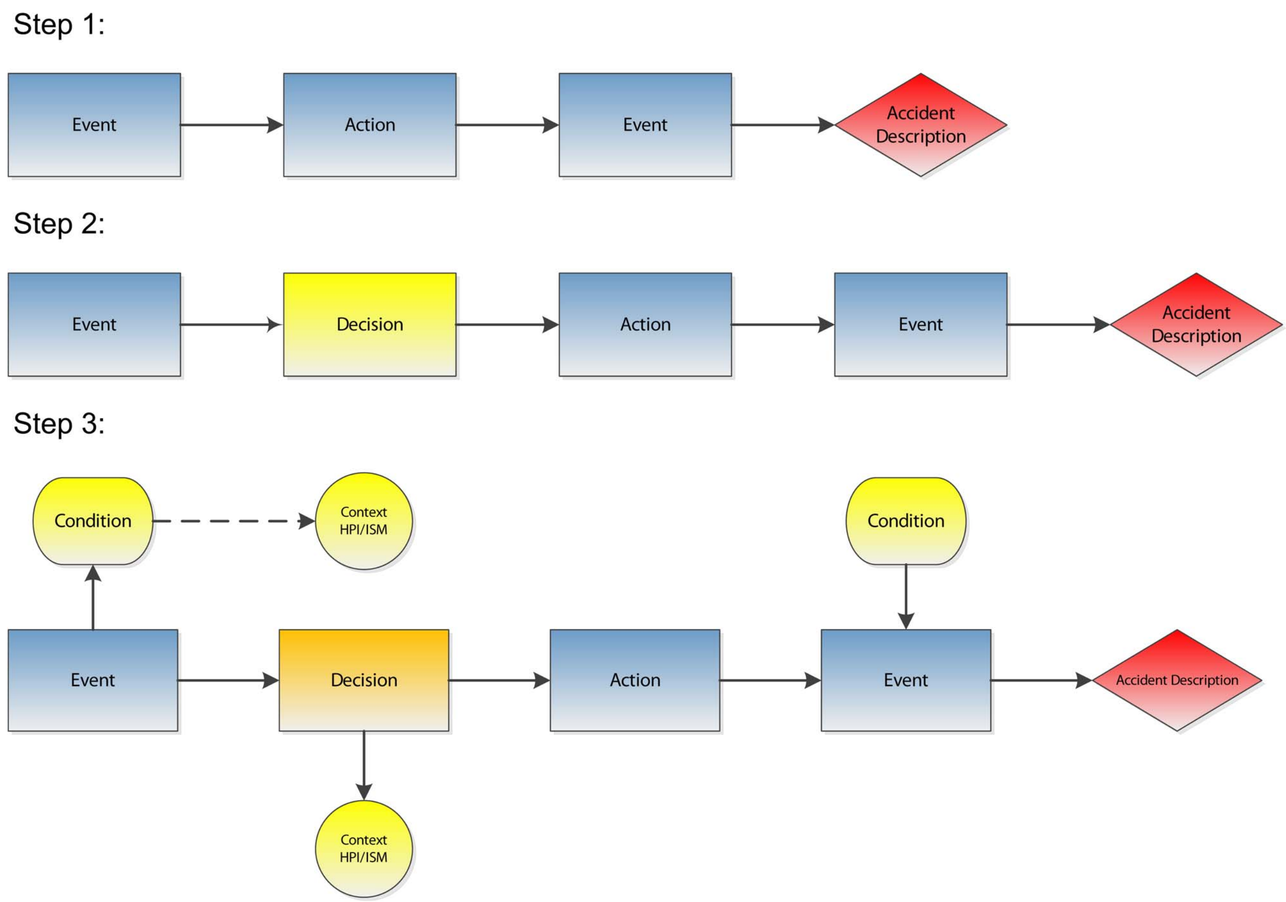

Fig. 7. ECFC adapted from the DoE accident investigation handbook [20].

TABLE I
SAMPLE BARRIER ANALYSIS WORKSHEET FROM THE DOE ACCIDENT INVESTIGATION HANDBOOK [20]

Hazard: Electrical Cable		**Target: Pipefitter**		
What were the barriers	**How did the barrier perform**	**Why did the barrier fail**	**How did the barrier effect the accident**	**Context** **Human Error Precursor Matrix** **Integrated Safety Management System**
Engineering Drawings	Failed to indicate cable	Final drawings not procured Preliminary design drawings used No as-built drawings	Failed to identify cable	Inaccurate mental picture (Human Nature) Inaccurate risk perception (Human Nature) Limited perspective (Individual Capabilities) Hazard Identification lacking (guiding Principles)

in the person performing the task. It is thus recommended that the six steps shown in Fig. 8 be evaluated in terms of the what, when, where, who, and how method. This leads to the tabular representation of the six steps using an example, as shown in Table II. The information from the change analysis worksheet is entered into the ECFC.

3) Causal Factor Analysis: Once the ECFC is constructed and analyzed using the barrier and change analyses, the causal factor analysis may be applied. The causal factor analysis entails the identification of causal factors and the classification of such into direct causes, contributing causes, and, most importantly, root causes.

Direct causes: These are the precedents to incidents and can be summarized by a single sentence, e.g., the direct cause of the incident was the contact between the tool and the energized conductor. Another example could be that the direct cause of the incident was the inadvertent energizing of the circuit that released CO_2 gas into an occupied area [20].

Contributing causes: These may not have directly led to the incident but had to be present to facilitate or increase the likelihood of the incident occurring. Contributing causes are also seen to favor the recurrence of incidents if left unaddressed, e.g., the failure to erect barricading or warning signs contributed to the incident. Another example of a contributing cause to the incident would be the failure to implement safety procedures for the project [20].

Root causes: Root cause analysis is not an exact science, and investigators are required to use the exhaustive list of facts

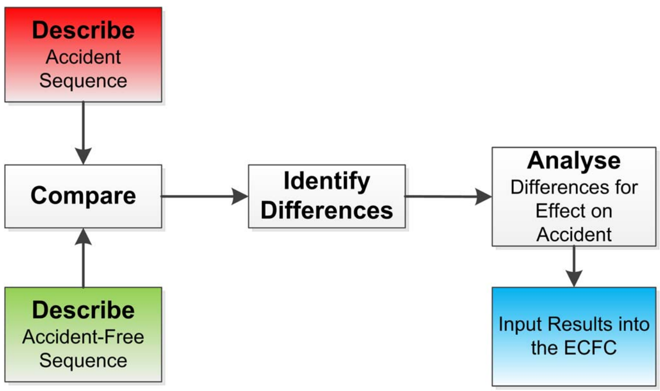

Fig. 8. Change analysis process from the DoE accident investigation handbook [20].

and results presented up to this stage of the investigation to select the higher organizational system failures that led to the incident [20].

Unlike direct causes that may be limited to certain operations, root causes are deficiencies in the higher management system that exposes all operations to the risk of incidents. As such, root causes are often broad statements. The handbook provides certain examples [20] that are presented with case studies as follows:

- failure to define roles and responsibilities, e.g., a contractor and the field office failed to understand the roles and responsibilities for safety procedure reviews that resulted in the absence of the safety procedure review;
- the system to ensure the competence by a task matrix or a proper review and the authorization of work is maintained, e.g., a field office oversight failed to review training and competence documentation;
- the provision to ensure that the resource distribution matches the critical safety work, e.g., a contractor and the field office failed to allocate safety officers to high-risk tasks;
- competence on safety standards is known and applied to work activities, or hazard identifications are thorough and complete for the task, e.g., a contractor used a routine safety policy for complex tasks involving nonroutine work.

Root causes aim not only to prevent the recurrence of the incident being investigated but also to address line management oversight and an organization's overarching integrated system management system deficiencies. Such deficiencies have the ability to cause or contribute to other incidents if not addressed [20].

IV. Question Development

The generalized shortcomings of incident investigation methods were discussed in Section II, and five incident investigation processes were presented in the previous section. This section analyzes the information presented with the aim to develop questions that can be used in future work to determine the effectiveness of the incident investigation process.

A. Incident Investigation Process: Summary

An incident investigation process should include the following common steps:

1) a statement of the loss that occurred in terms of people, property, or the environment [8], or a definition of the problem [35] and the organizational policy that defines what should be investigated;
2) the description of the incident; the collection of facts; the identification of the damage-causing substances, events, or energy; and the identification of substandard practices, substandard conditions [8], or other causal factors [35] that lack bias or influence;
3) the identification of root causes that lie in the lack of control within the workplace safety management systems [8];
4) the identification and evaluation of solutions to the root causes [35];
5) tracking the effectiveness of solutions [35] in certain cases even on a weekly basis [12];
6) program (incident investigation) audits [8].

B. Development of Questions

The following review method and survey questions have been developed to determine the effectiveness of the selected incident investigation method(s) and causation model(s).

1) For the purposes of this paper, the term incident refers to an event in which an injury or a fatality occurred (sometimes referred to as an accident) or could have occurred (sometimes referred to as a near miss, a near hit, a close call, or a dangerous occurrence [34], [39]. Near-miss events and accidents have similar root causes. Learning from external near-miss case histories is promoted as these provide invaluable opportunities to prevent future catastrophic incidents [20]. Cases such as the 1986 Space Shuttle Challenger, the 1997 Hindustan refinery explosion, the 1999 Paddington train collision, and the 1998 Morton explosion all displayed previous near-miss events that were not effectively resolved [36]. Taking these factors into consideration, the following questions may be posed.

