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IMPROVING SAFETY PERFORMANCE AND RISK MANAGEMENT THROUGH SOCIAL NETWORK ANALYSIS

by
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AN ABSTRACT OF THE THESIS OF

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Safety is one of the most critical issues that construction project managers need to prioritize as negligence may lead to loss of lives. The Middle East region witnesses very low levels of safety management where companies are not seeking to improve their performance as much as hiding their deficiencies. This constitutes the core problem as the safety culture is absent. The research study aims at evaluating safety performance and risk management through focusing on the network of people forming the system. Improving safety interaction on projects helps boosting the safety management process. In this research, the safety of a large contracting company in the Middle East is evaluated through choosing three projects and comparing their respective networks for safety management and communication. Data showing communication patterns and individuals was collected on each project and the safety network was mapped on Gephi to highlight visual features of the network. Using Social Network Analysis, various metrics were computed revealing network characteristics and communication patterns. Network resilience was then measured using resilience metrics collected on the project and through agent-based simulation on NetLogo. Finally, it was shown that networks with better interaction and structure have a higher resilience to prevalent risks and hence perform better on safety related issues.

CONTENTS

ILLUSTRATIONS

TABLES

Table Page

CHAPTER I

INTRODUCTION

Safety is crucial for successful construction project performance. It requires continuous monitoring as construction projects are highly prone to risks and involve human lives at the edge. As much as it impacts time, cost, and quality, safety is a critical performance indicator as it reflects work conditions, injuries, and the loss of human lives. However, safety remains marginalized in the Middle East region, leading to high accident rates with a number of undisclosed incidents. The work environment is described as a place where “no international safety and health standards currently exist” (Kenrick, 2012). The construction industry in the region has been growing significantly over the last years and is expected to provide projects worth 500 billion dollars by 2015 (Kenrick, 2012). In Qatar, where construction work is booming in preparation for the 2022 World Cup, the fatality rate is around eight times as high as it is for the construction industry in the UK (Sultan, 2013). Contracting companies do not enforce proper safety regulations and this causes injury rates to increase. Major reasons such as lack of accident reporting and absence of safety records are leading to alarming safety figures. For instance, “more than 1,000 workers were killed or injured in falls on construction sites in Qatar last year, an increase of two-thirds compared to 2008” (Sultan, 2013). In fact, construction projects are known for having inherent risks with high levels of uncertainty. Risks vary with project complexity but remain inevitable; hence risk management along with safety control should be more emphasized on construction projects. To improve safety performance and implement proper risk management on a project, it is very important to track how people interact with each other and how they deal with unfavorable conditions that jeopardize the work environment.

The goal of the research study is to evaluate safety performance for a major contractor in the Middle East by assessing the system resilience to prevalent risks. A recent research paper attempted to use Social Network Analysis (SNA) to study safety communication in small work crews in the US. In their article, Alsamadani et al. (2013) look at safety performance of different crews by investigating sociograms and detecting communication patterns visually. However, data analysis suggests that the general SNA metrics are not significant measures that distinguish high from low performing crews. This study challenges the last finding and introduces the concept of resilience to differentiate robust networks from weak ones.

This research employs SNA to map the network of people involved on projects and their communication patterns, and looks at different metrics to evaluate system resilience i.e. the ability of the system to avoid failures as well as to recover once they occur. Results from this study can assist construction practitioners in proper safety and risk management. The study includes a literature review section, a methodology, a sample survey at a case company, a social network analysis on Gephi, a simulation model on NetLogo, and a discussion of results to relate network characteristics to safety performance measures. The aim is to understand that the safety culture is a social collective effort and relies on proper communication among the network of people within an organization.

CHAPTER II

LITERATURE REVIEW

2.1. Safety Management

Safety performance remains the top concern of project managers as poor safety increases project failures and impacts all other Key Performance Indicators (KPI). For instance, unsafe work environment will undermine the quality of work thus incurring additional time and subsequent costs to cater for such conditions. Hence, monitoring safety should be integrated at all stages of the project. As “you can’t manage what you can’t measure”, proper safety management requires the tracking and monitoring of several safety performance indicators as bases for continuous improvement. Measuring and monitoring safety performance enables identification of safety issues, improvement of work processes, and better accident prevention measures.

Various indicators are used to measure safety performance. Among such metrics are the Occupational Safety and Health Administration (OSHA) recordable injury rate (RIR), the DART injury rate which stands for “days away, restricted, or transferred” work, and other measures that contractors use as benchmarks to assess their overall safety performance. In fact, the records of OSHA rates show that the construction industry has significantly improved in terms of safety performance from 1989 to 2009. However, an interesting observation is that the rate of improvement has declined since 1998 (Hinze et al. 2013).

Injuries on construction sites are mainly divided into two categories: lost time versus non-lost time injuries. These can be further categorized into severe and mild injuries. However, recent researchers are seeking better ways to measure safety by introducing *leading* versus *lagging* indicators. *Leading* indicators can be used as predictors to forecast potential hazards. The importance of such indicators lies in that they fall in the spectrum of hazard identification and risk analysis. On the other hand, OSHA rates are classified as *lagging* indicators as they are considered reactive indicators that denote after-the-fact measures. Grabowski argues that such indicators do not give insight to avoid future incidents (Grabowski et al., 2007).

Mitropoulos (2012) lays down a framework to integrate the safety system and production control system in a project. The safety outcomes of a project are then defined by these two organizational systems. As safety management dictates policies and practices that help reduce hazards on a project, the production control system establishes all the processes and decisions to ensure a safe work environment. Thus, enhancing safety is achieved through proper integration of safety management at the production level. Hinze (2002) discusses the importance of project planning and task planning for improving safety performance. Aslesen et al. (2013) explain how safety can be incorporated in production planning and control. A model integrating safety job analyses in the Last Planner System (LPS) helps reduce hazardous situations by allowing the detection of these early on. Wehbe and Hamzeh (2013) also suggest the integration of Failure Mode and Effect Analysis at the look ahead planning level of LPS as a risk management practice that avoids the emergence of safety hazards. In fact, safety management practices vary among different companies. Alarcon et al. (2011) identify seven safety practices that are statistically significant to reducing the accident rate in an organization. Among those are accident and incident reporting, management commitment, safety incentives, and others. The authors highlight the importance of choosing the right combination of prevention practices for better safety outcomes.

Construction companies are increasingly recognizing the value of Health and Safety management (Mitropoulos et al., 2005). The safety culture is perceived as a social and collective effort (Aslesen et al., 2013) and hence, the network of people (including communication patterns) in a company is a determining factor that reflects how the system performs. This is where Social Network Analysis intervenes to help assess the system and study its resilience.

2.2. Social Network Analysis

2.2.1. SNA overview

Social Network Analysis (SNA) is, as its name denotes, the analysis of social networks where social relationships are mapped in terms of network theory. Nodes represent individuals within the network and ties represent relationships between those individuals. The output is a social network diagram. Visualization of the network is crucial to the understanding of the network data and its analysis. This may be a powerful method for conveying complex information (Easley and Kleinberg, 2010).

SNA is used to study interactions and relationships among individuals through graphical representation. Visual and quantitative analyses can be used for interpretation purposes. SNA has been used in various fields and its application in organizational behavior studies is emerging recently. Given the interdisciplinary nature of construction projects, SNA serves studying and analyzing the relationships among people to manage communication and enhance the integration of different project participants. The output of SNA results in a network model with specific metrics used for further interpretation. A sample network diagram resembles the one shown in Figure 1 below.

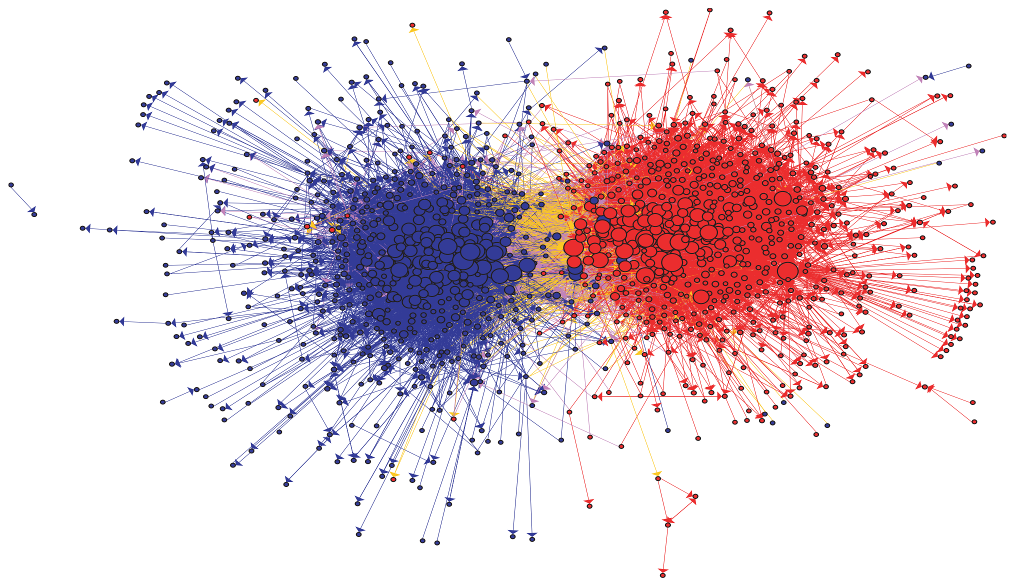

Figure 1: A sample network structure of political blogs prior to the 2004 U.S. Presidential election reveals two natural and well-separated clusters (Easley and Kleinberg 2010).

2.2.2. SNA applications

The social network theory has been applied in diverse fields such as sociology, anthropology, economics, biology, etc. Its application extends beyond areas of social sciences. It has contributed to different studies such as containing the spread of a mobile worm through connecting one of the largest networks of cellular phones (Zhu et al., 2012). Another use for mobile applications consists of studying a global instant messaging network to develop knowledge about different types of contagion in dynamic networks

(Aral et al., 2009). A remarkable contribution of SNA was witnessed in the field of epidemiology where diffusion phenomena of diseases were examined to suggest infection control strategies (Christley et al., 2005). Also, sexually transmitted diseases such as AIDS and Syphilis were among areas of interest through studying patterned networks of social contact (Rothenberg et al., 1998; Morris, 1993).

