January 2015

Leading Indicators of Safety in Nuclear Energy

Cameron Douglas Cowser
Eastern Kentucky University

Leading Indicators of Safety in Nuclear Energy

By

Cameron Cowser

Thesis Approved:

Chair, Advisory Committee

Member, Advisory Committee

Member, Advisory Committee

Dean, Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's of Science degree at Eastern Kentucky University, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made. Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in [his/her] absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature ____________________

Date 7-28-2015

Leading Indicators of Safety in Nuclear Energy

By

Cameron Cowser

Bachelor of Science,

Eastern Kentucky University

December, 2012

Submitted to the Faculty of the Graduate School of
Eastern Kentucky University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE,

August, 2015

DEDICATION

This thesis is dedicated to my parents, my fiancé, and to the memory of those who lost their lives during the Fukushima Daiichi accident.

ACKNOWLEDGMENTS

I would like to thank the members of the faculty who assisted me in earning my education, to Barry Spurlock for chairing my committee, to Sarah Morris for all her assistance, to Paul Grant for serving on my committee and serving as my mentor long beforehand.

ABSTRACT

The purpose of this research was to attempt to determine the key leading indicators of safety in the nuclear energy generation industry. A leading indicator is a metric of safety performance that is not dependent on trending injuries or incidents. This study was conducted by sending surveys to individuals working in the nuclear energy industry, and attempting to rate a set of indicators by their responses. This research was unsuccessful in empirical validation of any of the surveyed indicators, but does indicate that the concept is well known and accepted in the industry, and paves the way for a more in depth study in safety culture and systems in this highly specialized industry. Of the surveyed indicators, three seemed to have a more substantial impact than others according to feedback given. The three indicators are: maintenance of safety critical equipment, ease of use of technical manuals and guides, and relevance of employee training.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE PAGE

CHAPTER I

INTRODUCTION

As the demand for power from consumers grows higher and higher over the years, new forms of energy have been tapped to meet demand. One of those resources is nuclear energy generation. Nuclear energy has been powering America since 1973, and throughout the 40 years of operational service, it has proven to be a safe reliable method of generating power. One of the biggest issues holding back the continuing spread of nuclear energy is the publicity surrounding high impact low frequency disasters, like those at Three Mile Island, Chernobyl, and more recently the Fukushima incident in Japan.

The key distinguishing feature of leading indicators versus the more antiquated lagging lies in their relationship to the time of the incident. Leading indicators are viewed primarily as being preventative in nature, while lagging indicators happen after the incident (Reiman, 2012).While many different failures caused these incidents, the one to be explored in the following document is behavior based safety, and leading indicators of safety, and how they may be integrated into an industry in its renaissance (Fukushima, June 2012).

BACKGROUND

Atomic energy production relies on very complicated systems that, depending on the reactor, use heat generated from the reactor to produce steam, which turns a turbine and thus produces electricity. These systems are dependent on a complicated plethora of system safety controls for maximum stability. Undoubtedly, Fukushima, Three Mile Island, and Chernobyl emerge as some of the most startling examples of what can go wrong when strict adherence to a safety culture is faltered. However, these are but large examples of what can happen when small problems are misdiagnosed.

It is of no surprise that the nuclear industry is but one of many that are adopting leading indicators of safety in order to improve the reliability and fortitude of their safety climate. An indicator is defined as, “any measure- quantities or qualitative- that seeks to produce information on an issue of interest (Reiman, 2012).” However there is a distinctive need for knowing the difference between so called “leading” and “lagging” indicators. Reiman states that the difference between leading and lagging indicators can best be thought of by their relationship to the time of the incident. Leading indicators are viewed primarily as being preventative in nature, while lagging indicators happen after the incident (Reiman, 2012). Grabowski takes a view of leading indicators as the primary preventative countermeasure, and the best way to avoid future incidents (Grabowski, 2007).

Leading Indicators have long been accepted in the nuclear energy generation industry as useful, powerful, and privative tools. But the question remains, what are the key performance indicators of safety in this ever challenging industry?

Throughout the studies conducted on leading indicators, the clear focus seems to be that these measure need to be implemented on a much wider scale, and the nuclear industry is no exception as Martha Grabowski points out, “Some work has been done to identify predictive indicators for safety-critical systems such as nuclear power plants, but little work has been undertaken to empirically validate predictive leading indicators… (Grabowski, 2007).” The work referred to is a 2002 article entitled Safety Performance Measurement in Process Industries. The article is written by Lehtinenen and Walstrom and focuses on European, mostly Swiss and Finnish, organizations (Lehtinenen, 2002). During this study, the pair manages to identify 5 categories key indicators the individual plant (Lehtinenen, 2002). However, as Grabowski points out, these are not empirically validated. It is however shown that leading indicators of safety can be used a predictive tool in predicting incidents in the nuclear industry (Grabowski, 2007) (Lehtinenen, 2002) (Reiman, 2012). The aim of this study is apply known leading indicators from other industries that are analogous to the nuclear energy industry, and validate them into the Lehtinenen categories.

CHAPTER II

LITERATURE REVIEW

To being with, literature on the subject of nuclear energy in regards to occupational safety habits is scarce. As a result of this unfortunate shortage, most of the literature used to form this study is taken from analogous industries and general occupational safety and health.

The first key document used to understand the need of formal study in leading indicators in the nuclear energy generation field is a work by Harold Roland and Brian Moriarty entitled System Safety Engineering and Management. While this work bears very little direct relevance to the study at hand, it does provide a formal and technical background on the subject of systems safety. Perhaps the most pertinent section of the work in regards to this study is the section regarding preliminary hazard analysis, as well as the section on risk management.