   Are structured guidelines provided for the types of incidents that require investigation?

   Are near misses investigated?

   Are incidents with a high loss potential being investigated?
2) Incident investigations and problem solving are the cornerstones to safety in certain industry. The Toyota Way Fieldbook requires that all levels of organization understand this skill [30], including safety, operations, commercial, and financial [20]. Although one person may have the necessary skills, excellence is achieved by the collective knowledge of various subject-matter experts [27]. Another factor is the potential conflict of interest both professionally or financially. An example of this is a manager or an engineer who discusses the root causes with the investigation team before the investigation commences [19]. These factors lead to the following questions.

TABLE II
SAMPLE CHANGE ANALYSIS WORKSHEET AS ADAPTED FROM THE DoE ACCIDENT INVESTIGATION HANDBOOK [20]

Factors	Accident Situation	Accident-Free Situation	Difference	Evaluation of Effect
WHAT Conditions, occurrences, activities, equipment	1. Design and Safety reviews were not performed. 2. Established review process was bypassed. 3. Hazards associated with the work being performed were not identified. No review of as-built drawings. No excavation permits. No underground utility survey.	1. Project design and ES&H review are performed by appropriate groups to ensure adequate review and the safety and health of employees. 2. Construction packages are approved by facilities project delivery group. 3. A preliminary hazard analysis is performed on all work.	1 Environmental Group assumed design role and removed ES&H review from task. 2. Environmental Group approved work packages. 3. No preliminary hazard analysis was performed on construction task.	1. Design and ES&H reviews were not performed, contributing to the accident. 2. Construction packages were not approved by facilities group. 3. Hazards were not identified, contributing to the accident.
WHEN Occurred, identified, facility status, schedule				
WHERE Physical location, environmental conditions	Sump location was placed above a 13.2 kV electrical line.	Sump is placed in a non-hazardous location.	Inadequate design allowed sump to be located above a 13.2 kV line.	Sump location was placed above an electrical line, which was contacted by a worker jack- hammering in the area.
WHO Staff involved, training, qualification, supervision	Environmental Group assumed line responsibility for project.	Environmental Group serves as an oversight/support organization to assist line management in project.	Support organization took responsibility of line function for project management.	Lack of oversight on project.
HOW Control chain, hazard analysis	Management allowed Environmental Group to oversee construction tasks.	Management assures that work is performed by qualified groups.	Hazards analysis was not conducted.	Hazards were not identified, contributing to the accident.

Are label-independent subject-matter experts (technical and safety system related) included in the incident investigation group to prevent a biased outcome?

Is the incident investigation team represented by the correct mix of people to ensure that all important aspects are covered during an incident investigation (e.g., safety, health, environment, risk, and quality system experts and technical subject-matter experts)?

Is the investigation team provided with clear roles and responsibilities?

3) When an event occurs, an organization should be prepared to investigate. At that stage, it is too late to study the analytical tools and principles of incident investigations [27]. It is thus necessary for individuals to be trained and experienced on incident investigation policies and techniques [20]. The following questions arise from this information.

Are prospective incident investigators formally trained on an incident investigation method?

Are prospective incident investigators formally trained on the company's incident investigation policy?

Are prospective incident investigators experienced in incident investigation techniques?

4) Incident investigations require resources such as people, time, and, in certain cases, a budget [27]. Releasing a certain amount of competence that is required to solve the problem is a must for effective incident investigations [37]. Time frames should be clearly defined, and the investigation team should be available to meet this timeline [20]. These points lead up to the following questions.

Is the investigation team given adequate time to complete a thorough incident investigation?

Are time frames for the completion of the incident investigation report specified?

If time frames are specified, are these times adhered to?

Are investigators released from daily operational responsibilities and allowed to focus on a thorough incident investigation?

5) Reason states that human fallibility cannot be completely eliminated and can be useful in certain applications such as trial and error or knowledge-based learning [37]. In addition to investigating human factors, organizational circumstances or operational scenarios should be also considered in the context of the incident [20]. Literature shows that human error is not resolved by blaming people but by improving the safety management system or the

organizational culture [14], [15], [38]. Identifying the root causes of human error will lead to an improved safety management system. It is thus important that human error is considered a direct or contributory cause and never a root cause [20]. These important points lead to the following questions.

Do incident investigations culminate in personnel being disciplined?

Do investigators report human error as root causes?

Does the organization have a system to address human error?

Are investigators blaming people for incidents?

6) When investigating an incident, the number of causes leading up to an event can be infinite; as such, Ishikawa and Lu recommended the use of the Pareto principle that states that 80% of the effects come from 20% of the causes [25]. This implies that, by identifying and addressing 20% of the most significant causal factors, the investigating team will address 80% of the most significant effects [26]. A similar principle exists for the five whys method. It is important that the investigation team understand the key focus areas and should examine the causal factors that are within their control and within the context of the incident [30].

   More structured methods such as MORT, SCAT, and the ECFC method address multiple causal factors in order to improve the safety management system. These include human error management, maintenance, supervision, engineering, and safety systems [20], [27], [28].

   In order to focus on the critical components of the incident investigation, investigators should be asked the following questions.

   Are human behavioral management systems (e.g., individual development plans, job observations, and human factors) investigated?

   Are engineering management systems (e.g., change management, design approval, and drawings) investigated?

   Are maintenance management systems (e.g., maintenance strategies, maintenance plans, and quality control) investigated?

   Are operational management systems (e.g., safe operating procedures and operating instructions) investigated?

7) Root causes are higher organizational deficiencies that have a wide coverage [20]. Using an example cited previously, the root cause may be a failure to define roles and responsibilities, and the case may be that the contractor and the field office failed to understand the roles and responsibilities for safety procedure reviews that resulted in the absence of the safety procedure review. In this example, the root cause does not imply the end of the investigation. The investigator has to implement a global corrective action program (i.e., across all operating units) to assign roles and responsibilities between contractors and staff. Various alternative solutions should be analyzed before execution [30]. Following the execution, the effectiveness of the proposed solutions should be measured [30]. In order to ensure that the investigation is driven to completion, the following questions must be posed.

   Are incident investigations considered completed when the root causes are established?

   Are the actions and recommendations from the root causes of incidents communicated across all other operating units?

   Are the actions and recommendations from the root causes in one operating unit implemented across all operating units?

   Does a system exist to ensure that all actions (internal or external) are effectively completed?

8) Ishikawa and Lu discussed the need for the continuous improvement of systems and changes in the plan, do, check, and act cycle [25]. Not only should the investigation be examined for compliance to the incident investigation policy; the incident investigation policy itself should be periodically reviewed for effectiveness. This leads to the following questions.

   Are incident investigations reviewed by experts on the company's incident investigation policy?

   Is the incident investigation policy reviewed and improved periodically?

V. Conclusion

Electrical incidents can result in harm to people and the loss of equipment. The recurrence of events can be mitigated by investigating incidents that consists of both near misses and accidents. After gathering the facts and establishing an investigating team, an incident investigation method is used to analyze the facts and provide root causes. Upon the implementation of the actions required to address the root causes into safety management systems, recurrent events should be mitigated.

Such improvements or the prevention of repeat incidents are, however, only possible if the investigation process was effective. Merely generalizing that an investigation was ineffective does not allow for improvements since the specific weaknesses in the investigation process are not identified. This paper has studied the various incident investigation methods and determined the most common salient points.

The various steps of the investigation method were presented, and at each step, various questions were developed. Each group of questions is linked to a particular thread of the investigation. These questions may be used at any industry to determine the effectiveness of an incident investigation technique.

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The Analysis of an Incident Investigation System

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***Abstract*—Electrical incidents provide valuable learning opportunities if root causes are identified. Incident investigations which are unable to identify all root causes and address the shortcomings in the safety management system may result in recurring incidents. It is important that the entire incident investigation programme be guided by proven techniques and executed in a well-established manner. In a white paper titled "The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents," the authors analyzed commonly applied incident investigation techniques and suggested six salient incident investigation process requirements irrespective of the techniques used. This paper also suggested eight constructs, which could be used to determine the effectiveness of the incident investigation process. This paper utilizes the established learning and applies it to a large steel plant. A number of serious electrical incidents spanning many years at different operating units were analytically reviewed. A study of the organizational policy and one completed incident investigation report is analyzed to determine the effectiveness of the incident investigation process. Shortcomings in the process are discussed and possible salient practices that derogate from effective investigations are proposed. This paper forms part of a larger research project to determine the effectiveness of the application of the incident investigation process. The results and recommendations from the study aim to provide generic benchmarking of the incident investigation process, which could be used by organizations to improve its electrical safety performance.**

***Index Terms*—Accident investigation, human performance indicators, incident investigation, management oversight and risk tree (MORT), near hit, root cause analysis, sequential cause analysis technique (SCAT).**

I. INTRODUCTION

ELECTRICAL incidents can result in harm to persons and loss of equipment. Recurrent incidents can be prevented by investigating both near misses and accidents. Near misses or near hit are incidents which have a high potential to result in loss or harm. Accidents are incidents which resulted in loss or harm.