The use of SNA to study organizational behavior has been increasingly observed. Hatala and Lutta (2009) studied information sharing within an organization and its importance in increasing competitiveness by following a social network approach. Other studies also tackled the importance of information exchange to improve the delivery of information services (Haythornthwaite, 1996; Easley and Kleinberg, 2010). In construction, SNA was primarily implemented to discuss information flow among project participants and optimize communication and transparency (Alarcon et al., 2013; Hickethier et al., 2013). An interesting study done by Priven and Sacks (2013) focuses on the relationship between SNA and the Last Planner System (LPS) of production planning and control. It illustrates that a successful implementation of LPS is associated with a strong social network among construction crews.

Social Network Analysis has been limited to studying information flow and communication on construction projects. Studies found in literature emphasize on the aspect of information sharing without covering other issues pertaining to construction. Chinowsky et al. (2010) recognize the importance of the social network model of project teams to achieve high performance through better communication. Also, in another paper, Chinowsky et al. (2010) discuss the integration of traditional project management with the social network model of construction. The success of projects is hence not only associated with optimized project management practices but also with the performance of project teams and their level of communication. On another topic, Pryke (2004) used social network analysis to compare traditional and innovative approaches related to procurement and project management in construction projects.

This research targets a very sensitive topic raising concern among construction practitioners, and that is safety. It approaches safety from a social perspective and studies the network of people involved in safety issues on construction projects. A recent research paper by Alsamadani et al. (2013) also studies safety communication in small work crews using SNA. Safety performance of different crews is measured using communication patterns in sociograms, and then compared against a maximum performance. Moreover, the paper investigates the frequency and method of communication as differentiators in determining top performing crews. However, data analysis suggests that the resulting SNA metrics other than density are not significant measures to categorize crews. This paper picks up from there to prove that SNA metrics can actually be used as leading indicators for safety performance.

Hence, the objective of this research is to evaluate safety performance through mapping the interaction on safety matters, and to reflect on the system resilience to prevalent risks. After mapping the social network and building a network model, different network metrics will be retrieved and associated with safety indicators. Among these metrics are *density, average degree centrality, betweenness, closeness, cluster coefficient,* and others that translate complex visual patterns into quantitative values for interpretation of existing behaviors and node features (Wasserman and Faust, 1994). Each of these metrics reveals the relationships, connections, and characteristics pertaining to a node as well as to the whole network structure (ref. Table 1). The model also allows the measurement of “network resilience” which estimates the ability of the system to respond to incidents and recover from damages.

Table 1: Social Network sample metrics (Newman, 2010)

Type	Metric	Definition
Node	Degree Centrality	How many other nodes a node is connected to (undirected)
	Betweenness	How many pairs of individuals are connected through a node with least number of steps; brokerage role
	Closeness	How close a node is to other nodes, depends on shortest average path to the rest of the nodes
	Eigenvector Centrality	How central a node is depends on how central its neighboring nodes are (depends on importance or popularity of neighbors)
Network	Density	How many actual links exist between nodes divided by the number of total possible links in the network
	Clustering	How clustered groups of people are compared to the rest of the network, existence of closed triads and small communities
	Average Path Length	How many steps, on average, all nodes require to reach each other in the network
	Centralization	How central the most central node is compared to the centrality of the other nodes (shows evenness or dominance within a network)
	Cohesion	How resilient a network is, measures number of nodes to be removed that can dismantle the network

2.3. Network Resilience

2.3.1. Resilience engineering

Resilience engineering is a paradigm for safety management that focuses on how people cope with complexity under pressure to achieve success (Resilience Engineering Network, 2008). Wreathall (2006) associates resilience with the ability of an organization to keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major failure or in the presence of hurdles. Thus, resilience includes both the ability to avoid failures and losses, as well as the ability to respond effectively after these have occurred.

Resilience engineering is mostly useful for high-risk systems that involve complexities, and hence its value in studying safety on construction projects. The complex nature of construction projects lies in the high interdependency among components that comprise a system and in the high levels of uncertainty and variability omnipresent on a project. Applying resilience engineering to evaluate health and safety management systems is, as reported in many studies (Rasmussen, 1997; Hollnagel and Woods, 2005; Hale and Heijer, 2006; Wreathall, 2006; Saurin et al., 2008), based on four principles:

- Top management commitment to set Health and Safety a priority among company's objectives.
- Increasing flexibility to account for variability in the system and allow people to take important decisions when the need arises.

- Learning from both incidents and normal work to identify successful working strategies; this is possible if the work environment encourages incident reporting.
- Awareness of the system status to forecast potential changes that may affect the system and assess trade-offs in safety performance.

2.3.2. Resilience metrics definition

For the purpose of the research, resilience metrics are defined according to a study done by the European Network and Information Security Agency (ENISA). The study includes a comprehensive framework to define and assess resilience metrics for computer communication networks. A categorization of resilience metrics is suggested to reach a unified taxonomy using a two-dimensional approach. The incident-based dimension divides resilience into three phases. These pertain to a temporal view of an event or incident. First, preparing for resilience "before" the event happens, then delivering the service i.e. performing operations when the incident has already happened, and finally recovering to normal operation "after" the event.

Therefore, resilience metrics are grouped according to the different phases that the system undergoes. Resilience is thus expressed over the three phases: preparation phase, service delivery phase, and recovery phase. These phases are customized to match the scope of this research. The preparation phase includes all the measures implemented to help the system cope with risks and challenges and avoid their occurrence (called preparedness). On the other hand, the service delivery phase measures the system operation once an incident occurs, its functionality and readiness to detect faults (called incident occurrence). It highlights the difference in the system performance before and after the incident happens. Finally, the recovery phase relates to the state of the system after the incident has happened, it shows how fast normal operations are restored and includes possible mitigation measures for recovery (called recovery). Therefore, the three key phases at which resilience metrics have to be measured are: preparedness, incident occurrence, and recovery.

To assess the efficiency of protective measures and preparedness of the system, one can measure the percentage of the number of incidents out of the total number of events. Also, the nature of incidents plays a role in evaluating the strength of the system to cope with potential hazards. Incidents can be classified as light or severe depending on their impact. If the number of severe incidents exceeds a certain limit, then the system has very poor defensive strategies and hence is unsafe. In order to measure the impact of an incident, certain factors can be taken into consideration. Among those impact metrics, one can look for the number of deviation reports that were recorded before the incident happens. Also, the network of people affected and the financial losses generated can be indicators of the severity of an incident. Most importantly, the injuries caused are highly representative and can be used as the main critical factor. The impact of incidents on the system reflects on its robustness and availability of mitigation measures that reduce damages.

2.3.3. Network resilience significance

In the context of SNA, studying network resilience shows how robust a network is when confronted with hazards. In construction, this implies studying how people interact with each other when risks or accidents prevail on a project and measuring the impact of changes occurring to the network. This reflects how the network responds to risks, how fast it recovers after a failure, and the damages (i.e. lost connections or weaker links) that result from a breakdown. Looking at network resilience helps in:

- Reducing safety risks: identifying important features in the network helps in setting up ways for reducing failure probability of the system. (preparedness)
- Mitigating failures: analyzing important components of the network allows alleviating the consequences of safety risks through mitigation measures.
- Reducing time to recovery: understanding the relationships in the network makes it possible to seek quick reactive measures after failure. (recovery)

2.4. Risk Management

Despite the risky nature of the construction industry, risk management practices remain underutilized. This is mainly due to the unawareness of companies of risk management tools. Actually, risk management tools vary and are numerous but stay unpopular in the contracting field. Nowadays, more construction companies are becoming engaged in such practices which help improve their overall performance especially regarding safety. Risk management and safety performance are closely related since managing risks will inevitably reduce potential safety incidents.

The need for managing safety is hence bound to the growing need for a comprehensive risk management process. In fact, Rasmussen (1997) emphasizes the importance of managing risks in a dynamic society where drastic changes may affect work conditions. Rasmussen also points out the driving role of individuals in the propagation of an accidental course of events. People are hence the building blocks of a safe work environment. Thus, modeling the system behavior is essential to the risk management approach.

Risk management is perceived here as a controlling tool to maintain hazardous construction processes within the safe boundaries of work. The focus is on the network of people in the safety system. The different stages in the risk management process are: risk identification, risk assessment/analysis, and risk monitoring (Wehbe and Hamzeh, 2013). In this study, the network will be diagnosed to assess whether a risk management routine is employed or not. Each of the attributes will be addressed by understanding the social network of people comprising the system and ensuring that appropriate risk assessments and plans are done on each of the projects under study.

CHAPTER III

RESEARCH METHODOLOGY

3.1. Research objectives

The primary objective of the proposed study is to evaluate safety performance and relate it to network resilience through analyzing the social network of individuals to help industry practitioners improve their safety management systems. Studying and analyzing the network will allow participants to enhance the design of their safety system. What follows is a list of the specific aims of the research study.

- Understand network characteristics: quantitative network analysis where network metrics (density, average degree centrality, closeness, etc.) are computed using Gephi. Interpret each of the metrics and correlate it to the network structure through examining community patterns.
- Study how communication among individuals impacts safety performance: This includes examining different visual features of the network and relating them to safety behaviors (e.g. clustering show the formation of groups associated with teams), the impact of communication will be detected to assess how it shapes safety responses to hazards. Collaboration areas as well as problematic ones will be spotted.
- Assessing network resilience and relate it to safety performance: the resilience of the network is checked to evaluate how robust it is, whether it can absorb

safety risks and/or recover with the least damages. Resilience metrics are computed and compared for the various networks

- Simulation of the network model: this consists of running the NetLogo model to simulate the network under the scenario where a safety concern emerges to check how it actually reacts. Discuss differences between networks to evaluate and enhance the safety system. Discuss alternative means that could strengthen the system resilience to cope with hazards and/or improve safety interaction.

3.2. Research methodology

To answer the research questions, the methodology shown in figure 2 below was followed.