Dan Peterson's book entitled: Measurement of Safety Performance proved absolutely vital to defining the concept of leading indicators, and perhaps even more important, describing their practical usage. Peterson identifies that measuring safety performance is "the industry's' most serious problem (Peterson, 2005). Peterson offers a book not about traditional methods of safety performance, but rather a discussion of their weaknesses and an offer of improvements.

Above all, Peterson establishes the need of forward looking measurements, focused on behaviors and prevention, as opposed to the traditional methods of tracking OSHA reportable incidences and injury rates (Peterson, 2005). Peterson establishes a clear difference between leading and lagging indicators by example. According to Peterson, some examples of leading metrics are those focus on: process hazard reviews, incident investigation, behavioral observation, safety audits, employee attitude surveys, training records, and measure of potential incidents (Peterson, 2005).

Another key work in any discussion of safety metrics is William Tarrants' The Measurement of Safety Performance. Tarrants work is in depths look into the necessity and evolution of safety measurement, and offers several keen insights into the importance of effective indicators. Tarrants offers by far one of the best discussions on the establishment of a workable data collection methodology for the safety professional, establishing the clear need to a concise feedback and updates (Tarrants, 1980). Tarrants also makes clear the relationship between the measure and the countermeasure, as well as the use of control groups. Tarrants work is a far reaching broad analysis of a plethora of safety systems concepts and fundamental skills and is a must read for any working safety professional.

The data collection methodology described by Tarrants is based on inferential statics and the scientific method (Tarrants, 1980). Tarrants lays out the five steps that are typically recognized by researchers in intelligent problem solving, which are analogous to the scientific method (Tarrants, 1980). The planning steps established by Tarrants provide a guide to laying down a foundation upon which a safety culture built on leading indicators can be built. Tarrrants expresses very clearly that the most important part of the procedure is the overall understanding of scientific problem solving (Tarrants, 1980). Using data analysis methodology, the safety program administrator has a chance to formulate productive and effective countermeasure through controlled experiments as opposed to simple trial and error tests based on accident or injury data, or pure speculation (Tarrants, 1980). Data collection is also expressed in terms of its usefulness to the operator (Tarrants, 1980). For example, a nuclear facility may collect a plethora of data regarding potential hazards, but if a data collection methodology or administrator cannot establish an organized manner of data collection, or a set of data, established with a control group, the methodology may be under-utilized, or not effective in the manner in which it was originally contrived to be (Tarrants, 1980)

Martha Gradowski, Premnath Ayyalasomayajula, Jason Merrick, John Harrald, Karlene Roberts combine their expertise to offer an excellent in depth analysis of leading indicators in virtual organizations. Grabowski outlines the article with the mission statement of any safety program, which is “to develop intervention strategies to avoid future accidents (Martha Grabowski, 2007).” Grabowski continues to outline the importance of leading measures, “recognizing signals before an accident occurs offers the potential for improving safety, and many organizations have sought to develop programs that identify and benefit from alerts, signals, and prior indicators (Martha Grabowski, 2007).”

Grabowski’s article is focused primarily on virtual organizations, defined as those which are “temporarily linked together for a competitive advantage.” Such organizations do not translate directly to nuclear energy facilities, however, the groundwork Grabowski ET. Al. establish for leading measures is invaluable to any industry.

Perhaps the greatest take away from Grabowski’s article is the definitions of leading and lagging indicators, as well as the comparison of their effectiveness. Grabowski cites the definition of leading indicators as follows:

> “Leading indicators, one type of accident precursor, are conditions, events or measures that precede an undesirable event and that have some value in predicting the arrival of the event, whether it is an accident, incident, near miss, or undesirable safety state. Leading Indicators, sometimes referred to as performance indicators, metrics or indices, are associated with proactive activities that identify hazards and assess, eliminate, minimize and control risk (International Standards Organization, 1999; International Atomic Energy Agency, 2000; Lehtinen and Wahlstrom, 2002).”

To further reinforce the time and place for leading indicators, Trond Kongsvik, Petter Almklov, and Jorn Fenstad discuss the effectiveness of indicators in general on organizational wide issues and safety climate. In the article, Kongsvik argues that while leading indicators are undoubtedly effective in preventing accidents and establishing effective safety measure, alone they lack the scope to be effective in establishing a safety climate (Trond Kongsvik, 2010).

Kongsvik argues that in addition to safety indicators to keep small unit level incidents low, risk analysis and safety climate are effective supplemental tools to ensure organization wide issues are captured (Trond Kongsvik, 2010). Kongsvik aims in the article to explore the relationship between the indicators of safety when they address organizational qualities and complex causal chains of events (Trond Kongsvik, 2010). This approach, the author argues, will prove much more effective when "the organizational error is root cause in a large scale accident where technical failure or simple human error cannot serve as explanation alone (Trond Kongsvik, 2010)." The type of organizational failure described by Kongsvik is eerily reminiscent of the Fukushima Daiichi catastrophe and the several organizational and systems level failures that led to such a failure.

The ANS committee delves into the incident with an in depth accident analysis, in an attempt to determine root cause. Through this analysis several key factors become apparent. The first discovery of importance was that all Japanese Nuclear Power Plants use seismic instrumentation systems, which are designed to immediately shut down the reactors in the event of an earthquake, and that during the earthquake, these systems functioned as designed (Fukushima, June 2012). The ANS also determined that the emergency power generation systems functioned as designed during the earthquake. However, the waves of the tsunami caused by the earthquake where much more detrimental to the facility (Fukushima, June 2012).