After establishing an investigating team and gathering the facts, an incident investigation method is used to analyze the facts and identify root causes. Actions which address the root causes should be implemented and the effectiveness of these should be verified. Such actions must lead to changes in the safety management system or related management system (e.g., operations, maintenance, human resources, engineering, procurement, etc.). This theoretical model has been discussed in the paper titled "*The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents*" [1]. An understanding of the concepts discussed in the previous paper is a prerequisite to this paper.

It is the aim of the authors to develop a system which could be used by industry to independently benchmark in-house incident investigation processes. The benchmark will entail evaluating three streams viz:

1) the organizational policy on incident investigations;
2) completed incident investigations;
3) the investigator or investigative team performing the incident investigations.

In order for this system to be established, it should be tested using a case study. The case study for testing the effectiveness of the incident investigation process was conducted at a large steel plant in South Africa. The case study plant has a large employee base (>1000 personnel); operates multifaceted systems (e.g., steam generation, power generation, power transmission, power distribution, air generation, water treatment, ac and dc machines, etc.) and consists of support services (e.g., human resources, procurement, marketing, etc.). To limit the scope of the larger research project, heavy industry such as aluminium, glass, paper, chemical, and nuclear plants amongst others across various countries and continents were not examined. The aim of this paper was to sample one heavy industry as a prototype. Future work may incorporate a larger case study base. It should, however, be noted that the literature is developed from references across several heavy industries across various countries and continents.

This paper consists of the following major sections.

1) *Establishing the test reference:* This section will build on the literature which was established in the previous paper.
2) *Study of the organizational policy:* This will take the form of a gap analysis.
3) *Study of a completed incident investigation:* The completed case study will be measured against both the literature and the company policy.
4) *Conclusion:* The findings and recommendations will be incorporated into this section.

The previous paper [1] explored human performance interface using referenced sources. It is expanded upon in this paper to further support the test reference.

II. HUMAN PERFORMANCE INDICATOR—RECAP

In the previous paper, the authors stated that "...while analyzing aerospace incidents most reports stopped after assigning blame to a person and failed to identify the root causes..." [2]. In a similar vein, more than 75% of maritime accidents had

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some form of human error component [3]. When performing an incident investigation, it is easier to separate an individual's actions from the organization. Such actions are biased toward the company's reputation and are likely to mitigate legal exposure and further claims [4].

These findings create a context to look beyond the blame and rather explore the various types of human error and methods to reduce such errors. A mindset change is required to understand that human error is not the end of the investigation but rather the beginning. It is the chance to explore exactly how the various systems (plants, procedure, variances, etc.) drove the choice to deviate [5]. The context within which a human error occurs is a human performance variance—otherwise there will always be compliance and all errors will be inherently system based. This understanding provides for an interesting yet unintended realization that such performance variation is also the result of many process improvements [5].

It is clear that most incident investigation techniques now require some form of human performance indicator [5], [6]. It should be extremely clear though that the human performance indicator requires further exploration of human error. It does not completely absolve the investigator from determining wilful dangerous behavior or the ability of the investigator to differentiate between culpable and nonculpable unsafe acts [5].

Human performance indicators are a vast topic and cannot be discussed in detail within the finite limitations of this paper.

The next section will begin examining the test reference.

III. Creating a Benchmark Test Reference

In the paper titled "*The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents*" [1], the authors presented eight requirements to achieve a comprehensive and effective incident investigation. In this paper, those eight requirements are further refined to produce ten constructs, which in turn produced 31 singular (i.e., yes/no type) questions. These are displayed in a tabular format which is inserted in Appendix. It is recommended that the reader peruse the table before proceeding.

IV. Gap Analysis on the Organizational Policy

The case study plant has a global organizational policy which is applicable to all operating units across the country. A gap analysis was performed between the organizational policy and the literature presented in Appendix.

A gap analysis is the distance (or gap) between the status quo and a benchmark [7], [8]. Gap analysis can be performed using a tabular method to compare the benchmark to the status quo and identify any shortcomings where applicable.

The questions developed in Appendix are based on the literature and serve as the benchmark. This literature studied various investigation techniques used in heavy industry and listed the minimum commonalties to effective incident investigations. As such, each question is considered important. An omission or ineffective application of the related constructs in Appendix could lead to recurrent incidents. It is for this reason that a simplistic comparative table was used to achieve the goals of a gap analysis.

TABLE I
Layout of the Gap Analysis

No.:	Appearance		
	Benchmark Question	Case Study Global Policy	Is the construct achieved (explain)
1[a]	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors	Section 6.4.3 states "*an investigation is needed into the why of the detected human factor so actions can be taken to avoid repetition*"	Yes —Section 6.4.3 points the investigator to an international policy, which is dedicated to human factors. The content of this procedure aligns with the literature.

[a]Table 1 is a portion of the actual gap analysis performed. The full-gap analysis is not includ.

It is further required that the gap analysis determines whether the organizational policy has adequately guided the investigating team to achieve the desired objective of the construct. An example to demonstrate this point could be the analysis of human blame. The organizational policy may state "avoid blaming persons" but fails to explain how this should be done. In order to test for such objectives, the comparison table was formulated as described in Table I.

Each of the 31 questions was applied to the case study organizational policy and assessed in detail. A summarized example is provided in Table I. The answers (i.e., yes / no) with the comments were used to determine if compliance to the construct was achieved. This compliance was determined using a binary type "AND" function. All questions had to be answered with a "yes" for the construct to be a yes. If a single "no" existed, then the construct was not fully met (e.g., see question 7 in Table II). A second tier of analysis was then performed using the construct as can be seen in Table II. In certain cases, although all questions were answered with a "yes," there was still a lack of preciseness in the policy (e.g., see question 3 in Table II). In this case, the outcome was marked as "uncertain." In such cases, minor findings were noted which required clarification from the case study plant, before being formally reported as a noncompliance. Table II provides a summary of the gap analysis with relevant comments.

An area of concern was the absence of a clause stipulating that subject matter experts from all management systems be included. The involvement of such persons is left to the discretion of the lead investigator which implies that the lead investigator needs to preempt causal factors. A saving grace in this regard was that the templates covered procedures, systems, management amongst others.

Based on the detailed gap analysis of the organizational policy, it is clear that there is alignment to the literature. It can be concluded that strict adherence to this policy will result in effective incident investigations. Ineffectiveness will invariable be covered by the auditing governance required in the policy.

V. Gap Analysis on Completed Incident Investigations

Arc flash incidents at the case study plant include fatalities all the way down to near hits if a 20-year window is reviewed. For the purposes of this paper, serious lost time injuries, which

TABLE II
SUMMARY OF THE GAP ANALYSIS [b]

No.	Requirement	Compliance and Comments
1	Is there a culture to investigate incidents (both near misses and accidents)?	Yes—Detailed descriptions of each type of incident which requires investigation is provided
2	Is the correct mix of investigators deployed with relevant subject matter experts?	Yes—The investigation team together with roles and responsibilities of each member are clearly defined
3	Are incident investigators expertly trained and knowledgeable?	Uncertain—Although training on the policy is discussed extensively, training on investigation techniques were not present
4	Are incident investigations structured?	Yes—Although each section provides templates for reporting, it is left to the investigator to bring it together in a report.
5	Are incident investigations supported by the organization?	Yes—Clear deadlines are set out for major incidents (7 or 14 days). Investigation teams should be freed up to focus on the investigation.
6	Are investigators avoiding assigning blame and identifying human error as a root cause?	Yes—The policy is very specific about the need to investigate human factors in detail and provides guidelines in this regard. The investigator is advised against blaming.
7	Are all management systems being investigated?	No—The policy requires that various subject matter experts be part of the investigation; however, the various subject matters are not specified.
8	Are finding from investigations implemented globally, i.e., across the entire organization?	Yes—However, this action is at the discretion of the investigating team and the departmental management.
9	Are completed actions vetted for effectiveness?	Yes—Multiple tiers must analyze the effectiveness. In addition, a three-month follow-up after action close out is stipulated.
10	Are investigations audited for compliance and correctness?	Yes—Detailed auditing is stipulated on the investigation. No auditing requirement for the policy was noted. The international policy was also past the review date.

[b]The case study policy is protected by a confidentiality agreement prevents divulging specific clauses.

were investigated within the past five years, were considered. One such investigation is presented in this paper.

Since it was proven that the organizational policy is effective, the completed incident investigations could be analyzed using either the constructs or the organizational policy. It is difficult to effectively analyze completed incident investigations against the 31 questions or constructs as these cover the entire investigation process and not a completed report only. As an example, questioning whether near misses are investigated cannot yield useful results when analyzing an investigation report completed five years ago. In order to address such shortcomings, both the incident investigation policy and the investigation policy will be used for the gap analysis. Due to confidentially of these records, the investigation report cannot be published. In the interest of providing concise information, only the major findings of the investigation are discussed. Table III presents an abbreviated example of the comparison table for the analyses of a completed incident investigations.

The next section does not aim to present a direct mapping to the audit questions in Appendix, but rather provides an example of further probing why noncompliances to the benchmark were identified based on the construct. It is not the aim of this paper to address noncompliances, but to present the first step in identifying the problem or gap.