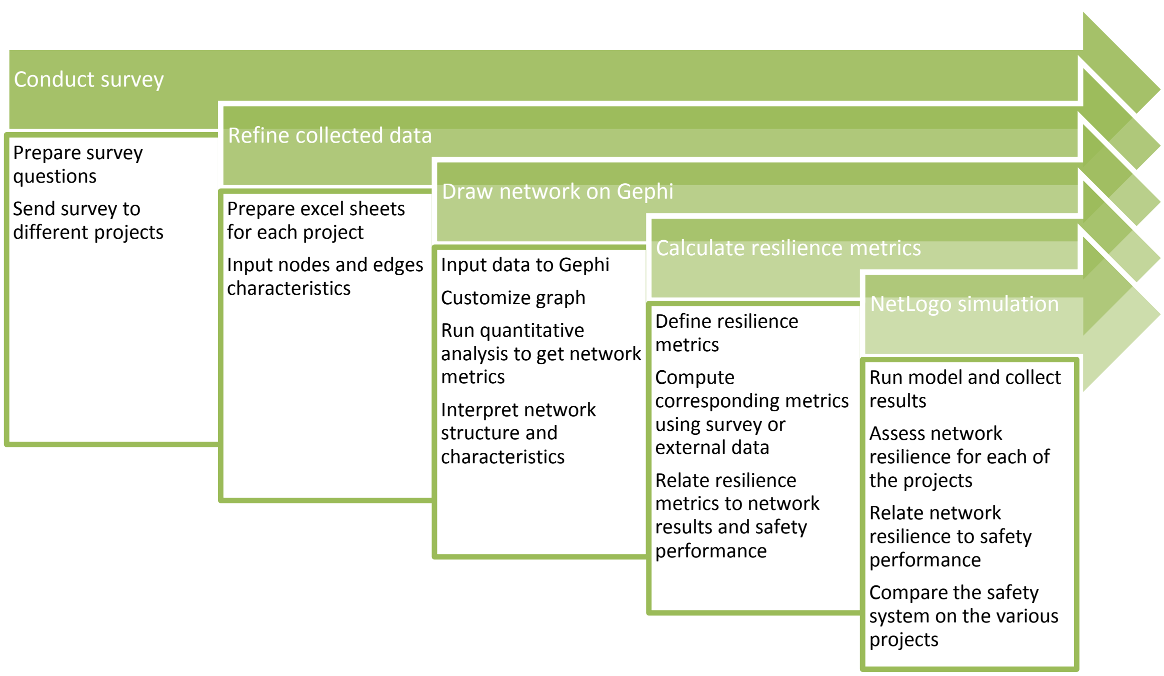

Figure 2: Research methodology

In order to collect the necessary data, a survey was prepared accordingly. The details of the survey conducted are presented in later sections. The survey serves to map the social network of individuals involved in safety on the given projects at the case company. The survey addresses questions that help depict relationships among different individuals on the project. The questions focus on safety interaction and protocols. The survey was also done online and sent to all participants.

After receiving enough responses from each of the projects, the data was collected and refined. Nodes and edges characteristics were input in an excel table to for use in Gephi. Later on, the network model pertaining to safety management on each of the projects was mapped. Each network depicts the dynamics of safety communication and the relationships among individuals.

The graph was customized and the layout adjusted to allow for proper visualization of data. The communities were defined and the weights were assigned to edges. After all modifications, the quantitative analysis was performed and network metrics were retrieved from Gephi. Those metrics along with the structure of the network were interpreted to assess the interaction about safety and hence reflect on safety performance. Central individuals as well as specific features of the network were noted down.

Next, the network resilience was measured through quantifying resilience metrics. Those were then reviewed against previous findings from SNA results. Finally, a NetLogo model was run to simulate each of the networks and inspect its behavior when a safety incident arises. Network resilience was then correlated with safety performance and results were discussed to compare the different projects and evaluate the safety system in place at the case company.

CHAPTER IV

SURVEY AND PROJECT DESCRIPTION

4.1. Survey

In order to perform the study and address the research questions, a survey was prepared and made online. The survey targets parties involved in safety including crews, foremen, superintendents, field engineers, and managers. The response rate for the survey was 84% with 52 respondents for project 1, 27 respondents for project 2, and 43 respondents for project 3.

The goal of the survey is to understand how communication occurs within the organization to have a clear vision of how individuals interact on safety issues. The questions address topics related to the list of contacts for each individual, the form and extent of contact, the nature of safety interaction, and the extent of safety interaction. The breakdown of the survey is as follows:

- Section 1 asks to list the people with whom the respondent interact (from within the organization) within the scope of his/her profession. For each person, a set of information is required regarding the interaction and information exchange occurring with this person. The names of the people, including the person, are confidential and will not be disclosed in any private or public analyses, and will be given alphanumeric codes (i.e., Name = A1 or B9...) or titles (each designated by position and numbered) for the mapping of the social network.

- Section 2 targets the nature of safety interaction with the assigned individuals.
- Section 3 looks at the extent of safety interaction.
- Section 4 addresses some safety processes held at the organization (risk assessment, soundness checks, etc.).

A sample of the survey is included in Appendix 4. The survey was performed at the company mainly by HSE personnel to capture the people actively involved in safety.

4.2. Project description

For the purpose of the study, three projects from the same contracting company were investigated. The company of interest is one of the largest contracting companies in the Middle East and ranks among the top 25 international contractors with a revenue of $5.3 billion in 2013. It has offices and projects in over 40 countries, and a workforce of more than 130,000 employees handling a variety of projects ranging from building and civil engineering to heavy civil works to pipelines and oil and gas projects. It is worth mentioning that the company has good records of safety on its projects and is keen on keeping safety at the top of its agenda. The company's share price ranks high and shows it as a major contractor representative of the industry in the Middle East. Future research might look at smaller companies to compare them to big ones and touch upon the core problem; however, shortage of data remains an essential problem when safety is discussed.

The projects under study vary in terms of project scope but are all interesting projects when it comes to safety. The first project aims at expanding the gas production of an existing plant. The project scope is to upgrade the gas gathering network in order to drill and tie-in additional new wells, and install new compression stations to increase the gas production handling capacity. The project will have gas compression facilities with a capacity of 600 million cubic feet /day and an upgraded gathering network. The value of the Engineering Procurement and Construction (EPC) contract is $203 million. The second project consists of a 265 kilometer long dual four-lane expressway with an estimated cost of $2.6 billion. The expressway will provide strong new impetus to economic investment through building a logistics gateway to the Gulf region. The third project comprises of engineering, procurement, construction and pre-commissioning and commissioning of a sulfur station and pipelines. The contract value is around $555 million with a 40 months duration.

All three projects are big in size and involve critical activities. Although project 2 has the highest cost; however, it may be considered as having the lowest risk compared to projects 1 and 3. Projects were chosen on the basis of peak man-hours since they are currently at the construction stage and involve many critical tasks requiring continuous safety monitoring.

CHAPTER V

RESULTS

5.1. Social Network Analysis

In order to study safety communication on each of the projects, Gephi was used to draw the networks consisting of nodes and edges. Gephi is a visualization tool that allows network analysis through various metrics that the software automatically generates, as well as it reveals patterns in the structure of each network. The resulting network diagrams are shown in the following figures. One can directly notice the clustering of groups which correspond to various teams on site. Also, it is well observed that management personnel have the biggest node sizes and represent influential individuals within each network. The ties within each team are stronger than those with separate teams; this is reflected in Gephi through assigning a higher weight to edges.

Looking at the network of project 1 (figure3), the network is centralized on the HSE supervisor who has the highest degree (20) followed by the HSE manager. The different teams can be clearly visualized through denser ties amongst team members. In fact, the various teams are assigned to different areas on site, and this is why little communication is noted between them. However, the HSE supervisor along with the HSE manager and HSE engineer play a brokerage role and bridge the communication between different parts of the network.

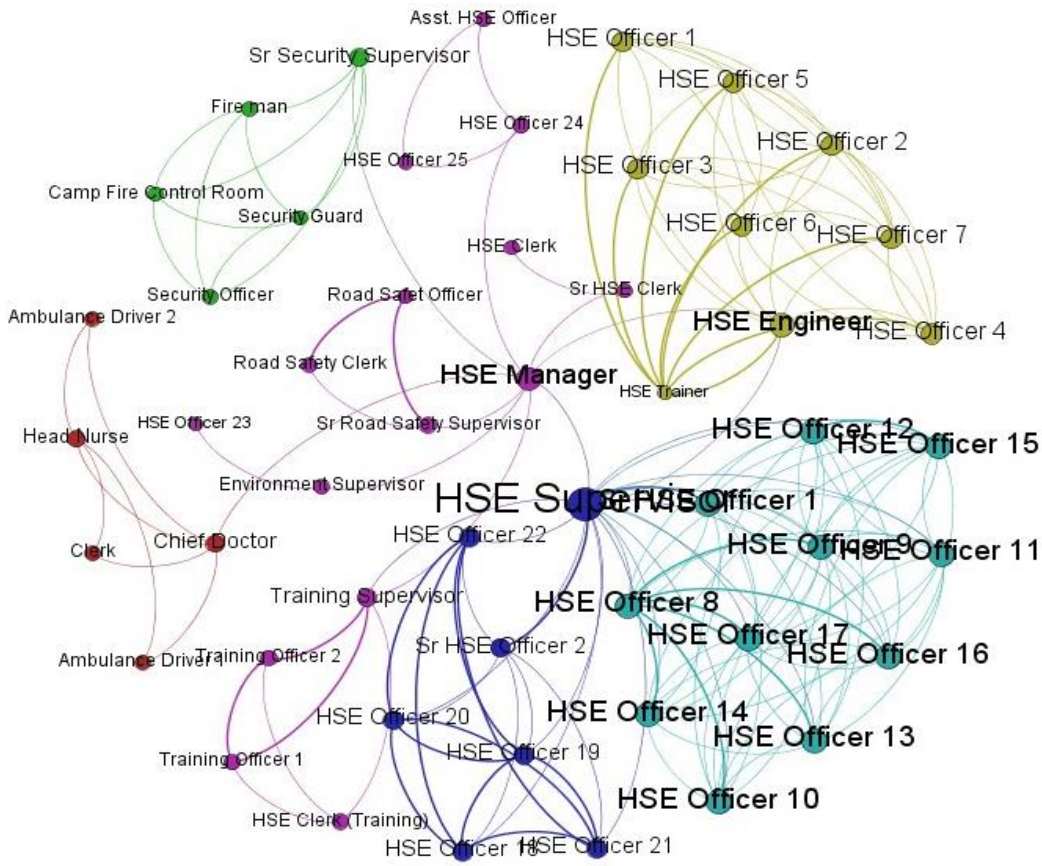

Figure 3: Project 1 network

Figure 4 below shows the network of project 2. The number of players involved in safety is lower than that of project 1, which is mainly related to the type of the project. Again the HSE manager is denoted with the biggest size node, along with the HSE admin. However, more nodes are observed at the periphery of the network with scarce communication. For instance, safety officers 6 and 7 are not easily reachable within the network which displays a high level of segregation.