While the individual technical analysis of the reactors and their particular fail modes is undoubtedly useful in understanding the incident, for the purposes of this study, only a simplistic high level understanding is necessary. The ANS analysis revealed that while the earthquake was catastrophic, and one of the largest seen in recent Japanese history, all of the safety systems functioned as designed, and prevented catastrophic damage to the reactors from the earthquake (Fukushima, June 2012). However, the Tsunami provided circumstances that the safety systems of the facility were not designed to overcome.

System safety is undoubtedly vital in the nuclear power generation industry, and as such leading indicators that directly tie into systems safety will prove vital tools in both accident prevention, and hardware failure. Teemu Reiman, and Elina Pietikainen explore such a concept in their safety science article. Reiman maintains the standing approximate definition of a leading indicator as and a monitor or drive based indicator, versus a reactive lagging indicator (Teemu Reiman, 2012). Reiman also maintains the agreement that simply implicating a hardware failure on a systems level incident or human error on an accident is not sufficient. Reiman outlines two types of leading indicators that are applicable to systems safety.

The first of them is the drive indicators. The drive indicators are “measures of the fulfillment of the selected safety management activities (Teemu Reiman, 2012).” Reiman uses these drive indicators to directly implement control measures which are designed to reduce or change the unsafe activities. Drive indicators are most effective while being used to determine if hazard control and safety development are performing as needed (Teemu Reiman, 2012). Reiman states the importance of the feedback loop as demonstrated below:

In addition to the drive indicators, there are also monitor indicators. Monitor indicators are defined as, “those which reflect the potential and capacity of the organization to perform safely (Teemu Reiman, 2012).” These indicators are a way to monitor not only the effectiveness of the drive indicators, and the controls that have been implemented as a result of them, but also seek to measure the internal dynamics of the safety system, and provide feedback as to the performance of that system (Teemu Reiman, 2012). Reiman also clearly outlines the need for these indicators to monitor factors that are outside of the organization’s control, for example new legislative and regulatory demands, that may affect the operations of the facility and the sociotechnical safety system.

CHAPTER III

METHODOLOGY

The methodology of this study centers around a 2002 study conducted by Lehtinen and Walstrom which centered around identifying key leading indicators in Swiss and Finnish nuclear power facilities (E. Lehtinen, 2002). In this study, 5 categories are established that can be used as a framework to establish specific and realistic leading indicators of safety for practical use by nuclear energy facilities. Using the framework of the Lehtinen study, a survey was conducted using key indicators taken from other analogous industries, and participants were asked to rate their agreement each individual indicator. This survey consisted of 27 indicators taken from a wide variety of sources.

The primary source for the indicators surveyed was process safety management, as it demonstrates several analogous qualities to the nuclear industry, such as the specificity of tasks, and the precision required of engineering personnel in a low frequency high risk environment (Teemu Reiman, 2012). While these leading indicators will certainly not encompass the complex and ever evolving need of the nuclear energy field, the aim of this study is merely to pilot leading indicators in a severely under research field. The survey sent to participants includes a list of 18 indicators and is anonymous. The survey was distributed using a "snowball" method consisting of sending the survey out to 30 initial contacts, and including the instructions to forward the survey to applicable participants that they may know. The 30 initial contact were obtained through research into various plants located across North America, and contacts were selected on the basis of available contact information, and employment in the nuclear energy generation field.

Ideally, participants would be selected on the basis of experience in the safety field as it pertains to nuclear energy as opposed to the nuclear industry in general, but given the difficulty in obtain such contacts without prior familiarity with such individuals is difficult. The snowball method was chosen as a means to pilot a wide range of participants in the industry and attempt to gather data from a representative sample. The questions were selected by perusing the available literature and either using examples given in the literature or formulating indicators based on the common themes of the literature. Many of the indicators used were sampled from literature based on process safety and systems safety backgrounds. These areas where chosen due their analogous nature with the nuclear industry in both complexity, and specificity of task (Fukushima, June 2012) (Harold Roland, 1990) (Martha Grabowski, 2007) (E. Lehtinen, 2002).

RESEARCH

The purpose of this study is to assist professionals working in the nuclear energy generation industry in creating indicators with which to measure their facility's safety performance.

The initial goal of the study was to identify and validate a group of 3-7 indicators which could be clearly identified as the key leading indicators of safety for this industry. However, due to a small sample size, and minimal variance amongst the responses to the surveyed indicators, this goal was not achieved.

What was achieved however, was a pilot study that offers a rare glimpse into the safety culture of a severely under researched industry. It is highly recommended that this study be repeated under more expansive circumstances by a researcher or research team with more access to those involved in the industry.

CHAPTER IV

RESULTS

Survey participants where asked about 18 different leading measures taken primarily from the process safety industry, and applied to the Lehtinen categories. Participants were asked to rate their agreement using a 1-5 scale ranging from “strongly agree” to “strongly disagree.” Each question also included a provisional “additional comments” are where the participant could elaborate on a particular response if desired. The survey was distributed using a “snowball” method in which the initial invitations where sent out to 30 individuals with a request to forward the survey to whoever they feel may be qualified to participate. There was a preliminary question asked regard the potential participant’s involvement in the industry. If it was determined the subject did not work in the nuclear energy industry, they were not allowed to submit responses to the survey questions.

The following leading indicators were chosen for this study:

1.Management Commitment to safety.

2.Management accountability.

3.Employee engagement in safety.

4. Relevance of employee training (I.E. the employee learned new skills, or reinforced established skills used in the employee's position).