TABLE III
GAP ANALYSIS OF A COMPLETED INVESTIGATION

	Appearance		
No.:	Audit Question	Yes/No	Is the construct achieved (explain)
1[a]	The incident investigation process begins as soon as the incident becomes known	Yes	The incident was registered within < 24 h
2[a]	Did the investigator consider the effectiveness of historical actions?	No	No references to prior actions were noted.

[a]Table III is a portion of the actual gap analysis performed. The full-gap analysis is not included in this paper due to space.

A. Accident Investigation 525-V Board

The incident investigation report was in the form of a slide presentation. The analysis could only be based on this information as supporting literature was not a part of the official documentation which was circulated. A template with the required information was forwarded to the lead investigator who aligned the investigation to this template. The accident occurred on 9 September 2010 and the presentation file was circulated on 23 September 2010. This was within the allowable time for this type of investigation.

Person A (PA) was required to service an 11-kV transformer feeder breaker and was accompanied by Person B (PB) who was supposed to redistribute the secondary low-voltage (LV) 525-V load. PB was unsuccessful in tripping the LV incoming breaker. PA came across from the 11-kV breaker room to assist. PA inserted the wooden handle of a duster into the 525-V breaker, while manipulating the trip switch to try and identify the problem. At that moment, an arc flash occurred. PA was not using arc rated personal protective equipment (PPE) at the time as he was not performing switching. PB used the required arc rated PPE as he was in the process of switching.

Although not indicated on the report, the lead investigator used Management Oversight and Risk Tree (MORT) analysis to determine the root causes. He then incorporated these findings into the report template. The final report which was circulated did not contain this MORT analysis, but a copy was provided to the authors. A sequential cause analysis technique (SCAT) analysis was also used to determine the root causes.

A summary of the analysis is as follows.

1) The 525-V breaker failed to trip on 8 September 2010 (the day before the accident). PB's superintendent told him that that he should not operate the breaker until further investigations were performed. The superintendent then approached a senior electrical technician the next day to investigate. In the interim, PB interpreted the discussion to mean that he (PB) had to investigate by himself.

   The incident investigators identified this as system deficiency and updated the switching authorization form. At this stage, the human performance indicators could have provided valuable information on a) how the superintendent communicated and b) why the communication was interpreted in the manner that it was. In order to support this argument, what prevents a similar instruction being misinterpreted by another employee on an unrelated task [i.e., ineffective communication]?

2) Another finding related to point 1 above is whether other switching authorization forms in other departments or other plants across the country could be affected. The action sheet did not request this finding to be investigated but rather marked it as complete since the specific switching authorization had been updated.
3) It is also unclear whether a hazardous and operability (HAZOP) study or some form of due diligence study was undertaken before implementing the change on the switching form.
4) A formal hazard identification and risk assessment (HIRA) which was duly supported by a switching authorization form was in place for this work. This risk assessment did not provide for faulty equipment. Once the breaker had failed to trip, a new HIRA was required but was not completed. Both PA and PB were instructed to undergo retraining on the HIRA process.
   This is another area where the reasons for the new HIRA not being performed was not investigated further. Why did employees not recognize a change in operating conditions *or* if such conditions are identified why was the required HIRA not performed?
5) PA did not use arc rated PPE. PB offered PA an arc rated face shield, which PA declined, as he believed that he was at a safe distance. Furthermore, PA used the wooden handle of a duster to manipulate the breaker.
   According to the electrical safety procedures, no "live" operation should be performed without arc rated PPE and the use of the applicable dielectric tool is mandatory. PB allowed PA to proceed working unsafely which was against company policy. It was claimed that due to multiple decades of experience between the two workers they should have applied their judgement better. Both PA and PB were disciplined and temporarily suspended without pay.
   a) Why did PA believe that he was at a safe distance? The investigators could have probed whether the level of the arc flash safety training was adequate. The investigators needed to explore the extent of the knowledge of personnel at other operating units with regard to safe working distances—Is working within the arc flash boundary a common phenomenon? Do they also engage in similar work practices?
   b) Why did PA use the handle of a duster instead of dielectric tools? The investigators failed to determine the reason for using non-compliant "tools." Did the section have dielectric tools and are these tools easily accessible at short notice?
   c) Why did PB allow PA to continue with this unsafe act? The investigators did not explore a possible deficiency in terms of communication and engagement between employees. Maybe this is not a problem and PB did not foresee the risk; however, if communication between workers was not investigated no claim can be made in either support or rejection of this fact.
   d) On the point of investigating all management systems, no mention was made of an arc flash engineering study or arc flash safety signs on the breaker. Was this an isolated incident if in fact it was the case? Could other operational units be exposed to the same risks?
   e) It was claimed that the LV breaker fed backup and nonessential loads. Why then did the workers decide to undertake this work "live" instead of isolating the entire system? What is the mindset of workers who place operations before safety? Is it a common occurrence as part of an operational culture or is it an isolated incident?
6) The 525-V breaker was being tripped locally at the breaker. A follow-up action was to implement remote switching on the remaining incomer breaker. This action was assigned for this board only.
   a) What was the status of other high risk boards across all operating units? Should a study not be undertaken across the organization to ensure that all high-risk incoming boards are operated remotely?
   b) Was this an isolated incident or is this a latent defect on similar year, model, type, or make of breakers?
7) The report did not indicate the composition of the investigating team. This would be important if further enquiries arise.

A second serious incident investigation report was also analyzed. Similar findings were noted.

VI. Conclusion

In a previous paper titled "*The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents*" [1], the authors aimed at providing a tool which could ultimately lead to the reduction of electrical arc flash incidents. In this paper, the questions were applied to a case study steel plant testing the plant's organizational policy and completed incident investigation reports.

The aim was to demonstrate, to a limited extent, the intended application of the tool. In analyzing the case study organizational policy and completed incident reports, the authors were able to identify three areas which should be reviewed (at the case study plant).

1) Incidents appeared to culminate in nonconformance to operating procedures. In these cases, the possibility to understand why such nonconformances occurred or understand the driving factors to such human errors was opportunities lost.
2) Investigations appear to focus at a local level. Actions tend to be directed to interdepartmental personnel. This deprives the organization of learning and improvement opportunities.

3) There appears to be gaps between the organizational policy and the execution of the investigation process. Since this paper forms part of a larger research study, it is recommended that incident investigators be interviewed to understand why such disparities exist.

The three areas identified as requiring review were based on a study of a limited pool of information; however, these findings are valid in the context of the case study over a limited period and against a single incident investigation policy. The authors have provided the tools to analyze the effectiveness of all incident investigation processes at heavy industries using, the literature references provided in this paper, the questions and constructs provided in the Appendix, and the method of application as discussed in this paper.

Although accidents and near hits are seen in a negative light, these can in fact be a learning tool. This paper is part of a series of steps in which the authors attempt to promote effective incident investigation processes. Effective investigations which produce effective actions executed in a sustainable manner will lead to the reduction of electrical incidents in the future. It is recommended that readers attempt to apply these analysis techniques at heavy industry.

APPENDIX[1]

No.:	Theory	Construct	Audit Questions
1	The term incident refers to an event in which an injury or a fatality occurred (sometimes referred to as an accident) or could have occurred (sometimes referred to as a near miss, a near hit, a close call, or a dangerous occurrence. Near-miss events and accidents have similar root causes. Learning from external near-miss case histories is promoted as these provide invaluable opportunities to prevent future catastrophic incidents. Cases such as the 1986 Space Shuttle Challenger, the 1997 Hindustan refinery explosion, the 1999 Paddington train collision, and the 1998 Morton explosion all displayed previous near-miss events that were not effectively resolved.	i. Is there a culture to investigate incidents (both near-misses and accidents)	Near misses are investigated in detail A structured guideline exists, which outlines what type of incidents need investigating The incident investigation process begins as soon as the incident becomes known Statements are collected as soon as the incident becomes known Incidents which require investigation are being investigated
2	Incident investigations and problem solving is the corner stone to safety in certain industry. The Toyota Way Fieldbook requires that all levels of organization understand this skill including safety, operations, commercial, and financial. Although one person may have the necessary skills, excellence is achieved by the collective knowledge of various subject matter experts. Another factor is the potential conflict of interest both professionally or financially. An example of this is a manager or engineer who discusses the root causes with the investigation team before the investigation commences.	ii. Are the correct mix of investigators deployed with relevant subject matter experts	Independent persons (e.g., an engineer from another plant) are included in the incident investigation group to prevent biased outcomes The incident investigation team represents the correct mix of people to ensure that all-important aspects are covered during an incident investigation (e.g., a SHERQ systems expert, mechanical engineer, electrical engineer, etc.)
3	When an event occurs, an organization should be prepared to investigate. At that stage, it is too late to study the analytical tools and principles of incident investigations. It is thus necessary for individuals to be trained and experienced on incident investigation policies and techniques.	iii. Are incident investigators expertly trained and knowledgeable	At this company, I have received formal training on an incident investigation technique (e.g., RCAT, CED, 5 Whys, etc.) I have received formal training on my company's incident investigation policy I am well experienced in incident investigation techniques Other investigators are well experienced in incident investigation techniques
4	Incident investigations require resources, such as people, time, and, in certain cases, a budget. Releasing a certain amount of competence that is required to solve the problem is must for effective incident investigations. Time frames should be clearly defined, and the investigation team should be available to meet this timeline.	iv. Are incident investigations structured v. Are incident investigations supported by the organization	An incident investigation team is provided with clear roles and responsibilities Time frames are specified for the completion of incident investigation reports If time frames are specified, these times are adhered to Investigators are somewhat protected from operational responsibilities and are allowed to focus on a thorough incident investigation Investigators are given adequate time to complete a thorough incident investigation
5	James Reason states that human fallibility cannot be completely eliminated and can be useful in certain applications such as trial and error or knowledge-based learning. In addition to investigate human factors, organizational circumstances or operational scenarios should also be considered in the context of the incident. Literature shows that human error is not resolved by blaming people but by improving the safety management system or the organizational culture. Identifying the root causes of human error will lead to an improved safety management system. It is thus important that human error is considered a direct or contributory cause and never a root cause.	vi. Are investigators avoiding assigning blame and identifying human error as a root cause	Where human error is a factor, investigators have a sound guideline or matrix pertaining to human error causal factors and working environment factors Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures) In cases where the HIRA was found to be deficient, it can be deduced that the task initiator had made an error Incident investigators blame people for incidents
6	When investigating an incident, the number of causes leading up to an event can be infinite; as such, the use of the Pareto principle which states that 80% of the effects come from 20% of the causes is recommended. This implies that by identifying and addressing 20% of the most significant causal factors, the investigating team will address 80% of the most significant effects. A similar principle exists for the five whys method. It is important that the investigation team understand the key focus areas and should examine the causal factors that are within their control and within the context of the incident. More structured methods such as MORT, SCAT, and the Events and Causal Factors Charting method address multiple causal factors in order to improve the safety management system. These include human error management, maintenance, supervision, engineering, and safety systems.	vii. Are all management systems being investigated (e.g., maintenance, engineering, operations, human resources, etc.)	Incident investigators probe human behavioral management systems (e.g., individual development plan) Incident investigators probe engineering management systems (e.g., change management) Incident investigators probe maintenance management systems (e.g., maintenance strategies) Incident investigators probe operational management systems (e.g., safe operating procedures)