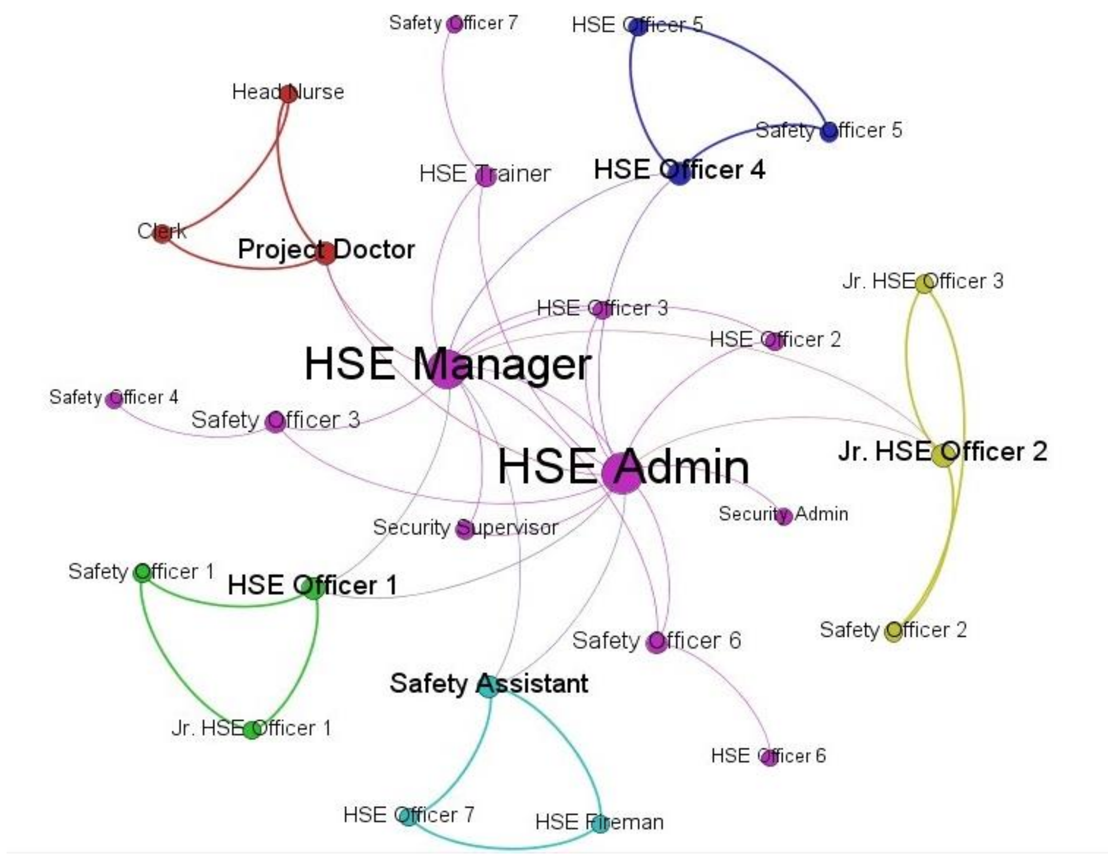

Figure 4: Project 2 network

Finally, figure 5 below illustrates the network on project 3 which resembles that of project 1 to a certain extent. However, upon closer observation and after dividing the network based on modularity classes, two community structures (at the upper right and lower left) seem to have moderate communication between members. The edges connecting members have small thickness and hence indicate weak relationships among the team.

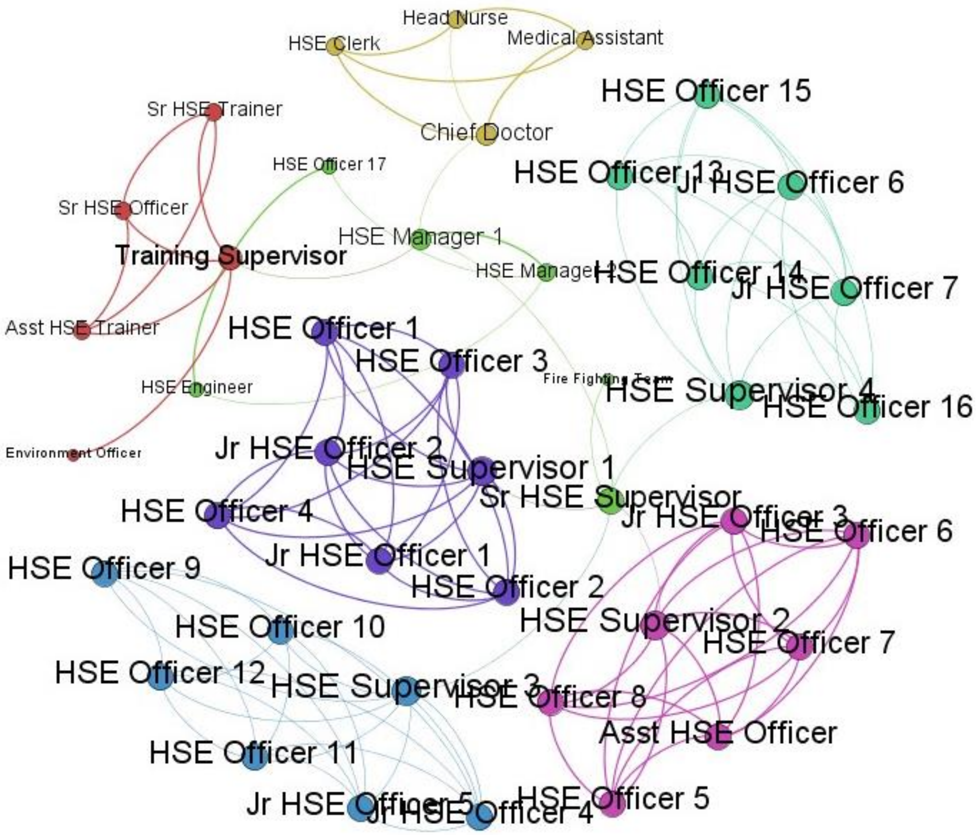

Figure 5: Project 3 network

Upon mapping the different networks, a visual inspection helps in gathering information regarding the overall structure and drawing conclusions about the interaction between actors. However, social network analysis is carried out to give credibility to observations and evaluate the performance of each network against specific measures. Thus, the quantitative social metrics are calculated for each of the project networks. Results were computed using Gephi and are summarized in table 2 below.

Table 2: Network metrics for the different projects

Type	Metric	Project 1	Project 2	Project 3
Structure	Number of Nodes	52	27	43
	Number of Edges	165	42	109
	Graph Type	Undirected	Undirected	Undirected
Node (Average)	Degree Centrality	5.96	3.11	5.07
	Betweenness	50.48	22.15	54
	Closeness	2.98	2.7	3.57
Network	Density	0.124	0.12	0.121
	Avg. Clustering Coefficient	0.851	0.695	0.878
	Average Path Length	2.98	2.704	3.571
	Diameter	4	4	5
	Modularity	0.692	0.671	0.769
	Number of Groups	7	6	7

The graph type is selected to be “undirected” for all networks, considering communication to be mutual amongst all individuals. Looking at the number of nodes, it is seen that the first project consists of the most popular network with the highest number of safety personnel involved on site and the highest interaction. The node metrics are averaged over the total number of nodes for each of the network. Average degree centrality represents the connectedness within a network and is highest for the first project. However, betweenness and closeness are higher for project 3. It is worth mentioning that a higher value of closeness indicates a more difficult communication path in the network.

Furthermore, the network density of project 1 is the highest and reveals a well-connected safety network. Comparing projects 1 and 3, one observes that Project 1 has a lower modularity, clustering coefficient, and path length. This denotes an easier way to reach other individuals in the network as well as less groupings i.e. more communication between different teams. As for the diameter metric, the value is approximately the same for all structures as the sizes of the networks are not drastically different.

5.2. Resilience metrics

To further evaluate safety performance, resilience metrics corresponding to each of the three phases previously identified were developed in line with some of the metrics stated in ENISA. The metrics used for the current study are shown in the table below.

Table 3: Resilience metrics corresponding to each phase (ENISA)

	Resilience metrics
Preparedness	• Risk assessment coverage • Risk management implementation • Soundness check for tasks
Incident occurrence	• Deviation reporting rate • Incident rate
Recovery	• Mean time to recovery • Network topology

Each of these metrics is explained in greater detail with their different aspects to constitute a measurement framework for resilient networks.

Table 4: Risk assessment coverage definition (ENISA)

Risk assessment coverage (RA)	
Description	This metric reports the percentage of job operations that undergo risk assessment.
Objective	Risk assessment reflects on the protective measures of the system and identifies level of risk on the project.
Measurement method	This metric can be measured by dividing the number of tasks subject to risk assessment by the total number of tasks on a given project. RA (%) = $\frac{Nbr\ of\ tasks\ with\ risk\ assessment}{Total\ nbr\ of\ tasks\ on\ the\ project} \times 100$
Frequency	This metric is ideally measured weekly for jobs assigned at the weekly work plan level.
Target values	Risk assessment should ideally be done on 100% of the jobs that present risks or potential safety issues. Although no specific target value is specified for this metric, critical tasks should be assessed.