5. Frequency of employee training.

6. Frequent review and update of safety programs.

7. Effective Management of Change practices.

8. Frequent update and review of employee training materials.

9. Ease of use of technical manuals and guides.

10. Effectiveness of system safety management systems (FTA, FEMA, MORT).

11. Follow up on safety action items.

12. Inspections of safety critical plant items and equipment.
13. Auditing of safety systems.
14. Fatigue Risk education.
15. Maintenance rate of safety critical systems.
16. Control Loop Performance.
17. Alarm Management.
18. Deviations from standard operation.

The overall response rate to the survey was disappointingly low. Out of the 30 initial surveys sent out, only 6 were returned complete. However responses from the 6 were very concise and many offered insightful feedback on safety culture and leading indicators in the nuclear industry (Table 1).

Table 1

Survey response data

Indicator	Average
Management commitment to safety	4.3
Management accountability	4.3
Employee engagement in safety	4
Relevance of employee training	4.3
Frequency of employee training	4.3
Frequent review and update of safety programs	4.1
Effective management of change practices	4
Frequent update and review of employee training materials	4.3
Ease of use of technical manuals and guides	3.8
Effectiveness of system safety management systems	4.3
Follow up on safety action items	4.6
Inspections of safety critical plant items and equipment	4.5
Auditing of safety systems	4.3
Fatigue risk education	3.5
Maintenance rate of safety critical systems	4.3
Control loop performance	4
Alarm management	4
Deviations from standard operation	4.3

There are several recurring themes that participants repeatedly mentioned. And as a whole, safety is a clear priority in all of the respondent's minds. Safety governs the mindset of the operators in every action they take. There is a recurring mention of a "Safety Conscious work Environment" or "SCWE." Safety Conscious Work Environment is an example of organizational wide safety system that is involved in training, monitoring, and operations level actions taken at the facility. This type of organizational safety system which promotes a culture of safety consciousness would be able to greatly bolster an advantage through the implementation of leading measures.

It is important to note that through the comments of the survey several key recurring themes where identified. The first that is made very clear is that the nuclear industry is undoubtedly very highly regulated in the United States. There are wide varieties of governing agencies mentioned in the comments ranging from the NRC (Nuclear Regulatory Commission) to INPO (Institute of Nuclear Power Operations). These agencies are responsible for regulating safety concerns in the industry, and as such have touched everything from training, to equipment specifications to be used in U.S. plants. The survey revealed that these agencies even require the sites to demonstrate that they are capable of reporting an incident in a timely manner every fiscal quarter.

The second key theme revolves around the need for constantly improving training. This is another aspect of the industry that is heavily touched by regulating bodies. INPO and the NRC both regulate continuing education and licensing program for reactor operators and other key operational personnel. There is also mention of a concept known as "Just in Time Training." This process is described by the respondent as basing training evolutions on the current and most prevalent risk factors, and is used to ensure that the team can perform the task in the event of an emergency. Training materials are reviewed both prior to and post training to ensure that the training is applicable, strong, and is as up to date as it can be. It would seem that overall the nuclear industry is much attuned to the "Kaizen" mentality and is always seeking improvement. The respondents also mentioned a fear of complacency, further reinforcing the idea of continuous improvement, with one respondent saying, “it is easy to become complacent if the system works well, but then you are missing out on continuous improvements.”

The third major recurring theme is the familiarity with safety systems, and safety culture. Respondents mentioned a Safety Conscious Work Environment or SCWE several times in the survey. This would be an example of a safety system, which engages the employees and their systems into one harmonious culture designed around safe practices. SCWE encompasses training, maintenance of equipment, monitoring of safety critical systems, and management accountability. One response stated that SCWE was so ingrained into the culture of the facility, that it encompassed every action taken in the facility.

The responses are quite uniform to almost every indicator surveyed. This is likely due to the extremely small sample size, and the small likelihood of safety professionals being the ones actually taking the survey. Due to the nature of the respondents and the responses, nothing of statistical significance can be drawn from this research.

LIMITATIONS

The response rate to the previously mentioned survey was surprisingly small, although a number of factors may explain this. The first is that the nuclear industry is one that is under constant scrutiny from the public eye, and as a result many of the professionals surveyed may not have felt comfortable revealing such in depth information of the safety culture of their industry or facility. Another possible explanation for the low response rate is the level of secrecy, and perhaps questions, regarding the employee’s ability to respond to the survey in accordance with plant or company level non-disclosure agreements. Secrecy in the nuclear power generation industry is undoubtedly related to the security measures need to insure the safety of personnel working at these facilities from items such as terrorist attacks, cyber security threats, and an ever changing list of external hazards. The survey returned a small sample size of 6 individual completed surveys. This is not adequate enough of a sample size to fully empirically validate any indicator with the nuclear industry, and is not a representative sample of the industry.

Furthermore, the survey questions ask about the participant's background in the nuclear industry, but make no mention of experience in a safety management type of role. This was done in order to allow a larger sample size, and to maintain a representative sample of operators, managers, and other individuals who, in addition to the safety program manager, would have direct responsibility in organization level safety issues.