APPENDIX
(CONTINUED)

No.:	Theory	Construct	Audit Questions
7	Root causes are higher organizational deficiencies that have a wide coverage. Using an example cited previously, the root cause may be a failure to define roles and responsibilities, and the case may be that the contractor and the field office failed to understand the roles and responsibilities for safety procedure reviews that resulted in the absence of the safety procedure review. In this example, the root cause does not imply the end of the investigation. The investigator has to implement a global corrective action program (i.e., across all operating units) to assign roles and responsibilities between contractors and staff. Various alternative solutions should be analyzed before execution. Following the execution, the effectiveness of the proposed solutions should be measured.	viii. Are finding from investigations implemented globally, i.e., across the entire organization?	I am aware of the outcomes of incident investigations, which occur at other operating units. (Please note that this point does not refer to a 24 h or one page report of the incident, but rather to the detailed accident investigation)
			A system exists to enforce the actions from other operating units' incident investigations in my department
		ix. Are completed actions vetted for effectiveness?	An incident investigation is considered to be completed once the root causes have been established
			A system exists to ensure that the implementation of all actions are effectively completed
8	There is a need for the continuous improvement of systems and changes in the plan, do, check, and act cycle. Not only should the investigation be examined for compliance to the incident investigation policy; the incident investigation policy itself should be periodically reviewed for effectiveness.	x. Are investigations audited for compliance and correctness	A system exists to ensure that incidents are investigated thoroughly
			Completed incident investigations are audited against the company policy
			Completed incident investigations are reviewed by experts on the company's incident investigation policy

[1]Further reading on the theory and referencing of this table can be found in the paper titled "*The Development of Questions to Determine the Effectiveness of the Incident Investigation Process for Electrical Incidents*" [1].

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Case History: Arc flash incident on a locked out (LO/TO) 3.3kV fused contactor

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Abstract – As part of a drive to improve electrical safety in heavy industry, this paper presents a case history on an electrical arc flash accident. The accident occurred on a 3.3kV fused contactor which was locked out and tagged out.

The paper describes the scenario leading up to the accident, the damage causing mechanisms and concludes with certain root causes. It is envisaged that this paper will provide awareness on the importance of adequate management systems and the need to improve safety through design.

Index terms — incident investigation, accident investigation, root cause analysis, human performance indicators, human factors

I. INTRODUCTION

On the 19th May 2014 at 10:38, three electrical workers were severely injured when a 3.3kV fused contactor, which was racked out and locked out, failed resulting in a massive electrical arc flash. The senior electrician, aged 31 at the time, sustained the most injuries and was only able to return to work 24 months later. He had suffered electrical shock and electrical arc flash related burn wounds to his face, neck and hands. The apprentice millwright, aged 22, received minor burn wounds to the right hand while the senior millwright, aged 55, received burn wounds to the face and neck. Both millwrights returned to work the next day.

This paper presents the case history of the accident. It concludes with the root causes which can be used in industry to help prevent recurrence of similar incidents.

II. BACKGROUND

The accident occurred at a steel mill, following a planned maintenance shutdown. The 3.3kV fused contactor fed a motor which supplied a water pump. Starting and stopping of the motor was achieved through a contactor. The contactor was operated via a Supervisory Control And Data Acquisition (SCADA) and Programmable Logic Controller (PLC). A planned maintenance event on the water pump required that the electrical system be placed in an electrically safe condition. Creating the electrically safe condition was governed by an isolation procedure. The isolation procedure stipulated that the 3.3kV incoming supply and the 3.3kV fused contactor be physically separated. This called for the racking-out, locking out and tagging of the fuse contactor.

Figure 1 provides a schematic representation of the electrical circuit. When the contactor is in the opened position, the fused contactor can be racked out by pulling on a handle. This action moves the fuse contactor from the 3.3kV incoming supply to an earth point. The handle is locked into this position using a padlock which ensures that the fused contactor is retained in the racked-out position. The load side is then tested for zero potential and tagged. The key for the padlock is controlled by the maintenance department which ensures that an electrically safe condition is maintained.

Once an electrically safe work condition is achieved, workers may interact with the equipment without the need for personal protective equipment against arc flash or shock. The sequence of events is presented in the next section.

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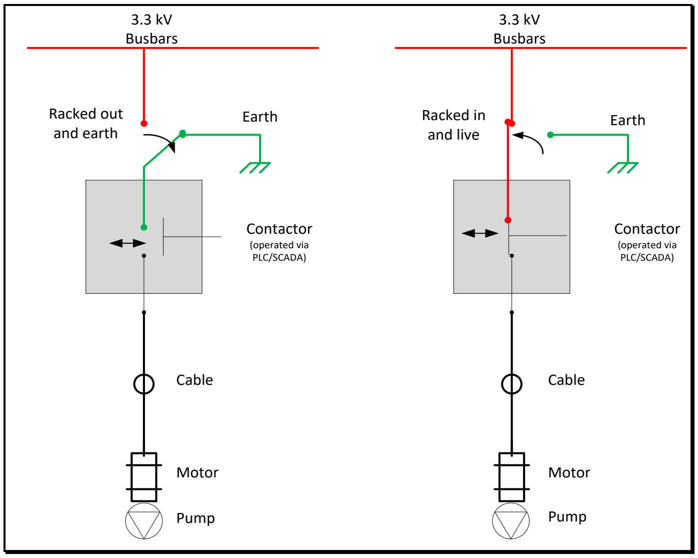


Figure 1: Schematic representation of the electrical circuit

III. SEQUENCE OF EVENTS

Dates and times of the events are as follows: The electrical equipment was placed in an electrically safe work condition on the 12th May 2014, the day of the planned maintenance shutdown. Following the completion of the maintenance activities, the process of returning the plant to service began on the 19th May 2014 at 06:30. The following sequence of events were recorded:

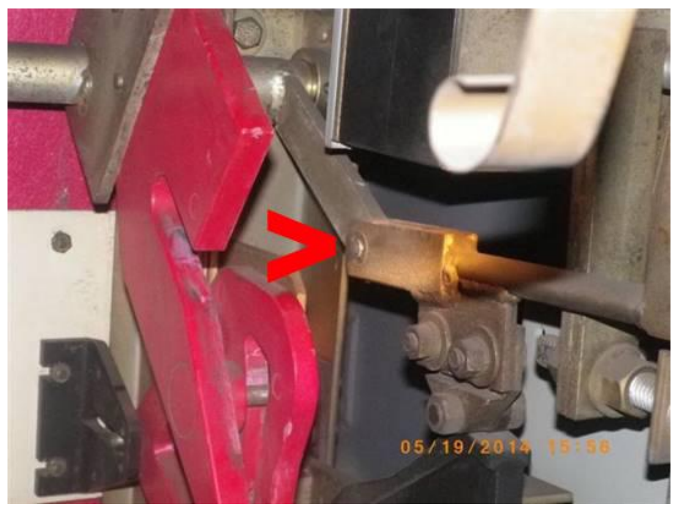
06:30-07:30:

- A request to reinstate power in order to start the water pump was issued by the plant
- The apprentice millwright, after following protocol, removed the padlock from the racking handle in an attempt to de-isolate the fused contactor
- The apprentice millwright attempted to rack-in the breaker using the racking handle. The racking handle moved but the fused contactor did not respond. It remained in the racked out position
- The apprentice millwright, then re-applied the padlock and left site to report the problem to the electrical supervisor

10:10-10:38

- The apprentice millwright, senior millwright and senior electrician go to the computer room to inspect the PLC and SCADA and confirm that no software or related interlocks was blocking the fuse contactor from being racked-in
- The workers leave the computer room and walk to the substation in order to inspect the fused contactor. At this stage all workers are using standard issue cotton jackets (unzipped), personal shirts and t-shits, standard issue cotton trousers, socks, leather safety shoes, safety glasses and hard hats
- The senior electrician, noticing the padlock was applied to the racking handle, assumes an electrically safe work condition on the fused contactor
- The senior electrician opens the fused contactor compartment door, kneels down (on one knee) in front of the fused contactor to begin troubleshooting
- The senior millwright and apprentice millwright stand on either side behind the senior electrician as shown in Picture 1
- The senior electrician observes that a pin which connects the racking handle to the chassis of the fused contactor had broken off. Picture 2, from a similar fused contactor, shows an example of the pin which had broken off
- The senior electrician, while still facing the fused contactor, starts discussing the possible repairs
- At that instant, an electrical arc flash occurs

Picture 1: Position of workers



Picture 2: Pin which had broken off

IV. FINDINGS

When the fused contactor is racked-out using the racking handle, the three phase conductors separate from the 3.3kV incoming supply and connect to the three corresponding earth straps as shown in Picture 3, Figure 2 and Figure 3.

Over the lifecycle of the fused contactor, maintenance workers found that the three earth straps did not make adequate contact with the three phase conductors in the racked-out position. In the absence of the original equipment manufacturer (OEM) or similar maintenance specifications, maintenance workers were not instructed on exactly how to maintain the earth straps. Consequently, the maintenance workers used brute force and manually coerced the earth straps in the direction of the phase conductors. This resulted in the earth straps being positioned in the travel path of the phase conductors when the fused contactor is racked-in or racked-out. This unsafe condition is shown in Picture 4. The original design had the earth straps positioned out of the travel path of the phase conductors as shown in Picture 3.

Picture 3 Fused contactor in a racked out and earth position

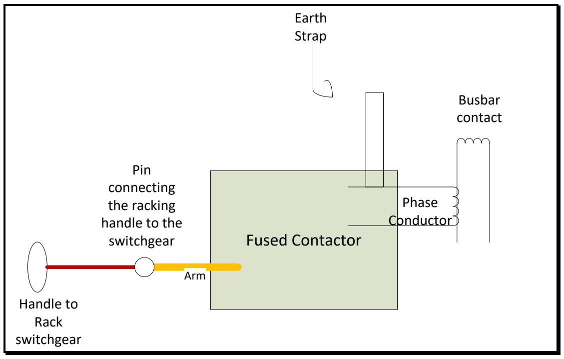


Figure 2: Diagrammatic representation of the fused contactor in a racked-in position

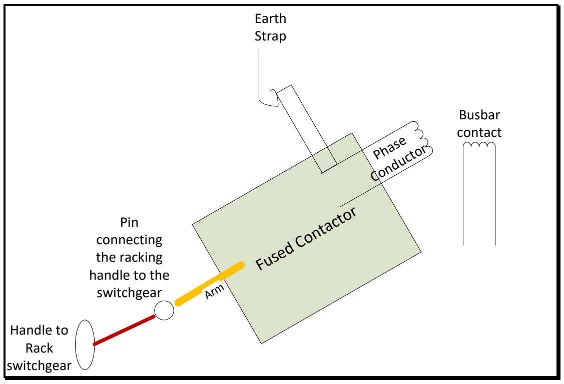


Figure 3: Diagrammatic representation of the fused contactor in a racked-out position

Picture 4 Incorrect maintenance led to the unsafe positioning of the earth strap

The incorrectly positioned coiled earth strap, shown in Picture 4, will minutely unravel after racking-out operations. Over time the clearance between earth and phase voltage will decrease as shown in Figure 4. The reduction of clearances is an important factor. Figure 3, showing the correct position of the earth straps, indicate that the phase conductors separate from the earth straps as soon as the racking action is initiated. Figure 4, showing the incorrect position of the earth straps, indicate that some travel distance is required before the phase conductors separate from the earth straps. During this (rack-in) travel the phase conductors are closer to the busbar on the one end whilst still connected to the earth strap on the other end thus reducing the effective distance and electrical clearances between earth and phase voltages.

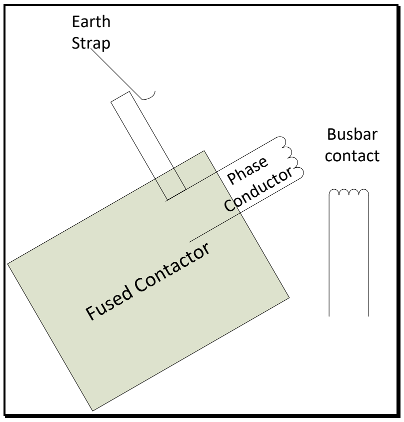


Figure 4: Diagrammatic representation of the incorrect positioning of the earth strap

The pin which had broken off connected the racking handle to the chassis of the fused contactor as shown in Figure 3. When the fused contactor was racked out, the chassis was held at a 45° angle to the floor. This position facilitated a safe electrical clearance between the phase conductors and the incoming 3.3kV supply. In the absence of the pin, the racking handle was no longer connected to the chassis. Since the padlock was applied to the handle, this implied that the fused contactor was not locked in the racked-out position. This rendered the isolation and the electrical safe condition both inadequate. During the troubleshooting process, the breaker fell into the racked-in position in an uncontrolled action. This uncontrolled movement of the breaker towards the incoming supply combined with the reduced electrical clearance between phase and earth resulted in an arc flash. The first arc initiated between the main 3.3kV incoming busbars and the earthed phased conductors.

The ungrounded wye 3.3kV system required a phase to phase fault (via the earth strap) to initiate the first arc. As shown in Picture 5, the arc initiated between the outer two phases as observed by the disintegration of the bottom guide plate. The loss of copper, on the outer two supply busbars, further supports this finding. The bottom plate on middle phase did not display any evidence of arcing during the first arc event. This suggests that the arc initiated around the 90° positive peak or 270° negative peak on one of the outer phases; a period which corresponds to a maximum electrical potential between the outer phases.

Picture 5: First arc initiation between the outer phases on the busbar side

As the phase conductors approached the 3.3kV busbars the arc impedance rapidly decreased resulting in the extinguishing of the first arc. This action was simultaneously accompanied by the initiation of a second arc between the earth strap and the phase conductors as seen in Picture 6. This picture clearly indicates a three phase arc. The fuses were subsequently tested and found to have not melted during the arc events. This evidence further supports a three phase fault between supply and earth.

In summary, the electrically safe condition observed by the padlock on the racking handle had failed due to a broken pin. The breaker which was not locked-out began free falling due to the absence of the pin. The incorrect positioning of the earth strap reduced the electrical clearance initiating the first phase to phase arc on the incoming 3.3kV busbar side. After falling into place, the extinguishing of the first arc was simultaneously followed by the initiation of a second three phase arc event on the earth side.

Picture 6: Initiation of the second arc on the earth side

V. THE INVESTIGATION

The investigation was undertaken by a multidisciplinary team using several investigation techniques including the events and causal factors charting, the cause and effect diagram and human performance indicators. Several immediate causes were discovered.

1) Failure to re-assess the change in scope

Human performance indicators were used to address the human factors aspect. The initial de-isolation by the apprentice millwright on the morning of 19th May 2014 was the first error. The original task was the maintenance shutdown for the water pump and did not include any electrical work. Once the shutdown was completed and the lock was removed, the padlock should not have been re-applied by the apprentice millwright. This was predominantly due to the fact that the task had changed from a *maintenance shutdown* to troubleshooting *a fused contactor which failed to rack-in*.

The initial work permit only covered mechanical work. When the fused contactor failed to rack-in, a new work permit was required. This new task required the

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identification of new hazards while working on the fused contactor. As an example, one hazard was the live 3.3kV incoming supply. Mitigating the risk of the hazard to cause harm may have required the isolation of the 3.3kV mains.

The apprentice millwright had been on the job for a month; however, the senior electrician had several years of experience. The senior electrician observed the padlock and assumed an electrically safe work condition. They began troubleshooting, thereby bypassing the isolation process and failing to identify the dangers of being exposed to a 3.3kV supply. This highlighted the organisational deficiency in the management system governing the identification of hazards and mitigating the associated risks. This oversight led to the senior millwright and apprentice millwright being unnecessarily present within the arc flash boundary and the absence of shock and arc rated PPE by all three workers.

The organization does warrant a new isolation process for a change in the scope of work. The isolation process also requires the establishment of shock and arc flash supplemented adequate PPE when working exposed to hazards. The first error was thus the apprentice millwright re-applying the padlock. The second error was the oversight of the workers to acknowledge the change of scope which was largely influence by the padlock being mentally equated to a lockout.

Following this finding, the organization attempted to address oversights due to scope changes by updating the isolation procedure, implemented roadshows with several examples and case studies and retrained employees in the organisation.