Table 5: Risk management implementation definition (ENISA)

Risk management implementation (RM)	
Description	This metric reports the percentage of job operations for which proper risk management plans were devised
Objective	Risk management level indicates that proper risk analysis has been performed after risks were evaluated. Mitigation measures should be put in place to reduce consequences or risks eliminated or accepted.
Measurement method	This metric can be measured by dividing the number of tasks with risk management plans by the total number of tasks assessed for risk. RM (%) = $\frac{Nbr\ of\ tasks\ with\ risk\ management\ plans}{Total\ nbr\ of\ tasks\ with\ RA\ coverage} \times 100$
Frequency	This metric is ideally measured weekly to track the jobs for which risk assessment was done.
Target values	Risk management should ideally be done on 100% of the jobs that were diagnosed as risky or presenting potential risks.

Table 6: Soundness checks definition (ENISA)

Soundness check for tasks (SC)	
Description	This metric reports the percentage of job operations that have been checked for soundness i.e. all prerequisites are available.
Objective	Checking that each task is sound is very important to ensure safe operations. This metric indicates if tasks are checked for safety risks (hazard analysis) as well as a comprehensive list of criteria.
Measurement method	This metric can be measured by dividing the number of tasks checked for soundness by the total number of tasks assigned. SC (%) = $\frac{Nbr\ of\ tasks\ checked\ for\ soundness}{Total\ nbr\ of\ tasks\ assigned} \times 100$
Frequency	This metric is measured at the look-ahead planning level i.e. three to six weeks prior to the tasks assigned.
Target values	Soundness checks should be done on 100% of the tasks assigned, however some new tasks may emerge during the week of execution.

Table 7: Deviation reporting rate definition (ENISA)

Deviation reporting rate (DR)	
Description	This metric measures the number of safety deviations that were reported in a given time period.
Objective	Deviation reporting rate indicates the number of detected deviations. This metric reflects on the readiness of the system to overcome risks, as well as the faults occurring in the current operations.
Measurement method	This rate is measured by counting the number of deviations recorded over a given period of time. DR = $\frac{Nbr\ of\ deviations\ reported}{Time\ period}$
Frequency	Deviation reporting should be done on a daily basis during the course of execution and aggregated to evaluate performance on a project.
Target values	No specific target value is set; however the deviations reported should not exceed a certain threshold and be used to trigger alarms for safety.

Table 8: Incident rate definition (ENISA)

Incident rate (IR)	
Description	This metric measures the number of safety incidents that occurred in a given time period.
Objective	Incident rate is an indicator of the efficiency of the safety system. It shows the level of risk threatening the system.
Measurement method	This rate is measured by counting the number of safety incidents occurring over a given period of time. IR = $\frac{Nbr\ of\ safety\ incidents}{Time\ period}$
Frequency	Incident rate should be monitored daily during the course of execution and aggregated to evaluate performance on a project.
Target values	It is ideally set to zero to reach a working environment with no safety incidents. It is crucial to track the number of severe incidents that should not occur and represent a threat to the safety system.

Table 9: Mean time to recovery definition (ENISA)

Mean time to recovery (TTR)	
Description	This metric measures the robustness of the safety system after incident occurrences.
Objective	Mean time to recovery shows the ability of the system to recover after an incident happens. Recovery is effective when precaution measures have been input in the system.
Measurement method	This time is calculated by dividing the time between incident occurrence and recovery over the number of incidents. TTR = $\frac{\sum(Incident\ recovery - Incident\ occurrence)}{Number\ of\ incidents}$ Alternatively, if incidents are categorized by lost time and non-lost time injuries, TTR is then measured through adding up all lost time from injuries over total number of injuries.
Frequency	Time to recovery should be checked continuously, depending on the frequency of incidents.
Target values	No specific target value is set, however this value should tend to be low. The faster the system recovers, the stronger it is against potential threats. A value of zero indicates instantaneous ideal recovery.

Table 10: Network topology definition (ENISA)

Network topology	
Description	This metric measures the robustness of the network against link and/or nodes failure.
Objective	Network resilience is directly related to its topology. Link/node failures represent risks that undermine the network performance as it loses its bonds and might lose its robustness.
Measurement method	This indicator is not calculated. Actually, network performance metrics are checked in function of node/link failures. Simulation of the network topology is done, where varying numbers of nodes and/or links are removed. The performance impact of certain response parameters is then recorded. Also, the effects of such failures are shown visually on the network. Network degradation along with comparison of resulting performance metrics reflect on resilience.

The metrics computed for each of the networks are summarized in table 11 below.

Table 11: Resilience metrics

	Metric	Project 1	Project 2	Project 3
Preparedness	Risk assessment coverage	100%	75%	85%
	Risk management plans	75%	60%	75%
	Soundness checks	100%	100%	100%
Incident occurrence	Deviation reporting rate	18.1	13.2	20.3
	Recordable incident rate	0.03	0.04	0.07
Recovery	Mean time to recovery*	0	0	0
	Network topology	NetLogo	NetLogo	NetLogo

*the company has no lost time injuries to date on the corresponding projects

The percentages corresponding to risk assessment were retrieved through averaging all answers from the last section of the survey (rf. Appendix 4). On the other hand, incident rates and mean time to recovery were computed after checking safety statistics reports from the company (rf. Appendix 1).

For instance, deviation reporting rate DRR was calculated as follows: (project 1)

$$\text{DRR} = \frac{Number\ of\ safety\ observations}{Total\ manhours\ worked} \times 1{,}000{,}000 = \frac{117}{6428987} \times 1{,}000{,}000 = 18.1$$

Looking at RIR values, if one includes First Aid Cases as recordable injuries to be more conservative, the incident rates still fall in the low range. A sample incident rate is computed below using data from statistics report (rf. Appendix 1). Note that OSHA Incident Rate Calculator compares values against the average incident rate for Construction that is equal to 4 (injuries and illnesses per 100 full-time workers).

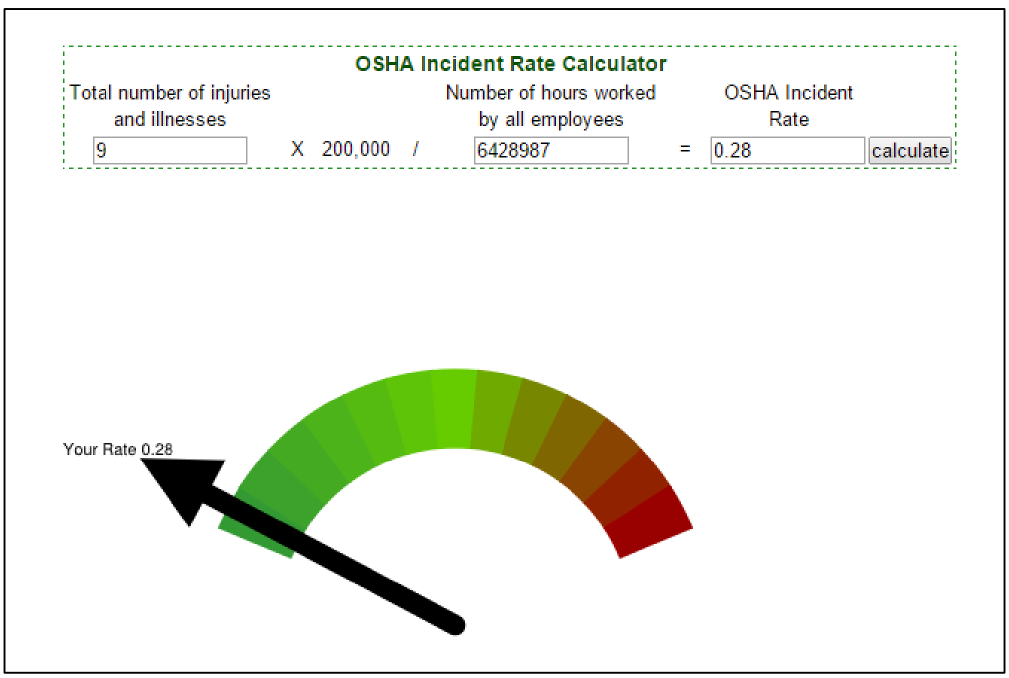

Figure 6: OSHA Incident Rate Calculator

(http://www.safetymanagementgroup.com/osha-incident-rate-calculator.aspx)

Actually, the resilience metrics shown above reflect that all networks perform proper risk assessment for tasks before execution, and devise risk management plans for implementation. Individuals claim that all tasks are checked for soundness to make sure all prerequisites are available prior to execution. However, it is not possible for soundness checks to be complete while risk assessment values are lower than 100%. This indicates that participants were not aware of the right meaning of "soundness" checks. As for DRR, project 3 scores highest along with the highest incident rate. On the other hand, project 2 has a low incident rate although risk assessment and management plans are done less often. This can be related to the smaller number of deviations on the project. Looking at the results, project 1 exhibits more resilience than the other projects, with a relatively high DRR. Deviation reporting is a double-edge sword: a high DRR indicates that the network uses reporting to avoid future recurrence of the problem through a learning process, however this also means that deviations are taking place. It is then important to study whether the network is able to contain them and keeping incident rate at a minimum.

Going back to the three criteria defined previously for network resilience, each of the resilience metrics reflects the network readiness to safety risks:

- A high preparedness metric implies a reduced failure probability. Since the system is well prepared, a safety incident will not induce critical failures.
- A low metric for incident occurrence indicates that the system is not highly affected by the incident and hence mitigation measures are effective.
- A low metric in the recovery phase denotes a reduced time to recovery, and hence a robust system.

5.3. NetLogo simulation model

Gephi allows the visualization of the various networks; however, the static structures generated by the software fail to assess the resilience of the networks. In order to do so, various resilience metrics were computed and compared in the previous section. Moreover, a dynamic simulation tool NetLogo was used to investigate the results through modeling the behavior of the different networks regarding safety matters. A built-in model "Virus on a Network" is modified to simulate different scenarios and predict the dynamics of the network to reach resilience. The aim is to measure the time it takes a percentage of individuals to become resilient when faced with a safety alert.