Another limitation is the geographical density of the survey respondents. All of the survey responses indicated they were located in the state of South Carolina. While this may seem insignificant, as the ANS points out, geographic placement of nuclear power plants has a huge effect on hazard analysis (Fukushima, June 2012). Perhaps a plant located in a more seismically active area, or one located in an area with very little water to support cooling would have rated risk analysis based questions much higher. This would also strongly indicate that all of the respondents are employed at a single plant, further narrowing a study meant to be representative of a large population. In addition to not being representative simply due to population, but also that this sample size may also not be representative due to the safety culture of a single area or plant. For example, nuclear facilities are under much more regulation and scrutiny in the United States as opposed to Japan (Fukushima, June 2012). This is primarily been attributed to the memory of the Three Mile Island incident still affecting the public, and therefore regulatory, view of the industry (Fukushima, June 2012).

The final primary weakness of this study is that the indicators are taken from an analysis of analogous industries and not from field research within a nuclear facility. While these indicators are mostly general, and could be applied to any task specific organization, they certainly may not represent the day to day safety struggles of a nuclear energy facility.

However, I do believe that the responses submitted, while low in number, provide a rare glimpse into the safety culture of the nuclear power industry. It is important to note however, that the respondents were not asked if they are safety professionals, and as a result, it is safe to assume that the majority of them are not. Perhaps another limitation to the study is the fact that many of the respondents may have been confused as to what exactly a leading indicator was, seeing as many where likely not safety professionals. Regardless, the insight of the operators and technicians is equally important in regards to gauging both the effectiveness of an indicator, as well as the overall safety climate of an institution. Nearly every candidate agrees strongly with the listed indicators, and even more importantly provided feedback in the form of open comments related to the individual indicators.

CHAPTER V

DISCUSSION

As the literature indicates, there is a strong current pushing the direction of safety management away from previously accepted lagging indicators (Tarrants, 1980). Leading indicators are not only more effective at accident prevention, but they also demonstrate system wide, and organizational issues if utilized in the proper way (Teemu Reiman, 2012). Leading indicators are also a better source of usable and actionable data, primarily due to the fact that an update of the data set can be performed at any time, without requiring someone to be injured (Trond Kongsvik, 2010).

The literature also indicates the need for a diverse array of leading indicators designed to measure all of the necessary aspects of a sociotechnical safety system (Teemu Reiman, 2012). The indicators surveyed where collected primarily from Process Safety related articles due to the somewhat analogous nature of the two industries in specificity of task, and the high impact low frequency failure, and also due to the lack of research into the nuclear industry on the matter of accident prevention measures. It is important to note that all in all, as the ANS points out, the North American nuclear industry is a very safe one, with several decades passing from the last major incident, and low rates of workplace injury or illness (Fukushima, June 2012). However this does not diminish the need to establishing an effective set of leading indicators which can be used by safety professionals to establish countermeasure to potential failures.

In recent years, the safety management profession has evolved substantially. New measure and countermeasures, as well as a greater focus on proactive prevention and improved data collection techniques, have created great strides in workplace safety (Peterson, 2005). Leading indicators have arisen as one of the most useful and consistently proactive tools the safety professional can have in their repertoire (Martha Grabowski, 2007).

Leading indicators are defined as those which: "…are associated with proactive activities that identify hazards and assess, eliminate, minimize and control risk (International Standards Organization, 1999; International Atomic Energy Agency, 2000; Lehtinen and Wahlstrom, 2002)."Found this in the Grabowski article, do I cite the whole deal or just Grabowski? Lagging indicators by contrast, rely on tracking previous attained data, such as accidents, or near misses, and then adjusting systems or behaviors as needed (Martha Grabowski, 2007).

The primary strength of leading indicators in general, is that they are a stronger representative of the organization's safety culture and performance (Martha Grabowski, 2007). Leading indicators, by definition focus on the behaviors and key organizational factors that directly impact the likely hood of an accident or incident (Teemu Reiman, 2012). The nature of leading indicators means that the safety system manager can obtain information that is both accurate and up to date, and does not require accidents or incidents to happen before measurement can be taken (Peterson, 2005). The use of leading indicators also enables a more effective feedback loop (Figure 1) to be formed, which will aid the safety program administrator in keeping the system dynamic.

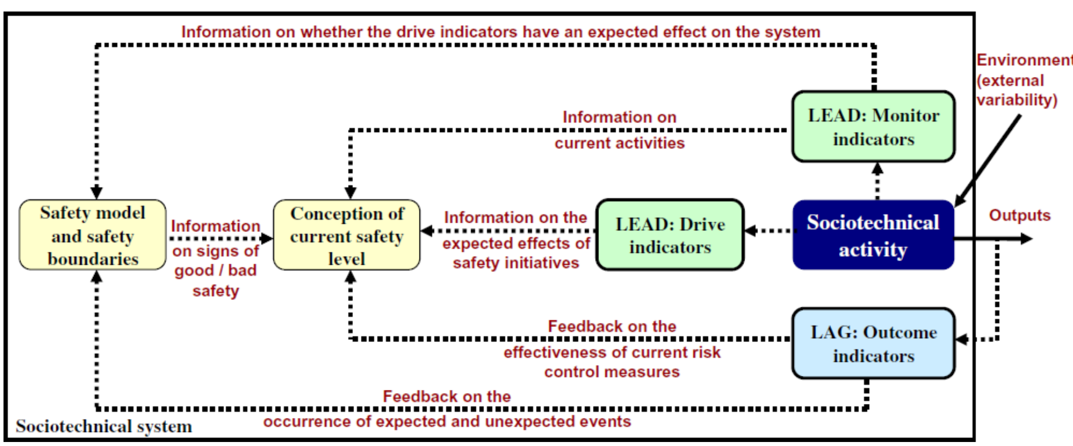

Figure 1 Feedback loop of Drive Indicators

Source: Teemu Reiman, E. P. (2012). Leading Indicators of System Safety-Monitoring and Driving the Organizational Safety Potential. Safety Science, 1993-2000.