2) Failure in maintenance management systems compounded by knowledge errors

It was found that the manipulation of the earth straps was a common practice. This action was identified as *knowledge based errors*. A global training program discussing basic electrical principles was undertaken. More importantly, however, was the vague maintenance instructions (e.g. check, inspect, clean, adjust etc.) which indirectly condoned such errors. As a corrective action, engineers and technologists were made to register or review maintenance plans and where applicable seek guidance from original equipment manufacturers (OEMs) and subject matter experts.

3) Failure in hazard identification compounded by complacency

The dislodging of the pin had occurred previously but was replaced and not reported. The millwrights and electricians considered it a rudimentary corrective maintenance task, overlooking the hazard created by the pin in possibly violating a lockout condition.
By amending management procedures it was mandated that a failure of any part that could influence a lockout, no matter how trivial, be reported and formally investigated by a technical specialist. A separate investigation to study a possible latent defect on the pin was undertaken.

Other actions included the need for electrical safety training and the initiation of a program to replace obsolete equipment based on risk assessments. All actions originating from the investigation were risk assessed, assigned to specific individuals and the progress of each action was monitored until close out. A few months after the close out, the actions were audited to determine the effectiveness.

Finally, one outcome from this incident requires special discussion. The alteration of the earth strap combined with the dislodging of the pin led to a more important consideration which is the importance of safety through design. OEMs need to take note of failures and shortcomings as discussed in this paper. Such failures and shortcoming reside not only in electrical and mechanical design considerations, but also human factors which provide valuable information on how a worker could possibly think or behave. Safety through design is not limited to new equipment only. Synergy between OEMs and end users can provide safety solutions for existing and sometimes obsolete infrastructure. This statement goes against the very principles of what makes equipment obsolete, however, the reality is that many organizations have obsolete equipment and may not necessarily have the capital to replace. Ageing and obsolescence demand greater man machine interfaces which in turn increase the possibility of exposure to arc flash incidents.

VI. CONCLUSION

This paper described an electrical arc flash accident which occurred on a fused contactor that was racked-out, locked out and tagged. Originally, a shutdown was requested for mechanical work on a water pump requiring that the electrical equipment be placed in an electrically safe work condition; however, no work was performed on the electrical equipment. After the shutdown, an apprentice millwright removed the padlock and attempted to rack-in the fuse contactor. When the fuse contactor failed to rack-in, the apprentice millwright replaced the padlock. The mechanical failure which prevented the switchgear from being returned to service also rendered the lockout device, a padlock, ineffective. Three electrical workers, who subsequently attempted to troubleshoot the fuse contactor, failed to reassess all hazards and associated risks. This was predominantly due to the fact that the padlock was still applied to the switchgear; a scenario which is psychologically associated with an electrically safe working condition. Since the original task consisted of *mechanical maintenance on a water pump* now changed to a second task consisting of *troubleshooting electrical equipment*, a new isolation process should have been followed.

The combination of incorrect maintenance, equipment failure and inadequate risk assessments provided the ideal circumstances to create an electrical arc flash which in the absence of adequate PPE resulted in serious burns to three workers.

The immediate causes revolved around human factors and management systems which are: 1) failure to re-asses the change in the task; 2) substandard maintenance management systems compounded by knowledge errors; and 3) failure to identify high risk failures which were masked by simple corrective maintenance. Root causes resulting in these immediate causes were identified and corrective actions were implemented across the organization. All actions were risk assessed, assigned to a responsible person and tracked until close-out. Actions were also assessed for effectiveness post close-out.

The importance of safety through design was not specifically discussed in the investigation process, but served as an important learning from this accident. The recommendation to OEMs was to learn from both human factors which describe worker behavior as well as mechanical design considerations based on historic failures. Safety through design requires synergy between end users and OEMs

VII. ACKNOWLEDGEMENTS

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VIII. VITA

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A METHOD TO MEASURE THE APPLICATION OF THE INCIDENT INVESTIGATION PROCESS FOR ELECTRICAL INCIDENTS

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Abstract - Electrical incidents provide a good learning opportunity. If an organization fails to capitalize on this opportunity, the incident could recur. An abundance of literature is available on the investigation process and various investigation techniques. There appears to be limited guidance on determining the effectiveness of the *application* of the investigation process after the investigation is complete. As part of a larger research project, a comprehensive study was undertaken at a steel plant in South Africa to address this gap.

The study analysed the organizational policy, completed investigations and surveyed investigators all to a common set of requirements established from literature. This paper focuses exclusively on the investigator survey.

The primary goal is to share the top findings from the survey, in tandem with other insights and recommendations on possible solutions. A secondary aim is to discuss the process so that it can be repeated in any heavy industry. This will facilitate a discussion on whether the findings presented in this paper are localized to the case study plant or are global challenges to effective incident investigations.

Index Terms — incident investigation, accident investigation, investigation process, survey, human factors.

I. INTRODUCTION

The need to adapt investigation processes to ever-changing industrial developments has seen investigation techniques boom from a mere 30 in 1980 to over 100 by 2010 [1]. As investigation techniques become more complex, the overall investigation process follows suit. Several papers provide commentary on the investigation process [2] [3] [4] which assists industry in understanding and executing the investigation process. Once an investigation is completed, there is a need to determine the effectiveness of the application of the investigation process, since an ineffective investigation may result in root causes not being sufficiently addressed [5]. A study undertaken at a steel plant in South Africa examined the effectiveness of the application of the investigation process. One part of that study involved the survey of more than 100 investigators. This paper presents the findings from the survey followed by possible recommendations for improvements.

Two previously published papers on the study of incident investigations [6] [7] preceded this paper. Understanding that work may be beneficial, but is not a compulsory precursor.

The incident investigators were invited to complete an online survey. Statistical methods were used for the analysis of the data which was followed by a critical review process and commentary. The process to issue the survey and demonstrate the validity and reliability of the results is briefly discussed in the next section. The findings and recommendations are then presented.

II. THE SURVEY PROCESS

It is important to determine how well investigators understand the investigation process, as well as offer them a platform to communicate organizational challenges they may experience. Additionally, a survey of the investigator provides valuable information which may not be easily identifiable in the completed investigation or the organizational policy [8].

Before issuing the survey, all required ethical guidelines and formal applications were filed. The survey questions were based on 31 minimum requirements used to determine the effectiveness of the application of the investigation process [6] [7]. Appendix A contains the survey statements that relate to the five findings discussed in this paper.

For the case study, a large steel plant in South Africa with over 5,000 workers was used. Within the facility, 214 investigators and potential investigations were identified. For practical purposes an online survey was created. The survey was based on a 5-point Likert Scale [9] with “1” corresponding

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to a “strongly disagree” response whilst a “5” corresponded to a “strongly agree” response. A link to the survey was e-mailed to the 214 subjects and reminders to complete the survey were sent periodically.

106 of the 214 investigators surveyed responded – an approximate 50% response rate. The statistical data was analysed using a statistical software program. The first step required that the reliability and validity of the data be established.

To test whether each of the 31 questions was valid, a statistical method was used to facilitate the removal of superfluous data and reduce redundancy. Three questions that investigated different aspects of human blame and thus fell within a “human blame” construct were identified as redundant using this statistical method. These questions were as follows:

1) In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.
2) Incident investigators blame people for incidents.
3) Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).

Since the above three questions were focusing on specific aspects of the “human blame” construct, these were not removed from the survey. Further statistical methods demonstrated that the data was valid and reliable and are detailed in Appendix A.

III. LIMITATIONS OF THE SURVEY RESULTS

The following survey results do not represent the global deficiencies in the application of the investigation process. Rather, these demonstrate the findings from a single case study plant. The outcome of the survey must be analysed in the context of the organizational policy, completed investigations and the 31 minimum requirements for an effective investigation process.

The next section presents the top five findings from the survey. The antecedents and the remedial actions to address these findings follow.

IV. SURVEY RESULTS

This section provides the top five findings from the survey, based on the strength of the statistical analysis.

1) Completed investigation reports are not disseminated between operational departments and business units, or considered in the incident investigation process.

58% of respondents are unaware of completed investigations from other operating units or business units. It is important that the identification of root causes not be limited to a specific plant but result in changes to global management systems [5]. As such, the dissemination of investigations is a key requirement for effective investigations [10] [11] [12]. This question specifically targeted the dissemination of the completed investigation report and not the notification, awareness or “flash” report or correspondence.

2) Investigators avoid direct blame, but indirect blame is a factor that influences uncovering root causes.

Avoiding blame during the investigation is a pivotal requirement for effective investigations. Blaming can detract the investigator from determining why such actions were performed in the first place and should be avoided [13]. 54% of respondents indicated that investigators do not blame people, while 22% remained neutral and 24% indicated that investigators do blame people.

Apart from outright assigning of blame, it is possible to assign blame indirectly. Two questions examined blaming people indirectly in terms of non-conformance to operational procedures and ineffective hazard identification and risk assessments. It was found that a mere 37% of respondents did not blame people for non-compliance to the risk assessments, while 40% did not blame people for non-conformance to procedures.

This highlighted the fact that whilst blatant assigning of blame was very low (a positive finding), the indirect assignment of blame appeared prevalent.

3) Investigators often must maintain their operational responsibilities while conducting incident investigations.

There is generally a conflict between production responsibilities and safety [14]. Less than 30% agreed with the statement that investigators are somewhat protected from operational responsibilities, allowing them to focus on the incident investigation.

4) Some investigators demonstrate poor knowledge of the investigation process.

Investigators must be proficient in the investigation process before they are called on to investigate. This includes the knowledge of the entire investigation process and all deliverables. 53% of investigators considered an investigation complete when the root causes had been identified and another 9% indicated uncertainty regarding this. Investigations are not complete until corrective actions have been implemented and verified for effectiveness [11]. This mistaken belief on the part of a majority of respondents may demonstrate a need for additional training. It also highlights a lack of comprehension that has an impact on the effectiveness of the investigation.

5) Incidents are not being thoroughly investigated.

The most infamous accidents in recent history, such as the 1986 Chernobyl disaster and the Challenger space shuttle, the 1997 Hindustan refinery explosion and the 1999 Paddington train collision, all were found to have had previous near misses [15]. Near misses are great learning opportunities without having to suffer a loss or harm. More than half of respondents indicated that near misses are not being investigated or that near misses are only investigated some of the time.

V. RECOMMENDATIONS

Additional factors related to the issues identified in the survey results and recommendations to address the deficiencies are outlined below.

1) Completed investigation reports are not disseminated between operational departments and business units, or considered in the incident investigation process.

a) Firstly, the organizational policy did not require the review of prior incidents. So, investigators had no need to request investigation reports, as evidenced by the total absence of any references to historical case studies in completed investigations. Secondly, the organizational policy placed the onus of the dissemination of information on the safety department. The safety department placed completed investigation reports on the company intranet and considered that a form of dissemination. This situation was worsened by the fact that some junior managers and supervisors displayed limited computer proficiency apart from reading/responding to e-mails, using word processors and printing. Thirdly, investigation reports can be complex and lengthy. The organizational policy did not require a summary report. It is questionable whether the dissemination of the detailed report would add the desired value.

When examining completed investigations, it was discovered some accidents demonstrated similar failure and error modes, illustrating why communication of results is a critical aspect to the investigative process.

b) In order to address this gap, it is recommended that the safety department undertake roadshows to broadcast accessibility of the investigation reports. This may promote interdepartmental communication between the safety and operational departments. A representative at the safety department or a member of the investigation team could compile an investigation report summary. If implemented, such recommendations would need to be specified within the investigation policy.

2) Investigators avoid direct blame, but indirect blame is a factor that influences uncovering root causes.

a) The antecedents to assigning blame can be considered human nature due to traditional practices in both the work and domestic environments. It can be noted that earlier generation investigations promoted this behaviour, which is echoed in modern-day judiciary systems.

To explore this further, the organizational policy and completed investigations were studied. It was found that the policy requires the investigator to avoid blame and provide a detailed analysis of the human performance factors to ascertain why the hazard identification and risk assessments or operational procedures were not followed. Several completed investigations managed to pinpoint specific points of noncompliance but failed to further investigate the human performance factors as to why these errors were committed, which in turn may have identified further root causes.

b) Additional training to seek out root causes may diminish the indirect blaming. Additionally, investigators can be coached through theory and practice on how to overcome this deficient behaviour of blame.

3) Investigators often must maintain their operational responsibilities while conducting incident investigations.

a) Modern-day operational challenges are exacerbated by safety documentation and procedures. Operational processes, along with staffing and budgets, become lean, while safety systems are bulging at the seams. Time allocation is determined by the most pressing issue rather than a strategic decision. Although the organizational policy requires that investigators be free of operational responsibilities to focus on the investigation, both managers and investigators must focus on multiple commitments rather than the investigation alone. Consequently, an examination of completed investigations showed that nearly 60% of all cases were not completed on time by investigators.

b) An option to address this problem may be the creation of a centralized or core team to support investigators. This may not only lessen the burden on plant personnel but also create an ever-learning and improving core team of investigators. Another important recommendation is the need to quantify the cost of substandard investigations in companies.

4) Some investigators demonstrated poor knowledge of the investigation process.

a) The survey results showing that 62% of investigators do not have a good understanding of the entire investigative process is the leading identifier of this deficiency. Supporting this is a disparity between the organizational policy and the review of completed investigations. Organizational policy requires management to verify the effectiveness of actions three months after implementation. In contrast, the completed investigations reveal that actions were verified only a few days after implementation. It was further noted that the investigators did not provide guidelines on how to determine the effectiveness of an implemented action.

b) This deficiency ties in with the recommendations presented previously. A core investigative team may address part of the problem. In this context, however, it may be further required that compliance to the organization policy be audited. This may identify substandard training and understanding.

5) Near miss incidents are not being thoroughly investigated.

a) When examining 12 serious electrical accidents over a six-year period (ending in 2015), only one near miss was investigated. It is noted that many unsafe acts lead to reportable incidents which lead to injuries [19] [20]. It is thus unlikely that only one near miss incident transpired over the same six-year period which produced 12 serious accidents. Possible reasons for not investigating near misses could be a lack of reporting, fear of victimization, inadequate training and awareness, or a lack of appreciation of the impact of not investigating near misses. A common term heard in this case study plant was "no harm, no foul." A reluctance to report can be part of an organizational culture, compounded by work overload. Another reason which may influence the reporting of a near miss is the fear of blame.

b) To address this deficiency, organisations may benefit by learning from high-reliability organisations which have mastered the ability to promote a blame-free culture. Educating electricians, artisans, millwrights and operators on the benefits of reporting combined with educating managers on handling a verbal report is the basis to address this gap.

This section did not aim to be conclusive in the recommendations. Any recommendation should be discussed, carefully constructed with the role players, and tested before implementation.

VI. CONCLUSION

This paper focussed on the survey of the investigators as part of an incident investigation study at a large steel facility. Although the organizational policy was thorough in its requirements, the survey of the investigators identified issues with the investigation process in action with the following five findings of notable importance:

1) There is a lack of dissemination of completed investigation reports between business units and departments.
2) Direct blaming was not prevalent in cases where human error was noted, and that was a positive finding. It was, however, noted that investigators may assign blame indirectly through noncompliance with hazard identifications and risk assessments and noncompliance with operational procedures.
3) Investigators indicated that operational responsibilities result in distractions to the point that the deadline or the quality of the investigation is influenced.
4) The majority of investigators incorrectly stated that an investigation is completed when root causes are identified. An investigation is completed once corrective actions are implemented and verified for its effectiveness.
5) A significant percent of investigators do not believe that near misses are investigated in detail although the organizational policy requires this.

Any industry can issue a similar survey to their investigators. Communicating findings from such studies may initiate a discussion on whether gaps in the investigation process are localised to a specific plant or whether these are global issues. Recommendations to address the findings were provided, but these should be adopted with the necessary due diligence required when altering organizational policies and procedures. In conclusion, the effective application of the investigation process will prevent recurrent incidents, resulting in a safer workplace.

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APPENDIX A
STATISTICAL METHODS

Table 1 presents the frequency of the responses related to the findings discussed in this paper.

To demonstrate the validity of the data, principle component analysis (PCA) was used. PCA is used to reduce or summarise the total number of items explaining a construct [21]. The PCA is summarised as follows [22]:

(i) Remove superfluous/unrelated items: reduction of items which are not measuring the construct or does not relate to other variables measuring the construct

(ii) Reduce redundancy in a set of variables: if multiple items are measuring the construct in an identical manner, these items can be reduced.

For the purposes of this paper, the authors used a software package to execute the PCA after taking cognizance of requirements and limitations of the data set. Data was largely reduced and redundancy omitted during the development of the survey questions. The PCA method did, however, identify the "human blame" construct as redundant. This was expected and the data was retained. The justification is handled in the body of the paper.

In addition to the PCA, the overall Kaiser-Meyer-Olkin (KMO) measure greater than was 0.74. KMO measures greater than 0.7 [10] support the validity of data. In order to demonstrate a good level of reliability a Chronbach's alpha greater than 0.7 [11] [12] was considered. The data from this survey demonstrated a high level of reliability with the Chronbach's alpha α = 0.878. ble 1: Frequency of responses for the findings discussed in this paper.

TABLE 1
Survey of Investigators Excerpts with Results

Finding #	Survey Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	I am aware of the outcomes of incident investigations, which occur at other operating units. (Please note that this point does not refer to a 24 hour or 1-pager report of the incident, but rather to the detailed accident investigation)	18.9	39.6	13.2	23.6	4.7
2	Incident investigators blame people for incidents	11.3	42.5	22.6	19.8	3.8
	Incidents are caused by people and not a failure in a management procedure (such as safe working or safe operating procedures).	7.5	32.1	33	25.5	1.9
	In cases where the Hazard Identification and Risk Assessment (HIRA) was found to be deficient, it can be deduced that the task initiator had made an error.	1.9	34.9	34.9	25.5	2.8
3	Investigators are somewhat protected from operational responsibilities and are allowed to focus on a thorough incident investigation	6.6	36.8	28.3	26.4	1.9
4	An incident investigation is considered to be completed once the root causes are established	4.7	33	8.5	41.5	12.3
5	Near misses are investigated in detail	10.5	25.7	21	40	2.9