In the following model, the evaluation of network resilience is based on the concept of chronic unease. This aspect is defined in behavioral safety as a state of skepticism about safety risks, as opposed to a normalization of risks. Put simply, chronic unease is the opposite of complacency and is crucial to achieve safety leadership. Hence, an efficient safety system encourages this feature amongst individuals who should not be tolerant about safety observations, but rather enquire and be aware of safety risks.

The scenario simulated using NetLogo is based on measuring how tolerant individuals are to recurring safety observations. Starting with an unusual safety observation (i.e. potential error), individuals in the network do not always attempt to investigate but rather wait until the error spreads and recurs with a certain spread chance. It is only after repetitive observations that individuals seek to check for possible reasons and resolve the error. At different instances, individuals succeed in preventing an error from generating a safety incident at a certain recovery chance. The network hence develops resistance to future incidents and strengthens its resilience against safety risks. The parameters used in NetLogo for the simulation are detailed in table 12 below.

Table 12: Parameters used in NetLogo

Parameter	Definition	Values
initial-outbreak-size	Number of individuals aware of safety observation	5
error-check-frequency	Frequency of safety checks to investigate observation	5 times after recurrence
error-spread-chance	Probability for safety observation to recur i.e. denoting a potential error	5%
recovery-chance	Probability that an individual fixes the error before it results in an incident	30%
gain-resistance-chance	Probability that an individual eliminates future errors due to lessons learned	30%

For the sake of comparison between networks, the same parameters were held constant and the behavior of each network was monitored to test for resilience. The error spread chance was kept constant at 5% to account for various random safety observations that do not involve any future incident or cause perturbations to the system. However, it is worth mentioning that this spread factor depends largely on the topology of the network along with other characteristics. The NetLogo interface resembles figure 7 below.

The values of the parameters were based on theoretical assumptions and held constant to allow for comparison. The simulation aims at studying the way the network reacts to a problem and not the effect of parameters on the network. The difference between recovery and resistance is important in this context. Recovery indicates that the safety observation didn't lead to a more serious incident, however it can still reoccur in the future; whereas resistance implies a shield that prevents that same problem from recurring.

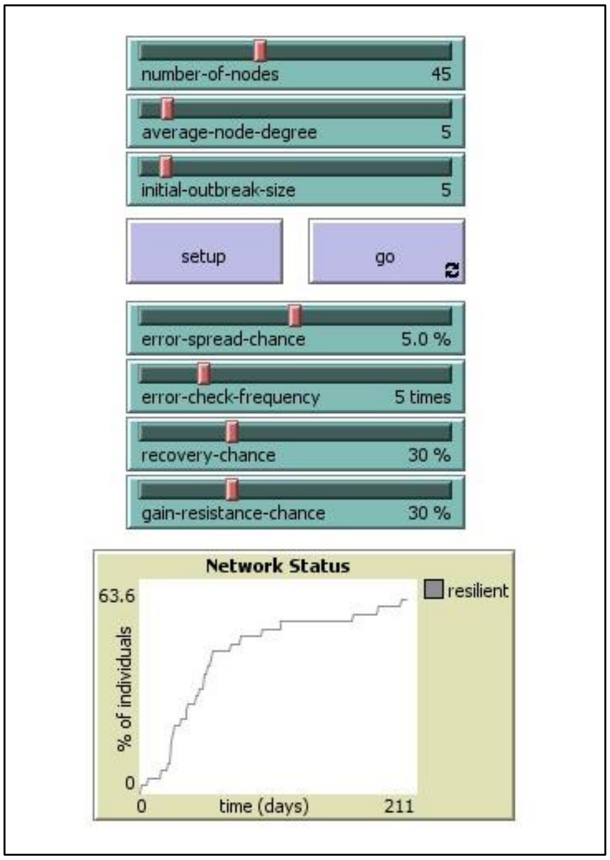

Figure 7: NetLogo interface for project 3

After running the model for each of the networks under various scenarios, results were averaged and resilience was associated with the ratio of resistant individuals in the network. This ratio was calculated through multiplying the percentage of resistant individuals by the total number of nodes in the network, and dividing it by the time required. The results are summarized in the table below.

Table 13: Ratios for measuring resilience (NetLogo output)

Project	% of individuals	Time (days)	Ratio
Project 1 (nodes = 50, degree = 6)	62	130	0.24
Project 2 (nodes = 30, degree = 3)	46	80	0.17
Project 3 (nodes = 45, degree = 5)	58	200	0.13

Looking at the results above, it is noticed that project 1 has the highest ratio of individuals who gained resistance following a learning process that consists of a barrier that protects the network from potential errors that could diffuse later. These individuals acquired a sense of urgency when confronted with similar safety observations and hence learned to avoid their emergence into incidents.

In fact, at the first glance one might question the longer time it takes the network of project 1 to become resilient. However, it is very important to account for the higher degree of the network. Although a high degree indicates better communication among individuals, it also denotes a faster spread of the problem. Having more connections causes the problem to spread to more people and hence it takes more time for the network to develop resistance. This doesn't imply that the network is weaker. Hence, computing the ratio accounts for the unequal sizes of the networks and provides a consistent way of evaluation. Therefore, project 1 has a better performance than project 2 irrespective of the decreased value in time.

It is important to note that the higher the recovery and resistance chances are, the faster the error spreads and ceases. Resilience of a certain network increases with better connectedness and smoother communication flow.

CHAPTER VI

DISCUSSION

The networks under study reveal different characteristics pertaining to the nature of safety interaction among the individuals. All networks are observed to have a relatively high modularity that shows dense connections within teams and weaker links across them. Also, the safety system in the case company is shown to be centralized on the upper management rather than being a shared responsibility. A more effective safety culture is an interdependent one where everyone seeks safety leadership and is equally responsible. However, higher betweenness and lower closeness on project 1 bridge the gap between different entities on site and ensure proper communication flow. Figure 8 below maps the reporting mechanism and information flow within the network of project 1. This once again depicts the centralization of safety communication on three most influential individuals in the network: HSE manager, HSE supervisor, and HSE engineer. The communication flow goes upward to reach management level. Although reporting typically follows this procedure, it is better practice to have two-way communication with managers and supervisors being more involved and providing feedback to workers at the low-end.

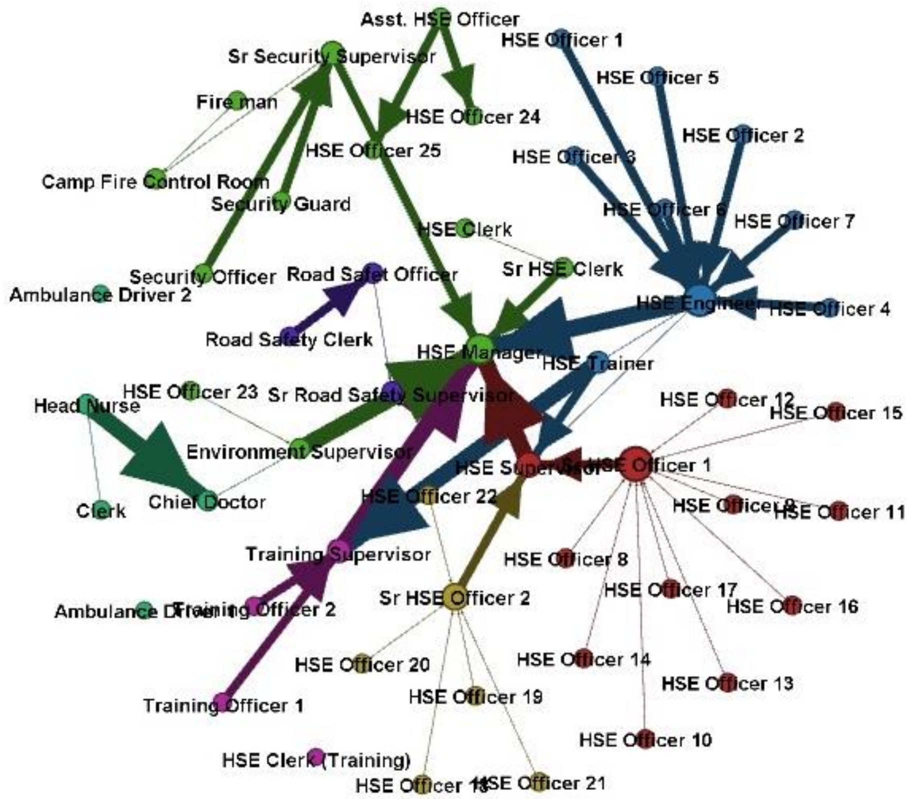

Figure 8: Reporting and safety information flow on project 1

On another note, the type of project affects the type of safety network captured. For instance, project 2 represents a transportation project and hence requires less involvement in safety than oil and gas projects which involve more critical tasks. This explains the lower number of individuals and edges present in the network as well as the emergence of periphery nodes. Projects 1 and 3 consist of denser and more complex networks.

The resulting node metrics show that the higher closeness and average path length values on project 3 reflect however a more segregated network where no proper communication is held and individuals are not all reachable everywhere in the network.

The resilience metrics calculated for all networks once again confirm that a stronger structure ensures better safety management via robust bonds among individuals. The network of project 1 turns out to be the most resilient network with the lowest incident rate and hence the best safety performance. A resilient network develops resistance to failures as it is shown to build up barriers and prevent recurrence of problems through a continuous learning process. Therefore, resilience is associated with a better safety performance as it allows the network to be more proactive and anticipate potential system errors. Individuals within such network develop chronic unease and become reluctant to tolerate deviations.

Finally, questions in the survey targeted the exchange means as well as the extent of safety interaction for each of the network. It is then important to note that project 1 with the best safety performance used face-to-face meetings as its primary means of communication, as opposed to project 2 which focused more on emails and meetings. However, almost all projects had a high extent of safety communication including all options (during meetings, safety briefings before jobs, training sessions, etc.).

In order to gather all data and carry out a comprehensive comparison of results, a summary table was prepared to summarize the findings of the research so far (table 14). The most important SNA metrics are used for comparison with the omission of a few that have the same connotation. Also, preparedness is calculated as a single average parameter. The main safety indices against which performance is measured on each of the project are: DRR, RIR, and LTIR which are based on actual data on the projects (Appendix 1).