Lagging indicators by their nature can be very deceptive. For example, and organization that has not seen an accident in an extended period of time, may or may not be any more effective in preventing accidents than other organizations (Martha Grabowski, 2007). This is because it is entirely possible for an accident not to happen, simply because it does not happen. Essentially, chance is a factor in workplace accidents, one organization may just get lucky, and as a result relax or under-observe certain safety counter measures, resulting in a detriment to the overall safety culture of the organization (Trond Kongsvik, 2010) (Teemu Reiman, 2012) (Martha Grabowski, 2007). Peterson uses the example of a supervisor, who has ten employees and retains and zero incident rate for a year with no action, just a bit of luck; this is simply unacceptable in industries where one failure can have catastrophic consequences (Peterson, 2005). Peterson continues on to describe in detail the failing of lagging indicators: they don't assess whether systems are better or worse than others, they are not diagnostic, they do not offer any insight as to corrective action, and that they have very little statistical validity in smaller groups (Peterson, 2005)

Lagging indicators are also much more limited in scope that leading indicators (Teemu Reiman, 2012). Monitoring injury rates may show partial effectiveness in prevented strains, sprains , and foreign objects to the eye, but they lack effectiveness in gauging the overall effectiveness of the safety program, and the organizational safety culture (Harold Roland, 1990) (Martha Grabowski, 2007) (Teemu Reiman, 2012) (Trond Kongsvik, 2010) (E. Lehtinen, 2002). As outcome indicators, they also much go must longer without being updated, due to the fact that an incident must first happen before data can be recorded (Teemu Reiman, 2012) (E. Lehtinen, 2002). Some argue that lagging indicators are to be used in conjunction with leading indicators to better construct s safety system that monitors all areas of effective data (Teemu Reiman, 2012). While this may be true, it does not discount the superiority of the information granted from leading indicators, and the proactive nature of safety systems based on leading indicators (Teemu Reiman, 2012) (Trond Kongsvik, 2010) (Tarrants, 1980).

The nuclear industry faces a few unique challenges due to the nature and high visibility of failures (Fukushima, June 2012) (E. Lehtinen, 2002). While leading indicators may be not the key to preventing a reactor from meltdown, they do aim to identify and create countermeasures to ground level or organizational safety issues, which may prevent the human or equipment failure leading to a larger incident (Fukushima, June 2012) (Harold Roland, 1990) (Martha Grabowski, 2007) (Trond Kongsvik, 2010) (E. Lehtinen, 2002). The nuclear industry in the United States is amongst the safest in the world, due to responsible regulations and a culture that promotes effective internal communication and constantly updated training (Fukushima, June 2012) (E. Lehtinen, 2002). As previously stated, a good safety record is no excuse for complacency, as the recent Fukushima Daiichi incident shows (Fukushima, June 2012). This is why the identification and usage of leading indicators in the nuclear industry is vital (E. Lehtinen, 2002).

Wahlstrom and Lehtinen argue that what is not measured cannot be managed, and that in order to be effective, management goals must be tied to operations in a synchronous manner (E. Lehtinen, 2002). Lehtinen and Walhstrom demonstrate that the industry has already adopted a desire for such measures in areas such as finance, and argue that the incorporation of leading measures into the everyday safety management program will prove highly effective. The argument is also made that the lower the organizational level, the higher the need for motivational means other than financial gain (E. Lehtinen, 2002).

Lehtinen offers a firm warning regarding the use of both qualitative and quantitative indicators in order to achieve safety goals. Many leading measure are by nature, qualitative, and can be difficult to measure as a result (E. Lehtinen, 2002) (Harold Roland, 1990) (Teemu Reiman, 2012). This means that the indicator and its data collection mechanism must be very carefully scrutinized and monitored to see if it must be revised (Trond Kongsvik, 2010) (Martha Grabowski, 2007) (E. Lehtinen, 2002). Lagging indicators, inversely, tend to be mostly quantitative in nature, and therefore may be easier to measure at first glance (E. Lehtinen, 2002). The issue with the duality of the two indicators is that many times, a safety system will end up measuring the wrong areas, simply because they are easier to measure (E. Lehtinen, 2002).

In addition to having the right indicators, one must also have the right means to measure them with. This is where a practical workable data collection methodology becomes absolutely vital (Tarrants, 1980) (E. Lehtinen, 2002) (Martha Grabowski, 2007). The data collection methodology described by Tarrants is based on inferential statics and the scientific method (Tarrants, 1980).

There are five steps that are typically recognized by researchers in intelligent problem solving, which are analogous to the scientific method (Tarrants, 1980). The planning steps provide a guide to laying down a foundation upon which a safety culture built on leading indicators can be built (Tarrants, 1980). Tarrrants expresses very clearly that the most important part of the procedure is the overall understanding of scientific problem solving (Tarrants, 1980). Using data analysis methodology, the safety program administrator has a chance to formulate productive and effective countermeasure through controlled experiments as opposed to simple trial and error tests based on accident or injury data, or pure speculation (Tarrants, 1980). Data collection is also expressed in terms of its usefulness to the operator (Tarrants, 1980) (E. Lehtinen, 2002) (Martha Grabowski, 2007). For example, a nuclear facility may collect a plethora of data regarding potential hazards, but if a data collection methodology or administrator cannot establish an organized manner of data collection, or a set of data, established with a control group, the methodology may be under-utilized, or not effective in the manner in which it was originally contrived to be (Tarrants, 1980) (E. Lehtinen, 2002) (Teemu Reiman, 2012).