Table 14: Summary of results

	Metric	Project 1	Project 2	Project 3
SNA metrics	Betweenness	50.48	22.15	54
	Closeness	2.98	2.7	3.57
	Density	0.124	0.12	0.121
	Average Path Length	2.98	2.704	3.571
	Modularity	0.692	0.671	0.769
Resilience metrics	Preparedness	92%	78%	87%
	Resilience ratio (NetLogo)	0.24	0.17	0.13
Safety indices	Deviation reporting rate	18.1	13.2	20.3
	Recordable incident rate	0.03	0.04	0.07
	Lost Time Incident rate	0	0	0

The SNA metrics on each of the projects reflect on their safety indices. For instance, low closeness and average path length values on project 1 reveal a connected network that has the lowest incident rate. Resilience metrics are also found to affect the safety performance of the network. When preparedness and resilience ratio increase, the safety indices turn out to be better. For example, project 1 has the lowest incident rate with 92% preparedness and 0.24 for the resilience ratio. For projects 2 and 3, although preparedness is better on project 3, the low resilience ratio has a bigger effect on safety performance. The incident rate on project 3 is higher than that of project 2, nevertheless one can argue that the two projects are not comparable due to belonging to different types. An incident rate of 0.07 on an oil and gas project may represent a better measure than a rate of 0.04 on a transportation project given the greater challenges in the oil and gas industry. The correlation amongst the various factors is not quite practical due to the limited values. A larger dataset is needed for this purpose.

As for the safety indices used, it is important to note that as previously mentioned, deviation reporting has two connotations. On one hand, it reflects that reporting of incidents is adequately carried out to keep lessons learned and avoid their recurrence i.e. develop resistance. On the other hand, once deviation reporting is increasing then deviations in the system are equally increasing. Project 1 has the lowest incident rate with a high DRR. This could denote that the network is resilient through absorbing the errors before they generate incidents and unfavorable consequences. Moreover, the weight assigned to the recordable incident rate RIR is greater than that of deviation reporting rate since RIR involves actual incidents whereas DRR only depicts potential incidents or simpler deviations to the safe working practices. This is why if a network has a higher incident rate even with lower deviations, it is still considered a weak network, while a network with a lower incident rate and high deviations is a robust network that can contain problems and prevent them from developing into incidents.

Project 3 has a high DRR with a high incident rate value. The deviation reporting in this case could be interpreted as a better readiness to face future challenges for the network, along with the high value for preparedness. However, the resilience ratio is low relating to the high incident rate. In fact, the resilience ratio is observed to be the most consistent metric dictating the performance of the networks. As such, project 1 has the best safety performance. Project 2 is not comparable given its scope, however it is interesting to see the difference between different types of projects.

Relating these interpretations to actual events, project 1 has an established schedule of regular HSE inspections to site. In November 2014 and during their regular site walkabout, the HSE team detected a gas leak of H2S. To contain the risk and mitigate any potential consequences, the team followed a series of prevention measures. First, they restricted the entrance to the designated area and distributed respiratory devices to all nearby areas. External comers were also prohibited from entering the site and workers who accessed the contaminated area previously were examined. The HSE team rechecked all H2S monitoring devices on site and performed a root cause analysis to reveal the reason behind the incident. The project also uses Safety Observation Cards to keep track of all deviations occurring on site. A sample observation card is shown in Appendix 2. The card details the case of a worker trying to heat his coverall using a heating torch. This act didn't cause any minor burn or injury, however it was flagged as an unsafe act. As a result, all supervisors held a toolbox talk the next day with their teams regarding burns and personal injuries (rf. Appendix 3). The safety team on the project encourages all personnel to actively engage in reporting any safety observation to constantly raise awareness at the workplace and avoid any potential incident.

CHAPTER VII

CONCLUSIONS AND FUTURE RESEARCH

Safety management practices rely on continuously monitoring statistics and devising new schemes to attain goals while neglecting the building blocks of a safety system: the network of people. Embracing a good safety culture consists of developing the individuals while understanding the dynamics of interaction between them. This research takes a different approach and deals with safety at the social level. Through mapping the network on Gephi, safety performance on projects is assessed based on the system resilience. Using social network theory, three projects were analyzed and compared through visualizing their structure and computing various metrics. NetLogo was also used to simulate the network model and check how it reacts to safety alerts. The network structure, metrics, and resilience were aligned and shaped the safety performance on the project. A more cohesive network structure on a project implies better safety communication and more resilience to safety risks. The stronger the network, the better its ability to respond to safety problems, recover effectively, and proactively engage in avoiding future occurrences. Better resilience is then directly associated with improved safety performance. The safety management system must be designed to allow for proper interaction among individuals who form a robust structure and ensure high performance.

Further research can be performed to investigate the behavioral aspects of a resilient network and determine which characteristics, apart from chronic unease, promote a better performing team on safety matters.

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APPENDIX 1: STATISTICS REPORT

Project Name:
Area:
Location:
Project Manager:
HSE Manager:

Project Number:
Project Start Date:
Project Finish Date:
Report Number:
Period Ending:

Segment:

NO.		DESCRIPTION	LAST PERIOD	THIS PERIOD	TOTAL TO-DATE
1		**No. of Employees (overall)**	3454	295	3749
2		**No. of Employees (HSE)**	31	0	31
3	RECORDABLE CASES	No. of Lost Time Injuries (LTIs)	0	0	0
4		No. of Restricted Work Cases	1	0	1
5		No. Occupational Illnesses	0	0	0
6		No. of Occupational Fatalities	0	0	0
7		No. of Medical Treatment Cases	0	0	0
8		No. of Loss Consciousness Case	0	0	0
9	NON-RECORDABLE	No. of First Aid Cases	8	0	8
10		No. of Near Misses	114	3	117
11		No. of Non-Occupational Fatalities	0	0	0
12	INDUCTION / TRAINING	No. of HSE Staff inducted	33	0	33
13		No. of **Project Personnel** inducted	5139	71	5210
14		No. of Employees Trained (other than Induction)	33344	670	34014
15		Total Man-hours for HSE Induction	77650	1136	78786
16		Total Man-hours for Training	78040	1941	79981
17	INSPECTION	No. of HSE Meetings	49	0	49
18		No. of HSE Inspections	30	0	30
19	ENVIRONMENT & SECURITY	No. of Fires	0	0	0
20		No. of Thefts	0	0	0
21		No. of Property Damage	3	3	6
22		No. of Alcohol Intoxication Cases	0	0	0
23		No. of Drugs Abuse Cases	0	0	0
24		No. of Spills / Leaks	0	0	0
25		No. of Chemical Releases	0	0	0
26	VEHICLES	No. of Vehicles (Group 5 & 9)	171	-11	160
27		Total Kms. Driven (Group 5 & 9)	5251307	167254	5418561
28		No. of Vehicle Accidents (Group 5 & 9)	0	0	0
29	MAN-HOURS	Total Man-hours Worked (Direct & Indirect)	6142851	286136	6428987
30		Total Days Lost due to **LTIs** "DAFW cases"	0	0	0
31		Total Man-hours from Last **LTI** "DAFW case" / Fatality	0	0	0
32	RATES	*LTI Frequency Rate (LTI FR)*	0	0	0
33		***Total Recordable Injury Rate (TRIR)***	0.03	0	0.03
34		*Severity Rate*	0	0	0
35		*Mean Duration*	0	0	0

Prepared by:

Checked by:

Approved by:

	TYPE	First Aid This period	First Aid To-date	Recordable This period	Recordable To-date
NATURE OF INJURY	Abrasion		3		
	Arc Eye				
	Asphyxiation				
	Blister				
	Burns				
	Contusion				
	Cut / wound				
	Dislocation				
	Electric shock				
	Foreign Body				
	Fracture				1
	Laceration		2		
	Puncture				
	Sprain / Strain				
	Concussion				
	Others				
	TOTAL		5		1
BODY PART AFFECTED	Ankle				
	Arm / Forearm		1		
	Back				
	Chest				
	Ear				
	Eye				
	Face				
	Finger		1		
	Foot		1		
	Groin				
	Hand				
	Head / Forehead				
	Internal Organs				
	Knee				
	Leg (Thigh / Calf)		1		
	Mouth		1		
	Neck				
	Shoulder				
	Skin				
	Torso				
	Wrist				
	Others				
	TOTAL		5		
[NA]TURE OF ILLNESS	Allergy				
	Avian Flu				
	Dermatitis				
	Frost Bite				
	Hearing Loss				
	Heat Stress		3		
	Malaria	1	2		
	Poisoning				
	Respiratory				

INCIDENT RATE CALCULATIONS:

32 LTI Frequency Rate (LTI FR): $\frac{\text{No. of Lost Time Injuries} \times 200{,}000}{\text{Total Man-hours Worked}}$ (Item 3)

33 Total Recordable Injury Rate (TRIR): $\frac{\text{Total Number of Recordable Cases} \times 200{,}000}{\text{Total Man-hours Worked}}$ (Items 3+4+5+6+7+8)

34 Severity Rate: $\frac{\text{Total Lost Man Days} \times 200{,}000}{\text{Total Man-hours Worked}}$ (Item 30)

Figure 9: Statistics report for project 1

APPENDIX 2: SAFETY OBSERVATION CARD


HSE OBSERVATION CARD

Observer's Information	Observation Details:
Name:	Date: 17/12/14
Badge: 72514	Time: 05:@ AM
Title: Safety officer.	Area: RMS-3
Company:	Location: B6-1008.

Category Mechanical.

☐ Unsafe Act ☐ Unsafe Condition ☑ Near Miss

☐ Positive Observation

Description of Observation

i found Grinding man Mr KAUSHAR ALI Badge No is 122377, his skin slightly heated up while warming their PPE by the help of heating touch, Luckily nothing could went harm to person.

Suggested Corrective Action

I immediately approached him and examined his hand for any burns. I found nothing. I reported to JP Mr Alam to have a hold on their crew.

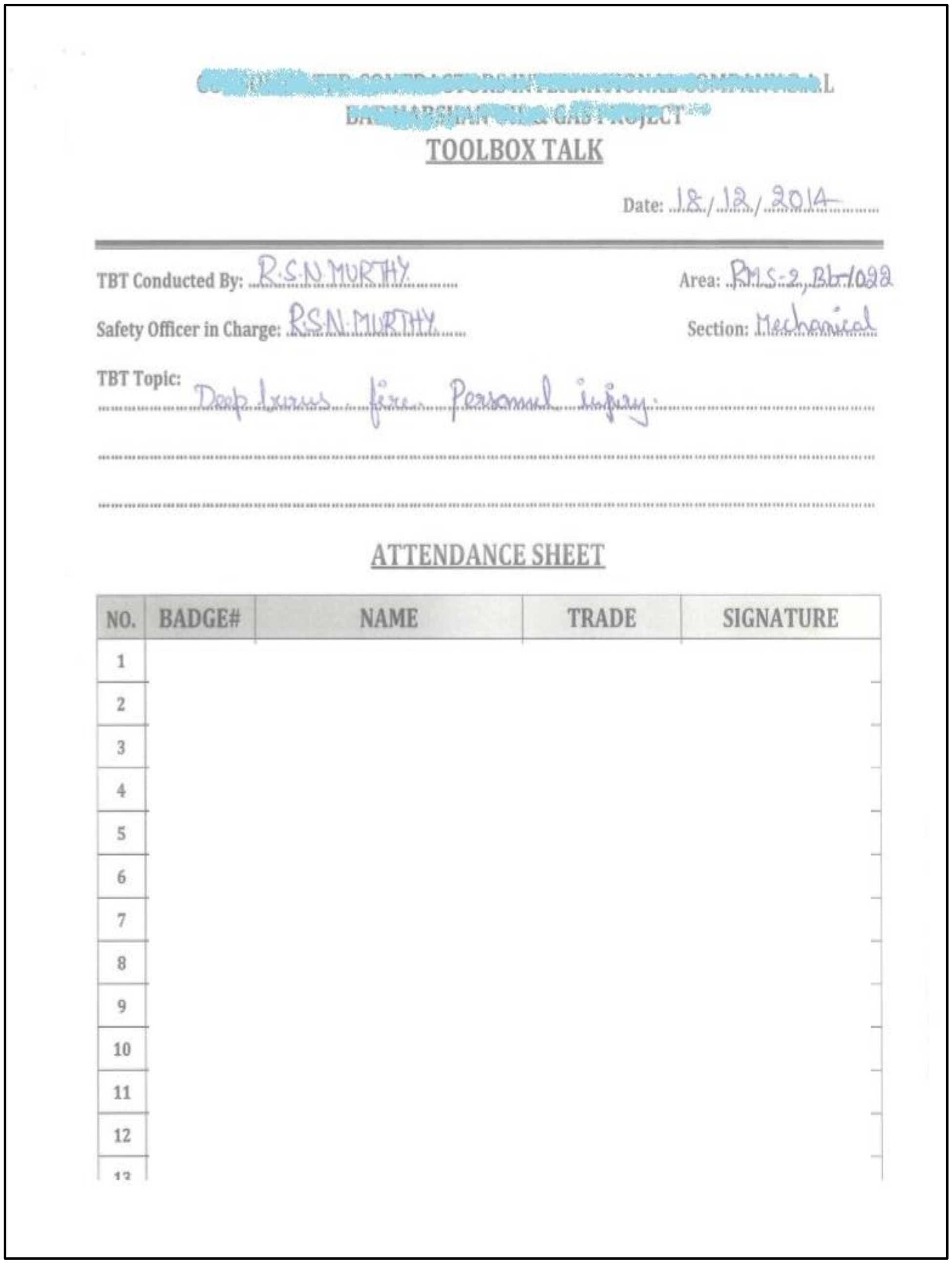
He strictly warned all workers to not to repeat such unsafe activity in future.

Status Observation

☐ Open Observation ☑ Closed Observation

Figure 10: HSE Observation Card for project 1

APPENDIX 3: TOOLBOX TALK



[redacted]L

BA[redacted] GAS PROJECT

TOOLBOX TALK

Date: 18/12/2014

TBT Conducted By: R.S.N MURTHY

Area: RMS-2, Bb-1022

Safety Officer in Charge: RSN MURTHY

Section: Mechanical

TBT Topic: Deep Issues fire Personnel injury

ATTENDANCE SHEET

NO.	BADGE#	NAME	TRADE	SIGNATURE
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				

Figure 11: Toolbox talk sheet for project 1

APPENDIX 4: SNA SURVEY

Preamble

❖ **Survey Goals**

The goal of the survey is to understand how individuals in your organization communicate on safety issues.

Moreover, the collected data from the survey will highlight potential hurdles preventing an effective safety performance within your organization and set a proper course of action to enhance it while analyzing safety processes.

❖ **Survey Sections**

The survey consists of 4 sections.

- Section 1 asks you to list the people with whom you interact (from within your organization) within the scope of your profession. For each person, a set of information is required regarding the interaction and information exchange occurring with this person. The names of the people, including yours, are confidential and will not be disclosed in any private or public analyses, and will be given alphanumeric codes (i.e., Name = A1 or B9…) for the mapping of the social network.
- Section 2 targets the nature of safety interaction with the assigned individuals.
- Section 3 looks at the extent of safety interaction.
- Section 4 addresses some safety processes held at your organization.

❖ **Your Consent**

I have read and I understand the preamble of this survey. I also understand that I will be required to provide my name and the names of the people I interact with, **which will not be published, but instead will be replaced by alphanumeric codes.**

Name & Contact (No. Or email): ---

Company's Name: ---

Department's Name: ---

General Information

Q1. How long have you worked for this firm?	Q2. How long have you worked in your current position?
☐ Less than 1 year ☐ 1 to 5 years ☐ 6 to 10 years ☐ 11 to 15 years ☐ 16 to 20 years ☐ more than 20 years	☐ Less than 1 year ☐ 1 to 5 years ☐ 6 to 10 years ☐ 11 to 15 years ☐ 16 to 20 years ☐ more than 20 years
Q3. Specify to which category you belong:	**Q4. What is your position on the project?**
☐ Veidekke employee ☐ Hired by Veidekke on temporary basis ☐ Subcontractor ☐ Hired by subcontractor	☐ Project planning manager ☐ Project manager ☐ Site manager ☐ Project engineer ☐ Safety supervisor ☐ Operational manager ☐ Foreman ☐ Supervisor of the craftsmen ☐ Skilled worker
Q5. Your experience in safety is:	**Q6. Do you work as safety supervisor?**
☐ None ☐ Less than 5 years ☐ 5 to 10 years ☐ 11 to 15 years ☐ 16 to 20 years ☐ More than 20 years	☐ Yes ☐ No ☐ Worked before

Safety Interaction Network

List 10 people with whom you interact about safety the most and specify how you communicate.

	Name	Department & Position	Hierarchical Level	Safety Information Exchange and % of Time	Safety Information Exchange Means and Respective Percentage	
Person 1			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 2			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 3			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 4			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 5			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 6			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 7			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 8			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 9			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%
Person 10			☐ Higher	☐ Receive From__%	☐ Face-to-face __%	☐ Emails__%
			☐ Same	☐ Provide To __%	☐ Meetings__%	☐ Green notes __%
			☐ Lower	☐ Both Ways (50-50)	☐ Telephone__%	☐ Other: __%

Nature of Safety Interaction

Please specify for what purpose you communicate on safety with the mentioned people, and specify how often each happens (circle a number for each entry that applies).

	Use of Information Exchanged *(1 is very rarely, 5 is very often)*				**When you communicate with this person, you:**
Person 1	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 2	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 3	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 4	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 5	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 6	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 7	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 8	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 9	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem
Person 10	☐Report safety issue	1 2 3 4 5	☐Solve safety issue	1 2 3 4 5	☐Take action directly
	☐Perform risk assessment	1 2 3 4 5	☐Send feedback on deviations	1 2 3 4 5	☐Trust them on the issue
	☐Perform safety checks	1 2 3 4 5	☐Safety inspection	1 2 3 4 5	☐Delay or transfer problem

Extent of Safety Interaction

Please specify the amount of time spent talking about safety and the frequency.

	Percentage of time communicating about ***safety*** problems		When do you talk about safety	
Person 1	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 2	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 3	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 4	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 5	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 6	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 7	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 8	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 9	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it
Person 10	☐0-20%	☐20-40%	☐ Every day	☐ Safety briefing before job
	☐40-60%	☐60-80%	☐ Before a meeting	☐ Safety training sessions
	☐80-100%	☐rarely	☐ During a meeting	☐ Only when you request it

Safety Processes

Q1. Out of all tasks assigned on your look-ahead schedule, specify the percentage of (i.e. how often the described process is done):

- Tasks that are checked for safety through risk assessment/hazard analysis/other tools before execution: ________ %
- Tasks that are checked for soundness before execution: ________ %
  (i.e. all prerequisites are available)

Q2. How often do you re-assess risks during task preparation, check all that apply:

☐ 5 weeks before

☐ 4-2 weeks before

☐ 1 week before

☐ 5-2 days before

☐ 1 day before

☐ Very rarely/never

Q3. How often do you notify others and deal with them on those risks (i.e. set risk management plans):

☐ 10% of the time

☐ 20-40% of the time

☐ 50% of the time

☐ 60-80% of the time

☐ All the time

☐ Very rarely/never

Q4. To what extent is data from deviation reporting (i.e. green notes) used in risk assessment:

☐ 10% of the time

☐ 20-40% of the time

☐ 50% of the time

☐ 60-80% of the time

☐ All the time

☐ Very rarely/never

Q5. If a safety accident happens, how much time does it take to implement precautions at the company to prevent its future recurrence?

☐ Few days

☐ Few weeks

☐ Few months

☐ At the end of the project

☐ Very rarely/never

☐ I don't know

Q6. When dealing with safety issues, rank your contacts from the most to the less reliable who you will ask for assistance?

- Person ___ (mostly reliable)
- Person ___
- Person ___
- Person ___
- Person ___
- Person ___
- Person ___
- Person ___
- Person ___
- Person ___ (less reliable)