Nuclear facilities are operated, generally speaking, in a very organized and methodical manner, due to the highly technical and sensitive nature of the processes involved (Fukushima, June 2012) (E. Lehtinen, 2002). This complicates the process of identifying and validating any kind of low level measures, due primarily to the fact that each and every plant is different, and that certain factors affect the general concerns of one facility over another. Regardless, the general safety science community is rapidly embracing leading measures, and the nuclear industry has no reason to fall behind. Recent history has shown that complacency can lead to failure, and that remaining vigilant is a must for the industry (Fukushima, June 2012).

Risk management is something that must indubitably be intertwined with any kind of effective safety management system (E. Lehtinen, 2002) (Peterson, 2005) (Teemu Reiman, 2012). Risk management by definition extends a company protection from all possible risks (E. Lehtinen, 2002). This includes damage to the environment and the community, as well as damages to the overall directive of the business (E. Lehtinen, 2002). Risk management is absolutely vital to preventing incidents in the nuclear industry (Fukushima, June 2012) (E. Lehtinen, 2002), and something can be monitored using leading measures (Martha Grabowski, 2007) (Teemu Reiman, 2012).

Risk management covers a vast majority of the external factors that could potentially lead to accidents and incidents, such as location of the facility itself (E. Lehtinen, 2002) (Fukushima, June 2012). It was determined that the primary issue that caused the failure of the spent fuel pools was an under designed flood line, and no protection from flooding was provided to the batteries that powered the cooling systems of the reactors (Fukushima, June 2012).

Another key concept necessary to consider when contemplating indicators for nuclear power facilities is the concept of defense in depth (E. Lehtinen, 2002) (Fukushima, June 2012). Defense in depth is a systems safety measure that consists of three primary principal actions. The first of which is keeping the reactors fuel cool, the second is confining the radioactive material, and the third is managing reactor power (E. Lehtinen, 2002). While highly regarded as an effective countermeasure in the nuclear industry, it is still predominantly a reactive measure.

REFERENCES

E. Lehtinen, B. W. (2002). Safety Performance Measurement in Process Industries. *Technical Research Center of Finland VIT Industrial Systems*.

Fukushima, T. A. (June 2012). *Fukushima Daiichi: ANS Committee Report.* The American Nuclear Society.

Harold Roland, B. M. (1990). *System Safety Engineering and Management.* New York: Wiley-Interscience.

Martha Grabowski, P. A. (2007). Leading Indicators of Safety in Vitrtual Organizations. *Safety Science*, 1013-1043.

Peterson, D. (2005). *Measurement of Safety Performance.* Des Plaines: American Society of Safety Engineers.

Tarrants, W. (1980). *The Measurement of Safety Performance.* Park Ridge: American Society of Safety Engineers.

Teemu Reiman, E. P. (2012). Leading Indicators of System Safety-Monitoring and Driving the Organizational Safety Potential. *Safety Science*, 1993-2000.

Trond Kongsvik, P. A. (2010). Organisational Safety Indicators: Some Conceptual Considerations and a Supplementary Qualitative Approach. *Safety Science*, 1402-1411.

APPENDIX A:

Survey

In which country do you reside?

- Afghanistan (1)
- Albania (2)
- Algeria (3)
- Andorra (4)
- Angola (5)
- Antigua and Barbuda (6)
- Argentina (7)
- Armenia (8)
- Australia (9)
- Austria (10)
- Azerbaijan (11)
- Bahamas (12)
- Bahrain (13)
- Bangladesh (14)
- Barbados (15)
- Belarus (16)
- Belgium (17)
- Belize (18)
- Benin (19)
- Bhutan (20)
- Bolivia (21)
- Bosnia and Herzegovina (22)
- Botswana (23)
- Brazil (24)
- Brunei Darussalam (25)
- Bulgaria (26)
- Burkina Faso (27)
- Burundi (28)
- Cambodia (29)
- Cameroon (30)
- Canada (31)
- Cape Verde (32)
- Central African Republic (33)
- Chad (34)
- Chile (35)
- China (36)
- Colombia (37)
- Comoros (38)
- Congo, Republic of the... (39)

- Costa Rica (40)
- Côte d'Ivoire (41)
- Croatia (42)
- Cuba (43)
- Cyprus (44)
- Czech Republic (45)
- Democratic People's Republic of Korea (46)
- Democratic Republic of the Congo (47)
- Denmark (48)
- Djibouti (49)
- Dominica (50)
- Dominican Republic (51)
- Ecuador (52)
- Egypt (53)
- El Salvador (54)
- Equatorial Guinea (55)
- Eritrea (56)
- Estonia (57)
- Ethiopia (58)
- Fiji (59)
- Finland (60)
- France (61)
- Gabon (62)
- Gambia (63)
- Georgia (64)
- Germany (65)
- Ghana (66)
- Greece (67)
- Grenada (68)
- Guatemala (69)
- Guinea (70)
- Guinea-Bissau (71)
- Guyana (72)
- Haiti (73)
- Honduras (74)
- Hong Kong (S.A.R.) (75)
- Hungary (76)
- Iceland (77)
- India (78)
- Indonesia (79)
- Iran, Islamic Republic of... (80)

- Iraq (81)
- Ireland (82)
- Israel (83)
- Italy (84)
- Jamaica (85)
- Japan (86)
- Jordan (87)
- Kazakhstan (88)
- Kenya (89)
- Kiribati (90)
- Kuwait (91)
- Kyrgyzstan (92)
- Lao People's Democratic Republic (93)
- Latvia (94)
- Lebanon (95)
- Lesotho (96)
- Liberia (97)
- Libyan Arab Jamahiriya (98)
- Liechtenstein (99)
- Lithuania (100)
- Luxembourg (101)
- Madagascar (102)
- Malawi (103)
- Malaysia (104)
- Maldives (105)
- Mali (106)
- Malta (107)
- Marshall Islands (108)
- Mauritania (109)
- Mauritius (110)
- Mexico (111)
- Micronesia, Federated States of... (112)
- Monaco (113)
- Mongolia (114)
- Montenegro (115)
- Morocco (116)
- Mozambique (117)
- Myanmar (118)
- Namibia (119)
- Nauru (120)
- Nepal (121)

- Netherlands (122)
- New Zealand (123)
- Nicaragua (124)
- Niger (125)
- Nigeria (126)
- Norway (127)
- Oman (128)
- Pakistan (129)
- Palau (130)
- Panama (131)
- Papua New Guinea (132)
- Paraguay (133)
- Peru (134)
- Philippines (135)
- Poland (136)
- Portugal (137)
- Qatar (138)
- Republic of Korea (139)
- Republic of Moldova (140)
- Romania (141)
- Russian Federation (142)
- Rwanda (143)
- Saint Kitts and Nevis (144)
- Saint Lucia (145)
- Saint Vincent and the Grenadines (146)
- Samoa (147)
- San Marino (148)
- Sao Tome and Principe (149)
- Saudi Arabia (150)
- Senegal (151)
- Serbia (152)
- Seychelles (153)
- Sierra Leone (154)
- Singapore (155)
- Slovakia (156)
- Slovenia (157)
- Solomon Islands (158)
- Somalia (159)
- South Africa (160)
- Spain (161)
- Sri Lanka (162)

- Sudan (163)
- Suriname (164)
- Swaziland (165)
- Sweden (166)
- Switzerland (167)
- Syrian Arab Republic (168)
- Tajikistan (169)
- Thailand (170)
- The former Yugoslav Republic of Macedonia (171)
- Timor-Leste (172)
- Togo (173)
- Tonga (174)
- Trinidad and Tobago (175)
- Tunisia (176)
- Turkey (177)
- Turkmenistan (178)
- Tuvalu (179)
- Uganda (180)
- Ukraine (181)
- United Arab Emirates (182)
- United Kingdom of Great Britain and Northern Ireland (183)
- United Republic of Tanzania (184)
- United States of America (185)
- Uruguay (186)
- Uzbekistan (187)
- Vanuatu (188)
- Venezuela, Bolivarian Republic of... (189)
- Viet Nam (190)
- Yemen (191)
- Zambia (192)
- Zimbabwe (193)

In what state do you currently reside?

- ❍ Alabama (1)
- ❍ Arizona (2)
- ❍ Arkansas (3)
- ❍ California (4)
- ❍ Colorado (5)
- ❍ Connecticut (6)
- ❍ Delaware (7)
- ❍ District of Columbia (8)
- ❍ Florida (9)
- ❍ Georgia (10)
- ❍ Idaho (11)
- ❍ Illinois (12)
- ❍ Indiana (13)
- ❍ Iowa (14)
- ❍ Kansas (15)
- ❍ Kentucky (16)
- ❍ Louisiana (17)
- ❍ Maine (18)
- ❍ Maryland (19)
- ❍ Massachusetts (20)
- ❍ Michigan (21)
- ❍ Minnesota (22)
- ❍ Mississippi (23)
- ❍ Missouri (24)
- ❍ Montana (25)
- ❍ Nebraska (26)
- ❍ Nevada (27)
- ❍ New Hampshire (28)
- ❍ New Jersey (29)
- ❍ New Mexico (30)
- ❍ New York (31)
- ❍ North Carolina (32)
- ❍ North Dakota (33)
- ❍ Ohio (34)
- ❍ Oklahoma (35)
- ❍ Oregon (36)
- ❍ Pennsylvania (37)
- ❍ Rhode Island (38)
- ❍ South Carolina (39)

- South Dakota (40)
- Tennessee (41)
- Texas (42)
- Utah (43)
- Vermont (44)
- Virginia (45)
- Washington (46)
- West Virginia (47)
- Wisconsin (48)
- Wyoming (49)
- Puerto Rico (50)
- Alaska (51)
- Hawaii (52)
- I do not reside in the United States (53)

Do you currently, or have you previously worked in the Nuclear Energy Generation Industry?

- Yes (1)
- No (2)

Please rate your agreement with the following statement: Management Commitment to safety is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Management accountability is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Employee engagement in safety is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Relevance of employee training (I.E. the employee learned new skills, or reinforced established skills used in the employee's position) is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Frequency of employee training is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Frequent review and update of safety programs is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Effective Management of Change practices are a key leading indicator in the Nuclear Energy Generation Industry.

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Frequent update and review of employee training materials is a key leading indicator in the Nuclear Energy Generation Industry.

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Ease of use of technical manuals and guides is a key leading indicator in the Nuclear Energy Generation Industry.

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Effectiveness of system safety management systems (FTA, FEMA, MORT) is a key leading indicator in the Nuclear Energy Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following Statement:Follow up on safety action items is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Inspections of safety critical plant items and equipment is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Auditing of safety systems is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Fatigue Risk education is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Maintenance rate of safety critical systems is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Control Loop Performance is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Alarm Management is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments:

Please rate your agreement with the following statement:Deviations from standard operation is a key leading indicator in the Nuclear Energy Generation Industry.

- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Additional Comments: