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DEVELOPMENT AND APPLICATION OF THE SAFE PERFORMANCE INDEX AS A RISK-BASED METHODOLOGY FOR IDENTIFYING MAJOR HAZARD-RELATED SAFETY ISSUES IN UNDERGROUND COAL MINES

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ABSTRACT

The underground coal mining industry has been under constant watch due to the high risk involved in its activities, and scrutiny increased because of the disasters that occurred in 2006-07. In the aftermath of the incidents, the U.S. Congress passed the Mine Improvement and New Emergency Response Act of 2006 (MINER Act), which strengthened the existing regulations and mandated new laws to address the various issues related to a safe working environment in the mines. Risk analysis in any form should be done on a regular basis to tackle the possibility of unwanted major hazard-related events such as explosions, outbursts, airbursts, inundations, spontaneous combustion, and roof fall instabilities. One of the responses by the Mine Safety and Health Administration (MSHA) in 2007 involved a new pattern of violations (POV) process to target mines with a poor safety performance, specifically to improve their safety. However, the 2010 disaster (worst in 40 years) gave an impression that the collective effort of the industry, federal/state agencies, and researchers to achieve the goal of zero fatalities and serious injuries has gone awry.

The Safe Performance Index (SPI) methodology developed in this research is a straight-forward, effective, transparent, and reproducible approach that can help in identifying and addressing some of the existing issues while targeting (poor safety performance) mines which need help. It combines three injury and three citation measures that are scaled to have an equal mean (5.0) in a balanced way with proportionate weighting factors (0.05, 0.15, 0.30) and overall normalizing factor (15) into a mine safety performance evaluation tool. It can be used to assess the relative safety-related risk of mines, including by mine-size category.

Using 2008 and 2009 data, comparisons were made of SPI-associated, normalized safety performance measures across mine-size categories, with emphasis on small-mine safety performance as compared to large- and medium-sized mines. The accident rates (NDL IR, NFDL

IR, SM/100) of very small and small mines in 2008 and 2009 were less than those of medium and large mines. The data indicates a heavy occurrence of very severe injuries in a number of very small and small mines.

In another application which is a part of this research, the six normalized safety measures and the SPI are used to evaluate the risk that existed at mines in the two years preceding the occurrence of a fatality. This mine safety performance tracking method could have been helpful to the companies, state agency, or MSHA in recognizing and addressing emerging problems with actions that may have been able to prevent high-risk conditions, the fatality, and/or other serious injuries. The approach would have given scrutiny to the risk of mines that encompassed 74% of the fatalities during 2007-2010.

In order to assess the SPI as a comparable risk measurement tool, a traditional risk approach is also developed using data embracing frequency and severity in the final equation to analyze the relative risk for all underground coal mines for the years 2007–2010. Then, the SPI is compared with this traditional risk analysis method to demonstrate that the results attained by either method provide the relative safety-related risk of underground coal mines regarding injuries and citations for violations of regulations. The comparison reveals that the SPI does emulate a traditional approach to risk analysis. A correlation coefficient of –0.89 or more was observed between the results of these two methodologies and either can be used to assist companies, the Mine Safety and Health Administration (MSHA), or state agencies in target-ing mines with high risk for serious injuries and elevated citations for remediation of their injury and/or violation experience. The SPI, however, provides a more understandable approach for mine operators to apply using measures compatible with MSHA's enforcement tools.

These methodologies form an all-encompassing approach that can be used to assist companies, the MSHA, or state agencies in targeting mines with high risk for serious injuries and elevated citations. Once targeted as high risk, mines can then pursue appropriate intervention to remediate their violation and/or injury experience. This research may help in plugging the gap in the safety system and better pursue the goal of zero fatalities and serious injuries in the underground coal mines.

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ABBREVIATIONS

C/100 IH	Citations per 100 Inspection Hours
Commission	Mine Safety Technology and Training Commission
FT IR	Fatality Incidence Rate
MINER Act	Mine Improvement and New Emergency Response Act
MHRA	Major Hazard Risk Assessment
MSHA	Mine Safety and Health Administration
NDL IR	No Lost-Time Reportable Accident/Injuries Incidence Rate
NFDL IR	Non-Fatal Days-Lost Incidence Rate
O/100 IH	Withdrawal Orders per 100 Inspection Hours
POV	Pattern of Violation
SM	Severity Measure
S&S	Significant and Substantial Citations
SS/100 IH	Significant and Substantial Citations per 100 Inspection Hours

Chapter 1

INTRODUCTION

Background

The mining industry has a prominent influence in fulfilling societal needs. Mining has come a long way in terms of methodologies and technologies. The mining industry around the world is striving hard to improve the safety of the miners. Mines are broadly classified as surface or underground based on the method of mining and are also categorized based on commodities mined such as coal, metal, non-metal, stone, and sand and gravel. Mining industry is on the safety radar as it is being portrayed by media as one of the most dangerous and hazardous industries. However, the mining industry in the U.S. is not even in the top 10 highest hazard industries list (Welhan, 2011) and has been striving hard over many decades to reduce its safety incidence rates and prevent catastrophic events. However, the industry's progress is persistently overshadowed by disasters, such as those that occurred in 2006, 2007 and 2010, which resulted in 19 of 37 fatalities in 2006, 9 of 18 fatalities in 2007, and 29 of 41 fatalities in 2010. A decade of data analysis, as shown in Figure **1-1**, reveals that underground coal mine fatalities in 2009 had reached a record low of 6 with a Fatal Incidence Rate (Fatal IR) of 0.013 fatalities per 200,000 employee-hours worked (equivalent to 100 miners working 2,000 hours in a year) as compared to a Fatal IR of 0.032 in 2002 (disaster free years). As shown in Figure **1-2**, the lost-time injury rate also decreased 49% over the period to a Non-Fatal Days Lost Incidence Rate (NFDL IR) of 3.89 from a NFDL IR of 7.66 in 2001. In the minds of many operators, no fatalities or lost-time injuries are acceptable in the industry. One of the main goals of the mining industry is to achieve the level of zero fatalities and accidents (Mine Safety Technology and Training Commission, 2006).

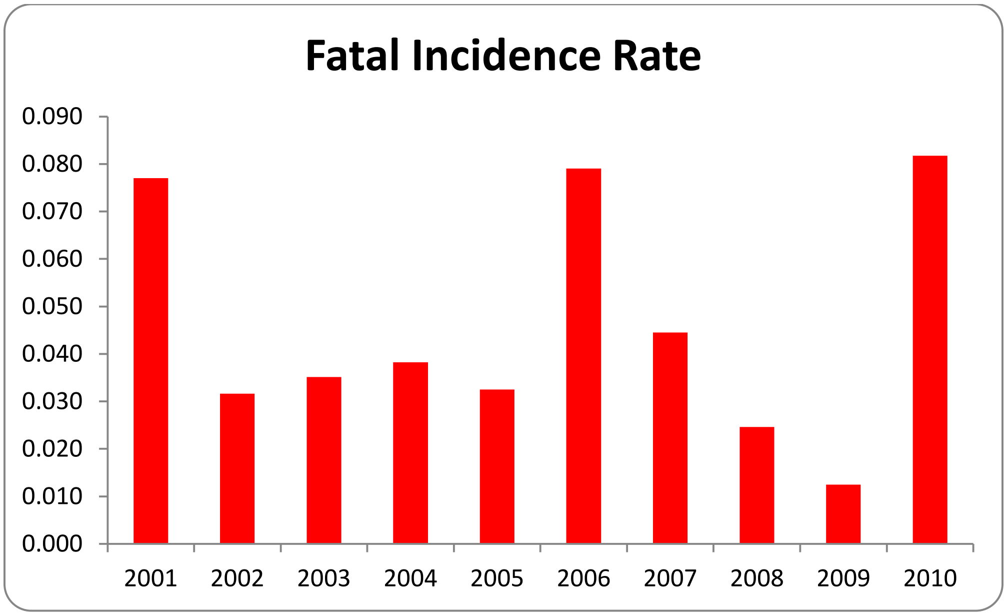

Figure 1-1. A decade trend of Fatal Incidence Rate (Fatal IR) (Source: MSHA)

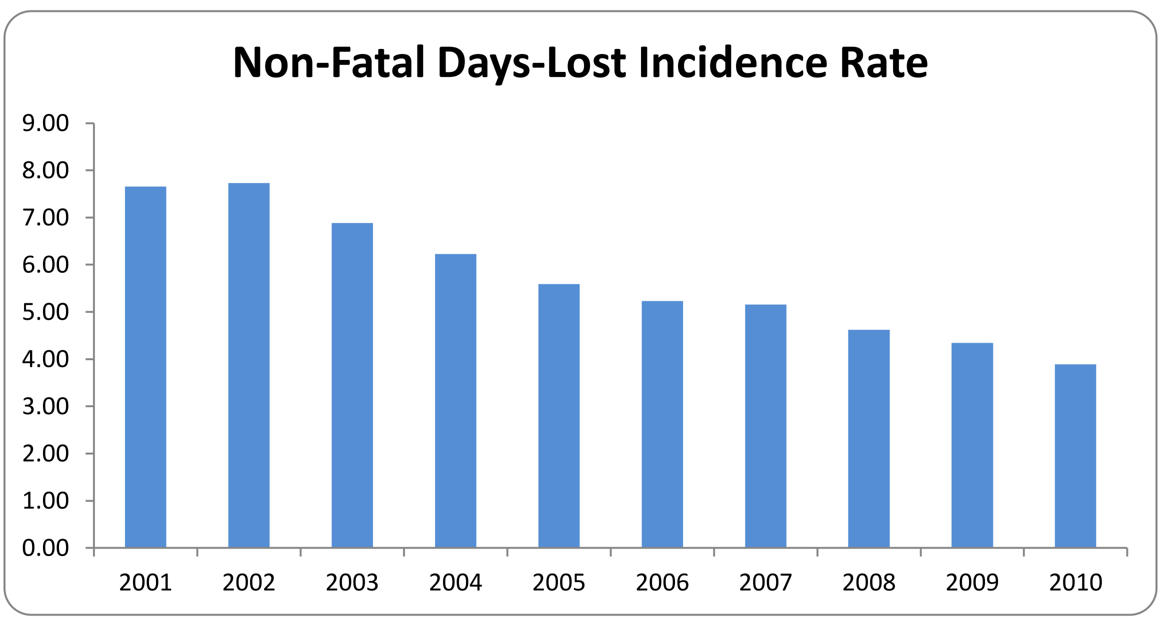

Figure 1-2. A decade trend of Non-Fatal Days Lost Incidence Rate (NFDL IR) (Source: MSHA)

Safety in the mining industry has been an issue over the decades among the top coal producing countries in the world. In the past, it took major disasters to achieve new legislation and regulation to improve safety standards. The recent U.S. underground coal mine disasters have posed tough, new challenges regarding the way underground coal mine managers assess and mitigate high-risk conditions. Australia imposed risk management in the daily work routine at mines, but a viable approach for doing this in U.S. underground coal mines remains elusive. Even today highly visible coal mine disasters persistently result in drastic government interventions, including legislative action leading to new safety regulations. In response to the underground coal mine disasters of 2006, the U.S. Congress passed the Mine Improvement and New Emergency Response Act (MINER Act, P.L. 109-236). It was enacted primarily to address several shortcomings in emergency preparedness and response, aiding miners in escaping and surviving emergency situations, and to increase the enforcement of safety in mines. Meanwhile, the National Mining Association established an independent, tripartite commission (Mine Safety Technology and Training Commission, 2006) to study the status of safety in underground coal mines and what may be done to move the industry to a global leadership position. The Commission published a consensus report aimed at preventing underground coal mine disasters in the future and targeting the goal of zero fatalities and lost-time accidents. The report called "for a new paradigm for ensuring safety in underground coal mines, one that focuses on systematic and comprehensive risk management as the foundation from which all life-safety efforts emanate." The report specified 75 recommendations that, if implemented, would set safe performance standards for achieving a culture of prevention at mines, including risk assessment, and noted that mines which could not meet the level of safety requirements specified in the report should not be allowed to mine coal. "As a minimum each mine should systematically identify its risks for an explosion, fire, or inundation" was one of the main recommendations.

Following publication of the Commission's report, the National Institute for Occupational Safety and Health (NIOSH) followed up on the Commission's recommendation that NIOSH ''develop a series of case studies that mines could use as templates (for risk assessment), and that it conduct workshops and seminars to diffuse this approach to safety throughout the industry.'' NIOSH completed its study, but there was little response by the industry to attend workshops to diffuse the major-hazard risk-assessment methodology. Thus, a key component of the Commission's report remained largely unaddressed, and it was critical for establishing a safety culture of prevention founded on systematic risk assessment and follow-up remediation of identified major hazard-related risks. Interestingly, until recently, with a few exceptions, MSHA citations have not generally been considered a component in assessing a mine's safety performance. The situation changed dramatically following the MINER Act of 2006, which increased fines for citations dramatically. Beyond ventilation and roof control plans, MSHA has pursued risk management over the years. Stop Look Analyze and Manage (SLAM), the Pattern of Violations (POV) provision, Rules to Live By, and Impact Inspections are the most recent examples (MSHA, 2010). The two-step POV process was initiated in earnest in June 2007. Then, problems persisted with the POV process, which depends on final citations, including elevated ones. The process was also not transparent to the mine safety community, was complex with 10 components comprising the calculation, and was cumbersome to enforce, particularly because a significant percentage of significant and substantial (S&S) citations and orders were challenged through the due process that operators exercise via the Mine Health and Safety Review Commission. MSHA's "Rules to Live By", initiative aims to improve the prevention of fatalities in mining by targeting 6 frequently cited health and safety standards that contribute to fatal accidents in mines in different accident categories.

The provisions of the MINER Act were largely implemented by 2009, with few exceptions, thereby increasing the protection of miners during emergencies and better preparing mines for effective emergency response. Post-MINER Act, MSHA increased enforcement of mines in all sectors, and the level of fines was about 3 times higher than pre-2006. Mine safety professionals hoped that major disasters would be avoided in the future. However, in spite of many efforts by the Federal government and a number of State governments, the worst underground coal mine disaster in 40 years occurred at the Upper Big Branch-South Mine on April 5, 2010. The POV process was called broken because of its failure to place any mine on POV status (MSHA, 2010a,b). During Congressional hearings on mine safety reform (H.R. 5663), U.S. Solicitor of Labor M. Patricia Smith (2010) noted that the POV process is legally complex and has not been effective in targeting poor-performing mines.

The U.S. news media followed the events very closely, and the industry was traumatized to its very core of safety values by the events. The industry's espoused goal of zero fatalities was tragically interrupted by the disaster. As expected, soon after the disaster, the U.S. Congress was presented with a new Act, called "the Robert C. Byrd Mine and Workplace Safety and Health Act of 2010," which was at first turned down by the House of Representatives, but it was reintroduced on January 24, 2011. There are other different forms of bills pending the U.S. House of Representatives and the U.S. Senate which propose some of the safety measures used and nurtured in this research.

Problem Statement

Underground coal mine fatalities in the U.S. have been reduced dramatically over the past three decades and eliminating multiple-fatality or disaster events is one of the most important safety issues in the U.S. mining industry. The industry has striven hard to establish a culture of safety and to be the world leader in safety by achieving zero accident levels. In spite of 2009 being a record low year for fatalities in underground coal mining history, the worst mining disaster in 40 years that occurred in 2010 shocked the mining community. In the U.S., there is a need to develop a systematic and integrated approach to achieve zero fatalities. The Mine Safety Technology and Training Commission's report "calls for a new paradigm for ensuring safety in underground coal mines, one that focuses on systematic and comprehensive risk management as the foundation from which all life-safety efforts emanate." The problem lies in developing and adopting a commonly acceptable, straight-forward, transparent, and systematic methodology that can be used by mine operators across mine sizes. There is no such methodology that benchmarks the overall safety performance of underground coal mines. This research takes a step forward with the developed methodology and its applications to help predict, reduce or eliminate multiple-fatality or disaster events in the U.S. underground coal mining industry.

Objective

The objective of this research is to develop a methodology for assessing safety risk that can be commonly adopted and is less complex that the POV method, straight-forward to implement, transparent, reproducible, and easily adoptable in underground coal mines irrespective of mine size, and by federal and state enforcement agencies. The methodology developed here can be used for benchmarking the safety performances of underground coal mines across mine sizes. Using this methodology, various applications will be further developed to address underground coal mine safety performance issues.

Structure of Dissertation

The dissertation is structured in the following manner. Chapter 1 presents a brief background on the U.S. mining industry, its safety incidence rates (as defined by MSHA) and fatality rate, recent disasters, and certain findings of the Mine Safety Technology and Training Commission report, which discussed crucial safety issues in underground coal mining. The key problems and the objectives of the research work are also highlighted in this chapter. Chapter 2 gives a brief idea about past research works in this area through a critical literature review. Chapter 3 highlights the methodologies developed to assess and benchmark underground coal mines' safety performances in the U.S. Chapter 4 presents the results from applying the developed methodologies and discussions of the results, followed by the summary and conclusions in the Chapter 5. The content of four peer-reviewed journal articles, the basis for this dissertation, are threaded throughout the manuscript and they are attached in Appendix E.

Chapter 2

LITERATURE REVIEW

The coal mining industry is complex by nature. There are different ways to produce coal but the one that is safe, environmentally friendly, and cost-effective should be the right way. The U.S. coal mining industry is one of the most regulated in protecting the environment and the health and safety of mine workers. This was not the case five decades before, and the industry has come a long way, which has resulted in the continuous improvement in the use of new technologies, methods of mining, safety culture, and proactive involvement of the operators and regulatory agencies. Certainly considerable national and international expertise exits today to help those interested in risk management to become proactive in dealing with their major hazards. NIOSH had published results on a pilot project, where the Major Hazard Risk Assessment (MHRA) methodology was used to investigate and conduct field trials at 10 pilot case-study mines, and the findings revealed the differences of major-hazard threats among different mine types, including facilities, and mine sizes (Iannacchione et al., 2007). Risk management systems are mandatory in some countries and many industries are using such systems to control inherent hazards in their business (Chapter 2, Section 10, Occupational Health and Safety Regulation 2001). According to Australian regulations, mines must perform a Major Hazard Risk Assessment (MHRA) on a regular basis to tackle the possibility of unwanted major hazard-related events such as explosions, outbursts, air bursts, inundations, spontaneous combustion events, and roof instabilities (Joy and Griffiths, 2007). Risk management has become an integrated part of their daily work routine. Risk management allows Australian operators to deal proactively with the major-hazard events which may cause multiple fatalities. Due to prompt adoption of MHRA, the Australian underground mining industry has the lowest fatality injury rate in the world

(Iannacchione et al., 2007). However, to successfully implement a formal risk management system, expertise in the methodology is essential, but it also has a long learning curve.

The South African mining industry "has established a Hazard Identification and Risk Assessment Program (HIRA-2003) to identify and record significant risks" (Md-Nor et al., 2008). The Domino theory of an accident states that "an injury is caused by an accident, which, in turn, is caused by unsafe acts or conditions" (Brauer, 1994). Obviously not every unsafe act or condition may lead to an accident, but instead combinations of multiple unsafe acts and conditions are often involved. Insufficient unsafe acts or conditions may give rise to near misses or near hits, and these events are not taken seriously because no damage or injury occurred to the worker (Chen and Yang, 2004). Often, fatality and injury rates are used to evaluate the safety performance of mines and their ability to manage risk. However, in the mining industry, elevated citations for certain violations of regulations (such as those designated as Significant and Substantial (S&S) and withdrawal or imminent danger orders) may reflect failures of mine personnel to manage risks and may result in "poor" mine safety performance.

According to Joy and Griffiths (2007), there are many different ways of doing risk analysis, qualitatively and quantitatively. Generally, experienced personnel are essential to make a good judgment in a qualitative risk analysis. Unfortunately, in the U.S., 60% of the underground coal mines are small-size mines, i.e. having less than 50 employees (Kinilakodi and Grayson, 2011b), and they are generally not equipped with on-site safety expertise capable of performing a complex or sophisticated formal risk analysis. Quantitative risk analysis has the advantage of using historical safety performance data to evaluate the frequency and severity in a more objective way. Historically, small underground coal mines have experienced higher fatality rates than larger mines (National Academy of Sciences, 1983; Peters and Fotta, 1994), and a similar trend was found in a recent study which "indicates a heavy occurrence of very severe injuries in a number of very small and small mines" (Kinilakodi and Grayson, 2011b). Mine size is highly correlated with coal seam height, and smaller mines tend to operate in significantly thinner coal seams than large mines. Miners are at higher risk of having a nonfatal injury as mining height decreases (Peters et al. 2001). Generally, small and very small mines (< 20 employees) do not possess resident safety expertise capable of performing a complex risk analysis.

Major-hazard events have contributed to considerable safety volatility, produced varied public reactions, created policy debates, sparked heated violation disputes between mine operators and MSHA, and generally contributed to mining industry frustrations. It is commonly practiced and accepted that "leading" indicators are clearly to be preferred over "lagging" indicators (Rogers et al., 2009). This implies that there is more motivation in reporting performance of preventative measures, compared to performance in the sense of occurrence of near-misses (Vinnema et al., 2006). One could surmise that a classic example of this condition is manifested by the Crandall Canyon Mine disaster in which mine management apparently did not take adequate preventive action when the first near-miss accident had occurred. In addition to that they neglected to report the significant coal bump incident, as required by law. If they would have considered this incident as a leading indicator, the disaster may have been prevented.

The National Mining Association established the independent Mine Safety Technology and Training Commission to study the safety situation following the 2006 mine disasters, and the Commission recommended "interventions in technology, emergency response and mine rescue procedures, and training directed at achieving the ultimate goal of zero fatalities and zero lost-time accidents." The Commission recognized that "not all mines have a familiarity with risk management," and therefore, it recommended that NIOSH "develop a series of case studies that mines could use as templates, and that NIOSH conduct workshops and seminars to diffuse this approach to safety throughout the industry" (Recommendation #3 under Risk Management, Mine Safety Technology and Training Commission, 2006). Good-performing, safe industries focus their risk management efforts on reducing the major risks as well as improving substandard performances, where accountability is also an important ingredient.

An industry's ability to manage risk is often evaluated by its injury and illness rates. However, in the mining industry, citations for certain violations of regulations may reflect failures of mine personnel to manage risks from major hazards, especially when elevated citations such as those designated as Significant and Substantial (S&S) and withdrawal orders occur. These may often appropriately be considered as "births" or root causes of major hazards, which eventually could lead to one or the other form of loss, including mine property damage, injury to miners, or financial loss. A basic requirement for successful risk management is the desire to become more proactive in dealing with the risk associated with major-hazard events, which can cause multiple fatalities. All the aforementioned formal and informal risk assessment techniques require people with sound knowledge about mining processes and proper understanding of major hazards associated with them.

The more knowledgeable miners have extensive experience but in the last decade the average hours worked per employee has been increasing, thereby affecting the productivity as shown in Figure **2-1**. Another of the main reasons for the decline in the productivity would be the increasing number of inexperienced employees. With the current growth in the mining industry and attrition due to the retiring workforce, the number of inexperienced or less-experienced miners may increase risk to injury. These scenarios are alarming, signaling a need to establish effective strategies to further reduce injuries and fatalities in the mining industry.

Quantitative performance measurement has been proven valuable in the fields such as economics, health care management, and education, where policies are driven by indicators such as the unemployment rate, infant mortality, and standardized test scores (Esty et al., 2006). Many successful performance indices have been adopted by different fields such as the Environmental Performance Index (EPI) (Esty et al., 2008), Academic Performance Index (API) (http://www.cde.ca.gov/ta/ac/ap/), and Assessment of Doctoral Programs (National Research Council, 2009), etc. Most of these index methodologies had considered assigning varied weights to each of the performance indicators and thus analyzing the sensitivity of these methodologies.

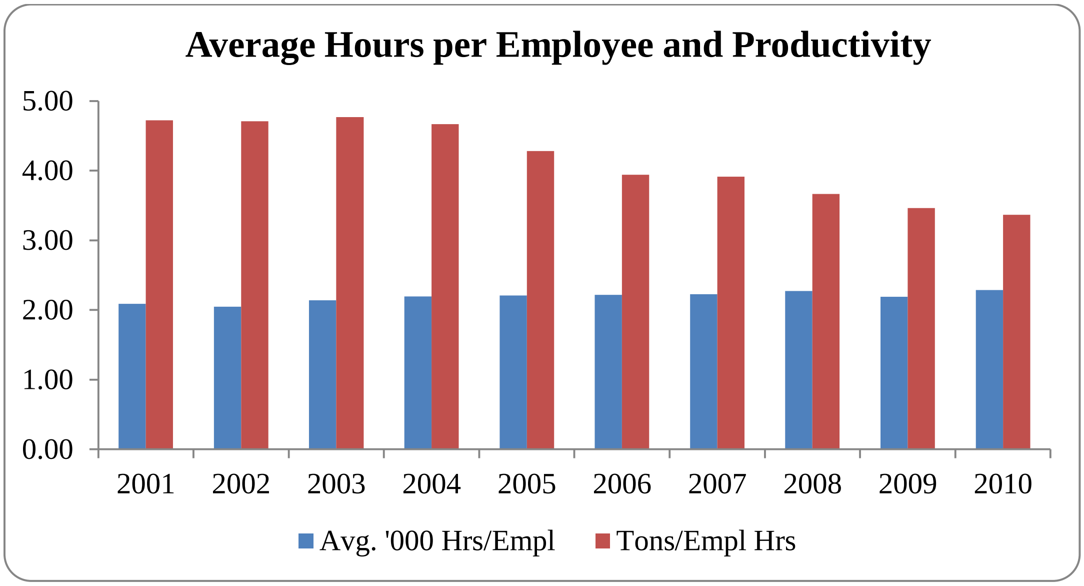

Figure 2-1. A decade trend of average hours worked per employee and productivity (Source: MSHA).

EPI ranks countries environmental performance, indicated by an index value, in descending order, i.e. from good performer to poor performer, and a similar ranking process may be considered to rank underground coal mines' performances. The need for carefully constructed matrices or indices for major-hazard control and risk management is required to commit the mines to progress on mitigating major hazard-related issues and disasters. The real value of the indices lies not in the overall rankings but for mining comes from systematic analysis of the data and the resulting major hazard-related indicators.

The policymakers in the U.S. mining industry have recognized the importance of data and analytically accurate details for decision-making. The vast safety-related data collected by regulatory agencies can be useful in validation, trend analysis, and interpretation of the industry safety data through various Safety Performance Matrices. If done in a transparent and largely acceptable way, this might be helpful in re-establishing and strengthening the links with federal and state regulatory agencies, safety researchers, and operators. These collaborations and information can be used to develop proactive and effective legislation, emphasize corporate strategies towards establishing an effective safety culture and linked processes, and offer transparent evaluation of the mines' safety performance to the industry. Over the years, the data collection has also enabled a range of comprehensive performance reports, with the ability to perform research and in-depth analysis.

Interestingly, until recently, with a few exceptions, MSHA citations have not generally been considered as a component in assessing a mine's safety performance. The situation changed dramatically following the MINER Act of 2006, which increased fines for citations dramatically. Its passage also caused MSHA to become more stringent with inspection of the mines, and put more pressure on operators to effectively enforce regulations internally. MSHA now more intensely uses citations to calculate the potential of a mine for getting into a Pattern of Violations (POV), which would impose another dramatic increase in fines and present a tremendous challenge to the operator to be removed from that status. By documenting the use of a major hazard-related event risk analysis to specific and general issues, this study provides a framework for others to judge the merits of the approach and to help in formulating risk-mitigating activities.

The citation of a major hazard-related standard, i.e., inadequate ventilation, accumulation of combustible materials, inadequate rock dusting, failure to maintain equipment in permissible condition, failure to follow roof control plan, etc., are cited for conditions that most often lead to accident(s) and disaster(s) in an underground coal mine. These are often elevated citations, too. For example, not maintaining equipment in permissible condition could lead to a spark that could ignite an explosive mixture of methane or other combustible material causing a potential threat to the miners. The elimination of major hazard-related disasters is one of the most important safety issues the U.S. mining industry is facing today. The real challenge lies in adopting acceptable, straightforward and systematic methodologies that will be readily adoptable by the majority of coal mine operators.

MHRA was developed by NIOSH to address major hazard-related safety issues, but unfortunately, it has not been adopted by many operators in the mining industry. Some of the reasons for the industry's reluctance toward adoption may be the lack of on-site safety expertise, complicated or sophisticated methodologies, large learning curve, and lack of a safety culture to support its use. The Safe Performance Index (SPI) developed in this research sought to give a less complicated and more straightforward, risk-based methodology for determining the relative safety risk among mines, using several normalized measures of the accident and citation experiences of mines. During Congressional hearings on mine safety reform (H.R. 5663), the SPI was presented as an alternative methodology to the POV process (Grayson, 2010), which provided a balanced assessment of a mine's safety performance, embracing accident and citation measures.

The mining industry believes that fatalities and serious injuries are preventable. In the 2011 fatality analysis report by MSHA, the Assistant Secretary (MSHA, 2012) had conveyed that "in order to prevent mine deaths, operators must have in place effective safety and health management programs that are constantly evaluated, find-and-fix programs to identify and eliminate mine hazards, and training for all mining personnel." Since the MINER Act, "MSHA has undertaken a number of measures to prevent mining deaths: increased surveillance and strategic enforcement through impact inspections at mines with troubling compliance histories; enhanced pattern of violations actions; special initiatives such as "Rules to Live By," which focuses attention on the most common causes of mining deaths; and outreach efforts such as "Safety Pro in a Box," which provides guidance to the metal/nonmetal mining industry on best practices and compliance responsibilities." Apart from the tools developed and utilized by MSHA, an alternative methodology for the operators could be to adopt the SPI as an effective risk analysis tool for incorporation in a safety and health management system.

In summary, the previous research or methodologies do not evaluate the mines' safety performances in a balanced way, and the influence of mine size has not been taken into consideration efficiently. The objective of this research is to develop a balanced approach towards evaluating underground coal mine safety performances using a less-complicated and more straight-forward methodology that has a small learning curve, and is transparent and reproducible by any stake holder.

Chapter 3

METHODOLOGY

Introduction

The purpose of the Mine Safety and Health Administration (MSHA) is to “prevent death, disease, and injury from mining and to promote safe and healthful workplaces for the Nation's miners” (MSHA, 2012b). MSHA has jurisdiction over all mining and mineral processing operations in the United States, regardless of size, number of employees, commodity mined, or method of extraction. “The Mine Act provides that MSHA inspectors shall inspect each surface mine at least 2 times a year and each underground mine at least 4 times a year (seasonal or intermittent operations are inspected less frequently) to determine whether there is compliance with health and safety standards or with any citation, order, or decision issued under the Mine Act and whether an imminent danger exists” (MSHA, 2012c). “The Open Government Memorandum called for more transparent, participatory, and collaborative government” (MSHA, 2010c).

This research is comprised of further developing the Safe Performance Index which was developed with a pilot sample of underground coal mines and an attempt to use much of the data in the MSHA databases for those sample mines in the year 2006. The pilot study established that the citation database can be used for quantitative risk analysis and in building a performance index. Additionally, the datasets of multiple years are used to determine the post-MINER Act impacts on the mining industry. In this chapter, a detailed description of the MSHA database and how to retrieve the data, and methodologies developed and for later applications are presented as extracted from four-reviewed journal articles.

MSHA Database

Prior to the Upper Big Branch Mine South disaster on April 5, 2010, mine accident and citation data were available via the Mine Data Retrieval System accessible on the MSHA website at the following URL: http://www.msha.gov/drs/drshome.htm. Using this system, it is relatively easy to access data on any mine, if its MSHA ID number, the accurate mine name, or the accurate operator name is known. Once the mine is found in the search, then the following data can be downloaded for analysis:

- Current mine information
- Overview information
- Information on inspections
- Information on accidents
- Information on violations
- Information on violations per inspector day
- Information on inspector respirable dust samples
- Information on operator respirable dust samples
- Information on analyses of quartz content in respirable dust samples
- Information on mine employment and coal production
- PPOV monitoring tool

Some of this information (data) can be obtained over limited time periods, as follows:

- Data on accidents back to 1983
- Data on violations back to 2000
- Data on results of quartz analyses back to 1995
- Data on violations per inspector day back to 2006

- Data on Metal/Nonmetal health samples back to October 1996

Using the Data Retrieval System for analysis of a mine's accident and citation performances is relatively easy to do, since all comprehensive data needed for normalized calculations for a desired time period can generally be downloaded for that mine quickly. The analysis of course takes longer and requires knowledge of how to calculate the standard normalized measures, e.g., the following:

- The No Days Lost Incidence Rate (NDL IR)
- The Non-fatal Days Lost Incidence Rate (NFDL IR)
- The Severity Measure (SM)
- The number of Citations per 100 Inspector Hours (C/100 IH)
- The number of Significant and Substantial (S&S) designated citations per 100 Inspector Hours (SS/100 IH)
- The number of withdrawal, unwarrantable failure, and imminent danger Orders per 100 Inspector Hours (O/100 IH)

Once the data is downloaded and the definitions of the desired measures are known, these calculations can easily be made using a spreadsheet, such as *Excel*. There is, however, some effort required to determine the inspector hours over a desired time period, such as one year. Although data is available on inspector hours in the Violations per Inspector Day file, the reported data covers a 15-month period of time. In order to get the number of inspector hours over one year, the Inspections file must be accessed for the 3-month period not desired and then those hours must be subtracted from the hours reported for the 15-month period.

It is also important to cross check data contained in the Overview file with data obtained and accumulated from the Accidents and Violations files. Discrepancies were found in past analyses, and accurate numbers must be determined.

In greater complexity, if comparisons are desired on several safety measures for entire sets of mines and between different mine sizes in the underground coal sector for a given period of time, then the amount of time and work effort required to get all the necessary information from the Data Retrieval System is prohibitive. In such a case, the information for comparisons can be obtained with some effort from the recently available Open Government Data Sets, which can be accessed at the following URL: http://www.msha.gov/OpenGovernmentData/OGIMSHA.asp. The availability of these data sets was announced by the MSHA News Release Number 10-1228-NAT, dated 9/9/10.

There are several data sets available at the MSHA Open Government Data Sets website, as follows:

- Accident Injuries Data Set
- Employment/Production Data Set (Yearly)
- Employment/Production Data Set (Quarterly)
- Inspections Data Set
- Mine Addresses of Record Data Set
- Mines Data Set
- Violations Data Set

Definitions for file contents are also available at the site as well as a spreadsheet containing 107(a) imminent danger orders, which reflect the most severe action by MSHA for violations of regulations. All files contain information for 13 years, going back to 2000. The files are updated weekly. At the site MSHA explains, “We have compressed each of the data files (.zip) to speed up the downloading time. The definition files are .txt type files. All of the data sets are text delimited files. The delimiter is a vertical bar (|). Each file's first row is a header containing the names of each field. Definitions of each of the fields in a data set are provided in a separate link."

Also explained is "How to work with the ***Definition files*** (.txt):

Save file as a TXT file.

Open your spreadsheet.

Open and then copy the TXT file to your spreadsheet.

Save the spread sheet."

and "How to work with the ***Data files*** (.zip):

Click/Save Target/File to your PC.

Unzip the files

Create a data base table by importing the data file.

Choose pipe delimited [|] for the data as the file type.

Save your work."

Some of the files are very large. One, the Violations (text) file, contains over 640 MB of data and over 1.4 million rows of records (*Excel*'s capacity is 1 million rows); thus it cannot be imported to *Excel* for selection of desired data by year, commodity, type mine, etc. The violation text file had to be split into 2 files with less than a million rows using an open source software called Gsplit (http://www.gdgsoft.com/gsplit) in order to be imported to *Excel*. A computer program is necessary to parse out the desired data. A computer program is also helpful in linking the data for a specific mine across data sets, and grouping linked data sets for groups of mines arranged by categories such as by commodity, type of mine, mine-size, operator, controller, etc. A computer program thus facilitates capture and efficient preparation of data for comparative analyses.

Database Retrieval

The procedure for retrieving required information from MSHA Open Government Data Sets using the combination of Hypertext Preprocessor (PHP), Structured Query Language (SQL), and Relational Database Management System (RDBMS) is explained next. The following procedure to retrieve necessary data in a time-efficient way for underground coal mines is used:

1. Download the zip files from the MSHA Open Government Data Sets website (http://www.msha.gov/OpenGovernmentData/OGIMSHA.asp) and extract the text files.
2. Import the text files into *MS Excel* worksheets using the pipe-delimited [|] format and save the *Excel* worksheets with appropriate names.
3. Import these *Excel* spreadsheets into *MS Access* by choosing only those columns that are required for the desired data analysis.
4. Export the same file from *Access* to the Open Database Connectivity (OBDC) database, which gets stored in the computer server through *MySQL* workbench.
5. Write *SQL* code to retrieve the desired data from the server/database using *PHP* (PHP is a popular open-source language for building web pages that retrieve dynamic content from a database) as given in Appendix **A**.
6. The web-based output is in xml form, which can be then imported to *Excel* for analysis.

To successfully complete this procedure, the following facilities and software were used:

- *MySQL Workbench* (http://wb.mysql.com/)
- *MySQL ODBC* driver (http://dev.mysql.com/downloads/connector/odbc): A driver that will enable viewing *MySQL* data with *MS Access*
- Server (Penn State) to host the database

Without such a procedure, it would be too time consuming to assemble the data and the massive number of separate downloads could lead to significant errors. This procedure allowed a relatively quick check of data accuracy, and it facilitated the capture of the Violations data, which was contained in a large-size text file that was so big that it could not be imported to an *Excel*. Developing a macrocode within the Excel worksheet was not a viable option, due to the limitation of macros.

In this way, the following information/data can be captured separately for all underground coal mines for the years 2001 to 2010:

- MSHA ID
- Number of fatalities
- Number of no days lost incidents
- Number of non-fatal days lost incidents
- Number of days lost, including restricted work days and statutorily charged days
- Number of employee hours worked
- Production
- Average number of employees for the year
- Number of inspector hours at the mine or facility
- Number of citations issued
- Number of citations designated as S&S
- Number of withdrawal, unwarrantable failure, and imminent danger orders issued

The successive research methodology in producing the four peer-reviewed journal articles will be presented next. The full text of each article can be seen in Appendix D.

Paper 1: A methodology for assessing underground coal mines for high safety related risk

A pilot study of 31 underground coal mines, stratified by mine size and state, was initiated to analyze the safety performance and comparative risk among them. One of the methodologies developed was the Safe Performance Index (SPI), which combines statistics on a mine's injury experience with its citation experience in determining its relative level of safety, or risk (Kinilakodi, 2009). Emulating the Environmental Performance Index (Emerson et al., 2010), the SPI was designed to provide a more straight-forward, transparent, understandable, and reproducible method for determining the relative risk of mines than the POV process. In the calculation, it gives greater weight to the injuries and citations that are more serious. It can be used to benchmark superior safety performance, including by mine size or type of mining, or for screening mines for improvement efforts. The details on the development of the SPI methodology are given next.

The fatal incidence rate (FT IR) is the most important component to be included in the performance index (PI), because of the fact that the entire industry is trying to eliminate fatalities, followed by reduction of the non-fatal days-lost incidence rate (NFDL IR) which is also a critical component (because at present mine's safety performance is measured based on its NFDL IR), and the national NFDL IR average is the benchmark for the respective year. MSHA uses the national average of both FT IR and NFDL IR as a benchmark to compare the safety performance of individual mines on a yearly basis. The no days lost incidence rate (NDL IR) was included in the index because it approximates near misses, often caused by many unsafe acts and conditions. Unfortunately, the NDL IR is not taken seriously by the industry or MSHA because little or no damage or injury is caused to the miner. The important action in response to no days-lost events is the identification of a major hazard that could have posed a serious threat to safe working conditions. Quantifying these major hazard-related events based on their risks provides a more systematic approach to prevention of losses. Severity measure (SM) is another vital component in the PI, because it reveals the extent of impact of an accident or an incident can cause on the employees working at the time of an event. It is also used by MSHA similar to FT IR and NFDL IR.

MSHA data for 2006 on the 31 mines in the stratified, random sample was used in the pilot study. When the project was begun, 2007 data was not yet available. The 31 pilot sample mines shown in Table 3-1 were created for the risk assessment exploratory study by Grayson et al. (2009). The pilot sample mines were created to study the MSHA citation database and it was the first attempt to use the MSHA citation database for a risk assessment study, other than MSHA using it in POV calculations. The 31 mines in the pilot study were randomly selected and stratified based on mine size and the state in which they are physically located. In 2006, there were 421 active underground coal mines with production greater than or equal to 10,000 tons. Out of 421 mines, 112 were very small mine-size (≤ 20 employees), 143 were small mine-size (21 to 50 employees), 78 were medium mine-size (51 to 100 employees), 49 were large mine-size (101 to 250 employees), and 39 were very large mine-size (≥ 251 employees). In the pilot sample there were 8 very small mines, 10 small mines, 6 medium-size mines, 4 large mines, and 3 very large mines which were proportionately represented the various mine-size categories and the nine different states (Alabama, Colorado, Illinois, Indiana, Kentucky, Pennsylvania, Utah, Virginia, West Virginia). Hence, the 31 mines sampled satisfy the size-wise and state-wise representation/distribution. In general, the 31 pilot sample mines represent the overall industry situation. The basic safety data on the sample mines is given in Table **3-1**. The 'inspector hours' field contains total inspector hours, primarily because the Pattern of Violation process (Smith, 2010) was not yet implemented. In the pilot study data there was no fatality, which reflects the low probability for an underground coal mine to have a fatality in a given year for all mines (approximately 4% chance) which ranged from 2.5% to 8.2% for 2001 – 2010.

Table 3-1. MSHA Safety Data on Pilot Study Mines.

Mine ID	No. Empl.	No. NLT Accidents	No. LT Accidents	Restricted and Lost Work Days	Empl. Hours	No. Citations	No. S&S	No. Orders	Insp. Hours
1	15	0	0	0	36004	16	3	0	237.50
2	13	0	0	0	8429	11	6	0	101.50
3	7	0	0	0	12285	11	4	0	307.75
4	20	7	3	8	54692	51	15	0	740.50
5	20	0	1	354	38214	150	84	0	518.00
6	15	2	2	162	36060	65	27	2	435.00
7	14	0	0	0	27067	7	1	0	212.25
8	15	0	1	120	14608	13	1	0	156.50
9	49	8	2	146	135414	512	228	76	2740.50
10	35	2	2	51	79853	54	23	1	434.00
11	21	0	2	60	36708	46	18	0	301.75
12	25	2	2	6	40880	47	20	0	356.75
13	21	0	0	0	38274	73	39	1	408.25
14	30	2	0	0	67958	55	11	2	1092.80
15	36	2	4	326	69822	9	5	0	181.50
16	42	0	1	9	106095	48	27	2	445.75
17	22	0	0	0	29166	84	32	3	416.00
18	37	2	5	384	93419	72	28	0	681.75
19	67	1	0	0	178226	107	53	0	825.75
20	72	4	2	16	71977	48	9	0	492.00
21	56	5	2	229	122416	65	20	0	364.00
22	72	15	11	1435	170692	96	41	4	619.75
23	63	6	23	1188	152847	141	45	1	1162.30
24	58	7	1	62	169469	86	57	10	588.00
25	142	10	5	47	278557	133	31	8	1556.50
26	107	13	3	165	257958	154	53	2	858.75
27	103	19	10	176	309759	167	92	2	845.00
28	231	10	4	428	499328	196	69	12	2088.00
29	390	30	8	658	894791	370	100	5	2861.50
30	303	13	12	392	655104	103	33	1	1706.50
31	383	29	16	1541	794802	517	128	5	2969.00

The measures used in calculating the Performance Index (PI), and later the SPI, for 2006 data included standard injury measures, i.e. the No Days Lost Incidence Rate (NDL IR, number of no lost-time accident/injuries per 200,000 employee hours), the Non-Fatal Days Lost Incidence Rate (NFDL IR, number of lost-time injuries per 200,000 employee hours), and the Severity Measure (SM, number of statutory, restricted, and lost work days per 200,000 employee hours, divided by 100), and citation-related measures, i.e. Citations per 100 Inspector Hours (C/100 IH), Significant and Substantial Citations per 100 Inspector Hours (SS/100 IH), and withdrawal Orders and unwarrantable failures per 100 Inspector Hours (O/100 IH), refer to Appendix B. They are shown in the Table **3-2** for the 31-mine sample.

As the first step in calculating the SPI, the PI is calculated as the summation of the safety measures. The PI thus gives a combined measure where the highest value is the 'worst' performer in the group of mines and the lowest value gives the 'best' performer. Since the PI had a wide range of values, it was considered useful to index the PI to give a range of values from 0 (best-performing mine) to 1 (the worst-performing mine). Thus the normalized PI was calculated as a mine's PI divided by the highest PI among all mines. The SPI was then calculated as the normalized PI times 100, with the result subtracted from 100. This gives the best-performing mine with zero injuries and zero citations, theoretically, having a value of 100, with the worst-performing mine having a value of zero. The results of the calculations are also presented in Table **3-2**.

Table 3-2. Normalized Safety Measures, PI, Normalized PI, and SPI.

Mine ID	NDL IR	NFDL IR	SM	C/100 IH	SS/100 IH	O/100 IH	PI	Norm PI	SPI
1	0.00	0.00	0.00	6.74	1.26	0.00	8.00	0.00	100
2	0.00	0.00	0.00	10.84	5.91	0.00	16.75	0.01	99
3	0.00	0.00	0.00	3.57	1.30	0.00	4.87	0.00	100
4	25.60	10.97	29.25	6.89	2.03	0.00	74.74	0.04	96
5	0.00	5.23	1852.72	28.96	16.22	0.00	1903.13	1.00	0
6	11.09	11.09	898.50	14.94	6.21	0.46	942.29	0.50	50
7	0.00	0.00	0.00	3.30	0.47	0.00	3.77	0.00	100
8	0.00	13.69	1642.94	8.31	0.64	0.00	1665.58	0.88	12
9	11.82	2.95	215.64	18.68	8.32	2.77	260.18	0.14	86
10	5.01	5.01	127.73	12.44	5.30	0.23	155.72	0.08	92
11	0.00	10.90	326.90	15.24	5.97	0.00	359.01	0.19	81
12	9.78	9.78	29.35	13.17	5.61	0.00	67.69	0.04	96
13	0.00	0.00	0.00	17.88	9.55	0.24	27.67	0.01	99
14	5.89	0.00	0.00	5.03	1.01	0.18	12.11	0.01	99
15	5.73	11.46	933.80	4.96	2.75	0.00	958.70	0.50	50
16	0.00	1.89	16.97	10.77	6.06	0.45	36.14	0.02	98
17	0.00	0.00	0.00	20.19	7.69	0.72	28.60	0.02	98
18	4.28	10.70	822.10	10.56	4.11	0.00	851.75	0.45	55
19	1.12	0.00	0.00	12.96	6.42	0.00	20.50	0.01	99
20	11.11	5.56	44.46	9.76	1.83	0.00	72.72	0.04	96
21	8.17	3.27	374.13	17.86	5.49	0.00	408.92	0.21	79
22	17.58	12.89	1681.39	15.49	6.62	0.65	1734.62	0.91	9
23	7.85	30.10	1554.50	12.13	3.87	0.09	1608.54	0.85	15
24	8.26	1.18	73.17	14.63	9.69	1.70	108.63	0.06	94
25	7.18	3.59	33.75	8.54	1.99	0.51	55.56	0.03	97
26	10.08	2.33	127.93	17.93	6.17	0.23	164.67	0.09	91
27	12.27	6.46	113.64	19.76	10.89	0.24	163.26	0.09	91
28	4.01	1.60	171.43	9.39	3.30	0.57	190.30	0.10	90
29	6.71	1.79	147.07	12.93	3.49	0.17	172.16	0.09	91
30	3.97	3.66	119.68	6.04	1.93	0.06	135.34	0.07	93
31	7.30	4.03	387.77	17.41	4.31	0.17	420.99	0.22	78

Modified Safe Performance Index using 2009 data

Following completion of the pilot study, MSHA 2009 data was captured to examine primarily the fluctuations in the SPI for the 31 mines. As this process unfolded in early 2010, the Upper Big Branch-South Mine disaster occurred and issues related to the ineffectiveness of the Pattern of Violations process were emphasized in the mainstream press and media, and to the U.S. Congress (Smith, 2010). This sparked an examination of all underground longwall coal mines as compared to the pilot-sample mines. Added to the list of mines to examine were the underground coal mines given to Congressman Miller (Chair, of the U.S. House Education and Labor Committee) by MSHA as 'dangerous' mines and mines that were targeted for special inspections by MSHA following the disaster. Ultimately, MSHA 2009 accident, injury and citation data were captured to form a database comprised of 107 mines. This provided a robust database (30% of all mines) for examining the overall value of the Safe Performance Index in specifying the relative risk of the mines and in identifying the high-risk underground coal mines. The 2009 MSHA data for the upper 5%, middle 5%, and lower 5%, representing the best-performing, average-performing, and worst-performing mines, respectively, of the 107 mines is given in Table **3-3**. The formulas to calculate each of the six normalized safety measures are given on the Appendix B.

Table 3-3. MSHA 2009 Safety Data on Upper 5%, Middle 5%, and Lower 5% of 107 Underground Coal Mines.

Mine ID	# NLT	# LT	Days Lost	# Fatals	Empl Hours	# Citations	# S&S	# Orders	Insp Hrs
Pilot Mine 3	0	0	0	0	15925	13	0	0	306.25
LW-19	17	0	0	0	370524	47	16	0	2225.50
LW-26	1	1	148	0	482319	80	12	0	1064.50
LW-25	2	1	27	0	772482	178	38	1	1807.00
LW-14	15	4	60	0	893530	160	37	0	1522.00
Pilot Mine 14	2	0	0	0	26612	24	9	0	485.75
					⋮				
LW-11	26	9	418	0	414021	355	71	10	1635.75
MB-13	6	4	97	0	166376	229	66	5	850.50
ML-15	13	13	471	0	451091	360	147	5	1584.25
LW-7	7	14	801	0	343844	250	28	0	965.00
ML-8	3	0	0	0	266533	715	205	36	2384.00
MB-28	16	5	152	0	204501	582	241	3	1890.75
					⋮				
LW-31	15	9	286	0	482132	517	202	56	1848.00
MB-22	6	6	179	0	169676	125	64	12	481.00
MB-16	8	4	3064	0	254779	437	85	4	2110.75
ML-2	15	11	6062	0	541880	619	198	14	2001.75
MB-12	13	12	6616	0	470964	322	134	2	2148.75
MB-9	6	13	6658	1	476391	362	138	3	2087.75

LW = Longwall mine; MB = MSHA blitz mine; ML - MSHA List to Congressman Miller

In order to better reflect the impact of fatalities and full and partial disabilities, the Severity Measure was modified to include statutorily charged days. Scrutiny of the previous model for calculating the SPI showed, for the larger sample, that the modified Severity Measure and to a lesser extent a couple of other measures would heavily influence the combination of the component measures. In order to avoid any heavy influence of an individual safety measure on the mine's SPI, each measure was scaled to have the same mean (5.00); essentially the data dispersion remained the same. After much iteration, it was determined that 5.00 was the best value based on the statistical distribution of the SPI and this approach allowed the weighting factors to weigh in properly, as designed (refer to Appendix C). Once equality of means was achieved, then the weighting factors were used to place proper weights on the most serious safety-compromising components, e.g., Severity Measure/100 and Orders/100 IH. Below the criteria used for assigning proper weights on safety measures are given.

Every underground coal mine in the U.S. is inspected by an MSHA inspector on a quarterly basis to check whether a mine is complying with the mandatory health and safety standards. During an inspection, the MSHA inspector(s) issue citation(s) for mandatory health and safety standards that are violated and determine the degree of seriousness based on tabled criteria and their judgment. According to case law (MSHA, 2010a), ''significant and substantial violations, which are more serious, must have four elements proved:

1. The underlying violation of a mandatory standard.
2. The existence of a discrete safety hazard contributed to by the violation.
3. A reasonable likelihood that the hazard contributed to will result in an injury.
4. A reasonable likelihood that the injury in question will be of a reasonably serious nature.''

If a violation is caused by an unwarrantable failure, where MSHA has determined that the ''mine operator has engaged in aggravated conduct constituting more than ordinary negligence'', then a withdrawal order is generally issued, and ‘‘a reasonable amount of punitive charges’’ are assessed (MSHA, 2010b). Thus, a weight of 0.05 was given to Citations/100 IH, 0.15 was given to SS/100 IH, and 0.30 was given to Orders/100 IH. In order to balance the consideration of accident and citation in determining a mine’s safety performance an equal weighting of the accident measures and citation measures are used. The case for accident/injury safety measures (NDL IR, NFDL IR, and Severity Measure/100) are similarly assigned analogous weighting factors based on the seriousness of the accidents. The weights assigned to the safety measures reflects the seriousness of the measures, i.e. the more serious the measure, the higher the weighting factor is. To achieve proper weighting factors, their sum was forced to 1. The SPI was then calculated as the sum of the weighting factors times the component measures and the resulting SPI average for all the mines was 66.65 each year. Table 3-4 shows the results of the scaled measures for mines given in Table **3-3**.

Table 3-4. Scaled Values for SPI Components for Upper 5%, Middle 5%, and Lower 5% of 107-Mine MSHA 2009 Data Sample.

Mine ID	**NDL IR**	**NFDL IR**	**SM/100**	**C/100 IH**	**SS/100 IH**	**O/100 IH**
Pilot Mine 3	0.00	0.00	0.00	1.00	0.00	0.00
LW-19	7.14	0.00	0.00	0.50	0.51	0.00
LW-26	0.32	0.62	0.60	1.76	0.81	0.00
LW-25	0.40	0.38	0.07	2.31	1.50	0.32
LW-14	2.61	1.33	0.13	2.47	1.74	0.00
Pilot Mine 14	11.70	0.00	0.00	1.16	1.32	0.00
			• • •			
LW-11	9.77	6.45	1.98	5.09	3.10	3.59
MB-13	5.61	7.13	1.15	6.32	5.54	3.45
ML-15	4.49	8.55	2.05	5.33	6.63	1.85
LW-7	3.17	12.08	4.58	6.08	2.07	0.00
ML-8	1.75	0.00	0.00	7.04	6.14	8.86
MB-28	12.18	7.26	1.46	7.23	9.10	0.93
			• • •			
LW-31	4.84	5.54	1.17	6.57	7.81	17.77
MB-22	5.50	10.49	2.07	6.10	9.50	14.63
MB-16	4.89	4.66	23.63	4.86	2.88	1.11
ML-2	4.31	6.02	21.98	7.26	7.07	4.10
MB-12	4.30	7.56	27.60	3.52	4.45	0.55
MB-9	1.96	8.10	27.46	4.07	4.72	0.84

Note: The means for each measure were scaled to 5.

In examining the calculations of the SPI using the original approach, it was found that dividing each mine's PI by an extremely high PI for the worst-performing mine would excessively inflate SPI values for the other mines. Because of this inflation, very few mines would have an SPI that fell below 50, even though some of the mines had one or more relatively poor safety measures. Thus to achieve a reasonable SPI that would be practically applicable in targeting poor-performing mines, a value of 15 was selected to normalize the PI for all mines (see

Appendix C). In the SPI calculation, poor-performing mines with PI values greater than 15 would then get negative SPI values for reporting purposes; these would be assigned the lowest SPI value of zero. As shown in Appendix C, the overall SPI distribution of 2009 mines from the scaled means of 5 and the normalizing factor of 15 looks similar to a normal distribution. Using fixed values of 5 for the scaled means of the safety measures and 15 for normalizing the PI, a straight-forward and transparent methodology was thus developed for the screening of poor-performing mines. In this way, each stakeholder group would use the same methodology when making SPI calculations. The results of the SPI calculations are given in Table **3-5** for the mines listed in Table **3-3** and Table **3-4**.

Table 3-5. PI, Normalized PI and SPI Values for Upper 5%, Middle 5%, and Lower 5% of 107-Mine MSHA 2009 Data Sample.

Mine ID	PI	Norm PI	SPI
Pilot Mine 3	0.05	0.00	99.7
LW-19	0.46	0.03	96.9
LW-26	0.50	0.03	96.7
LW-25	0.54	0.04	96.4
LW-14	0.75	0.05	95.0
Pilot Mine 14	0.84	0.06	94.4
		. . .	
LW-11	3.85	0.26	74.4
MB-13	3.88	0.26	74.2
ML-15	3.94	0.26	73.7
LW-7	3.96	0.26	73.6
ML-8	4.02	0.27	73.2
MB-28	4.14	0.28	72.4
		. . .	
LW-31	8.25	0.55	45.0
MB-22	8.59	0.57	42.7
MB-16	9.04	0.60	39.7
ML-2	10.37	0.69	30.9
MB-12	10.64	0.71	29.1
MB-9	10.71	0.71	28.6

Paper 2: Assessing small underground coal mines for high safety-related risk

This paper focuses on comparing high safety-related risk measures for very small and small mines versus medium and large mine-sizes.

The citation data and accident/injury data for the years 2008 and 2009 were downloaded from the MSHA website (MSHA, 2010c). The mines with zero production and inspection hours were filtered out. In 2008, after filtering, there were 583 underground coal mines and in 2009, there were 539. The mines were categorized based on the average number of employees in a mine. The four categories were very small mines, small mines, medium mines, and large mines, defined as shown in the Table **3-6**.

Table 3-6. Mine-size categorization based on the number of average employees in a mine.

Mine Size	**Number of Employees**	**2008**	**2009**
Very Small	≤ 19 employees	161	139
Small	19 < employees ≤ 49	218	184
Medium	49 < employees ≤ 99	96	103
Large	> 99 employees	108	113

The mine-size categorization adopted in this study is similar to MSHA categorization except for reducing the number of mine-size categories from nine to four. Table **3-6** shows that in 2008 there were 161 very small mines, 218 small mines, 96 medium mines, and 108 large mines, while in 2009 there were 139 very small mines, 184 small mines, 103 medium mines, and 113 large mines. There were 11 and 3 mines with less than 5 employees in 2008 and 2009, respectively, and 43 (26.7%) and 31 (22.3%) mines with less than 9 employees in 2008 and 2009, respectively. In 2008, 122 (75.77%) very small mines and 79 (36.24%) small mines did not have a lost–time accident whereas in 2009, 105 (75.54%) very small mines and 73 (39.67%) small mines did not have a lost-time accident.

High safety-related risk measures

This study used the six normalized safety measures that were incorporated in the Safe Performance Index (SPI) methodology (Kinilakodi and Grayson, 2011a), which was used to benchmark superior safety performance, including by mine size and type of mining, or for screening mines for improvement efforts.

The six normalized safety measures are:

- No days-lost incidence rate (NDL IR)
- Non-fatal days-lost incidence rate (NFDL IR)
- Severity measure (SM/100)
- Citations per 100 inspection hours (C/100 IH)
- Significant and Substantial (S&S) citations per 100 inspection hours (S&S/100 IH)
- Orders per 100 inspection hours (O/100 IH)

The severity measure incorporated statutorily charged days along with lost and restricted workdays. This modification places higher visibility on the most severe injuries.

Test of Significance

The safety measures were calculated as described in Kinilakodi and Grayson (2011a) but without scaling the safety measures' mean to 5.00 and tested for normality. The probability plot indicated that it was not normal and the variances of the safety measures were different. The non-parametric Mann Whitney test was used for statistical comparisons, which uses the safety measures' median instead of the mean. The test assumes that the populations are independent and have similar shapes and spreads (need not be symmetric), which is the case for this data. A statistical software (Minitab) was used for statistical comparisons.

Paper 3: Tracking mine safety performance trends to assess the risk for a fatality

The accident/injury data and the violation/citation data for the years 2007 to 2010 were downloaded through the Open Governmental Data Sets link on the MSHA website (MSHA, 2010c). The mines with no production and inspection hours were excluded. In 2007, there were 563 underground coal mines, 583 in 2008, 539 in 2009 and 496 in 2010. In order to evaluate the mines with a fatality in 2007, the two years (2005 and 2006) preceding the occurrences of a fatality were also downloaded to construct the SPI. Using the MSHA fatalgrams (MSHA, 2011), the number of mines with a fatality were noted for the years 2007-2010. There were 40 mines that had single or multiple fatalities, which led to 78 fatalities in total.

In this paper, a semi-quantitative risk-based methodology is developed using the SPI and its six safety measures for tracking the mine safety performance trends and assessing the risk for a fatality. The SPI is a balanced methodology, which encompasses three accident/injury and three violation safety measures. As described in Kinilakodi and Grayson (2011a), the six safety measures are the no days-lost incidence rate (NDL IR), the non-fatal days-lost incidence rate (NFDL IR), the severity measure (SM/100), citations per 100 inspection hours (C/100 IH), significant and substantial (S&S) citations per 100 inspection hours (S&S/100 IH), and orders per 100 inspection hours (O/100 IH). Using fixed value of 5.00 for the scaled means of the safety measure, which becomes the industry average, makes the process transparent and reproducible by any stake-holder. In combining these measures into the SPI, weighting factors of 0.05, 0.15, 0.3, 0.05, 0.15, and 0.3, respectively, were used and the resulting SPI average for all the mines was 66.65 each year. The weights assigned to the safety measures reflects the seriousness of the measures, i.e. the more serious the measure, the higher the weighting factor is. In order to avoid any heavy influence of an individual safety measure on the mine’s SPI, each measure was scaled to have the same mean. After much iteration, it was determined that 5.00 was the best value based on the statistical distribution of the SPI and this approach allows the weighting factors to weigh in properly.

In applying the methodology, the health and safety risk that existed at the mines in the two years preceding the occurrence of a fatality is scrutinized. Once the data is downloaded, they are segregated by year (2005 – 2010) and necessary information such as employee hours worked, the number of lost-time accidents, the non-fatal days lost, the number of citations, the number of S&S citations, the number of withdrawal orders, and on-site inspector hours are tabulated to calculate the SPI for each year separately. For each year, the SPI is divided into four quartiles, I, II, III, and IV, based on the descending SPI score. Quartile I represents the top SPI score (good-performing mines) and quartile IV represents the lowest SPI score, generally, below average or poor-performing mines. Next the mine safety performances are categorized into five categories based on the SPI and six safety measures trend as shown in the Table **3-7**.

Table 3-7. Tracking Categorization based on the Mine Safety Performance.

Abbreviation	**Description**	**SPI Quartile**	**Number of Measures***	**Trends$**
P	Predictable	I – II to III – IV	4 – 5	Increasing
SP	Somewhat Predictable	I – II to III – IV	3 – 4	Increasing or decreasing
BA	Below Average	III – IV (SPI< 66.00)	2 – 3	Decreasing
A, F,U $_{wc}$	Average/Fluctuating/Unpredictable (with clues)	I – IV	1 – 2	Erratic or none
A, F,U $_{nc}$	Average/Fluctuating/Unpredictable (no clues)	I – IV	0 – 1	None

Note: * Number of measures out of six
$ Measures trend (above the mean of 5) from the preceding years

In this paper, an attempt is made to define the predictable nature of the mine safety performance trends and evaluate the risk that existed at the mines two years preceding the occurrence of a fatality. The P, SP, BA, and $A/F/U_{wc}$ represent mines which probably had sufficient information to recognize a trend and predict a fatality and $A/F/U_{nc}$ represent mines which probably had insufficient information to identify a trend and predict a fatality. The mine safety performance trend is categorized as 'predictable', if the SPI of the mine deteriorates from quartile I or II to quartile III or IV and five or four of the safety measures' values are above the mean of 5.00 and have an increasing trend from the preceding years.

Similarly, a mine is categorized as 'somewhat predictable', if the SPI deteriorates from quartile I or II to quartile III or IV and four or three of the safety measures' values are above the mean of 5.00, and have a decreasing or increasing trend from the previous years. A mine is categorized as 'below average', if the SPI is below 66.00 and three or two of safety measures' values are above the mean of 5.00, and have a decreasing trend compared to the previous years. A mine is categorized as 'average', if the SPI is in quartile III and two or one of the safety measures' values are near the mean of 5.00, but decreasing or increasing from the previous years; 'fluctuating', if the mine SPI varies from quartile I to IV in no particular order and two or one of the safety measure(s) has erratic values compared to the previous years; 'unpredictable', if the SPI of the mine is in the quartile I or II and six or five of the safety measures' values are below the mean of 5.00, and have no trends compared to the previous years. The average/fluctuating/unpredictable category is designated as 'with clues', if one or two safety measure(s) values is (are) greater than or equal to the mean of 5.00 and have increasing or decreasing trends compared to the previous years. Similarly, if there is no trend in the safety measures and the SPI, then the average/fluctuating/unpredictable category is designated as 'no clue'.

Paper 4: Evaluating equivalence of the Safe Performance Index (SPI) to a traditional risk analysis

In this paper, a risk analysis method is developed and compared with the previously developed SPI methodology. Comparison is made to evaluate the equivalence of the SPI in assessing the risk of accident and citation data of differing severity in a combined measure (the SPI) to a risk analysis approach.

Risk Analysis

Generally, risk is defined as the product of the probability of occurrence (frequency) of an event and its severity of impact. In this study, the probability of occurrence is the normalized safety measure and severity is determined from the relative level of associated loss. For example, a general citation has low severity, an S&S citation has medium severity, and an order has high severity; a similar scheme is applied to the accident/injury measures. Accordingly, a risk analysis approach is developed by assigning five risk levels (very low, low, medium, high, and very high) to the six normalized safety measures, which are calculated using downloaded calendar-year data on injuries, employee-hours worked, citations, and inspection hours.

The six safety measures are the no days-lost incidence rate (NDL IR, number of no lost-time accident/injuries per 200,000 employee hours), the non-fatal days-lost incidence rate (NFDL IR, number of lost-time injuries per 200,000 employee hours), the severity measure (SM/100, number of statutory, restricted, and lost work days per 200,000 employee hours, divided by 100), the number of citations per 100 inspector hours (C/100 IH), the number of significant and substantial citations per 100 inspector hours (SS/100 IH), and the number of withdrawal orders and unwarrantable failures per 100 inspector hours (O/100 IH).

Each measure's range of values is divided into five equal intervals in ascending order, and risk values of 1 (very low), 2 (low), 3 (medium), 4 (high), and 5 (very high) are assigned accordingly. In the majority of the cases, there will be few extreme values that influence the determination of the ranges of values for a normalized safety measure, and in this case, it was no different. In order to negate the influence of extreme values, the boxplot method, available in the Minitab statistical software (Minitab, 2011), is used to determine the lower quartile, upper quartile, and interquartile range values. In examining the data, the boxplot, a non-parametric statistical method, is used to identify outliers and extreme outliers without making any assumptions about the population distribution. For each normalized safety measure, the interquartile range (IQR: the absolute difference between the upper and lower quartile) is calculated using the values from the boxplot as shown in Figure **3-1**, Figure **3-2**, Figure **3-3**, and Figure **3-4**. The outliers and extreme outliers are calculated as follows (Ott and Longnecker, 2001):

IQR = upper quartile (Q3) – lower quartile (Q1) …...…………… Equation (1)

Outlier > upper quartile (Q3) + 1.5 (IQR) ………………………… Equation (2)

Extreme Outlier > upper quartile (Q3) + 3.0 (IQR) ……...………… Equation (3)

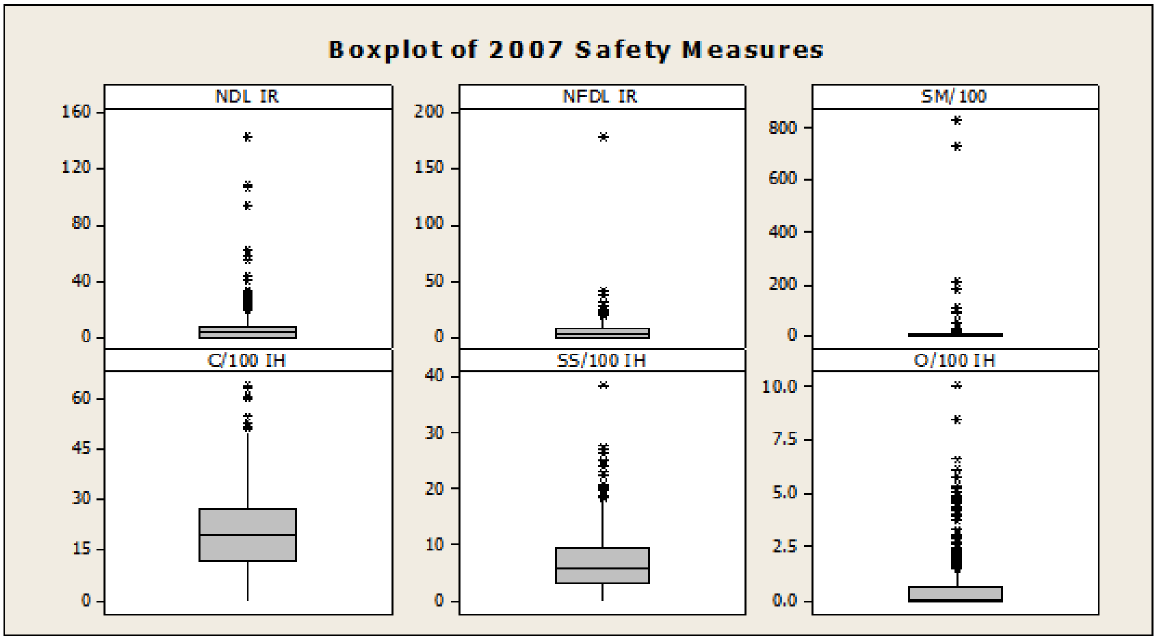

Figure 3-1. Boxplot of 2007 safety measures

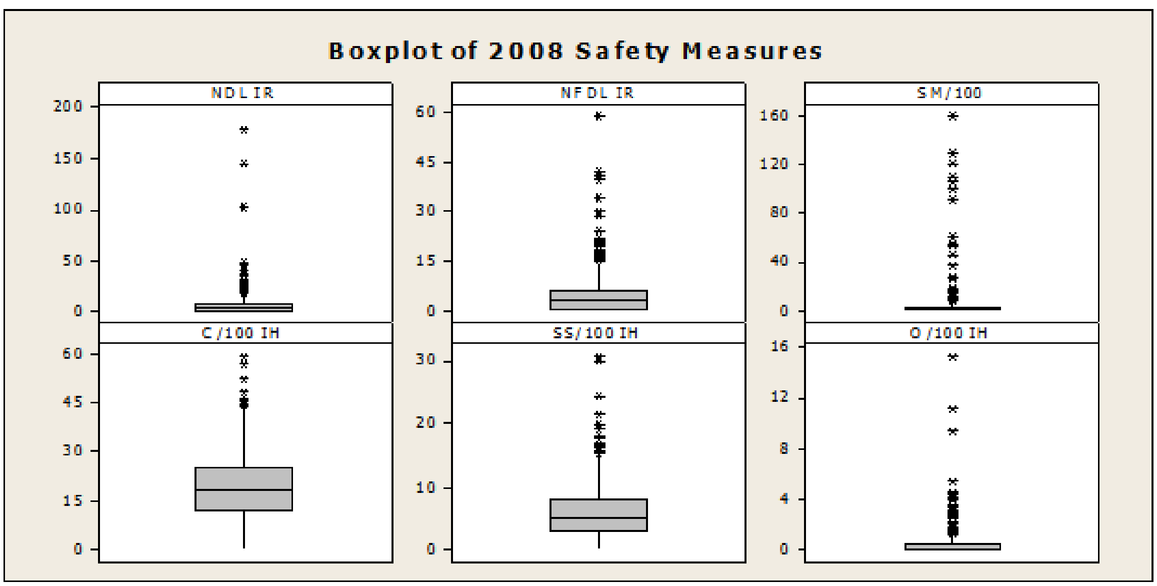

Figure 3-2. Boxplot of 2008 safety measures

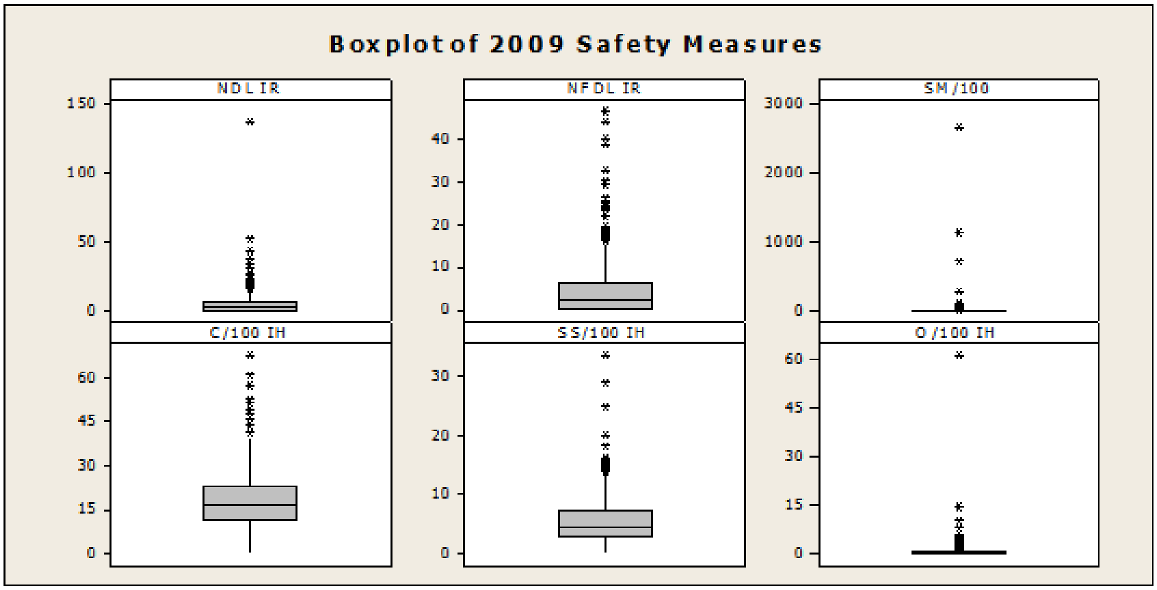

Figure 3-3. Boxplot of 2009 safety measures

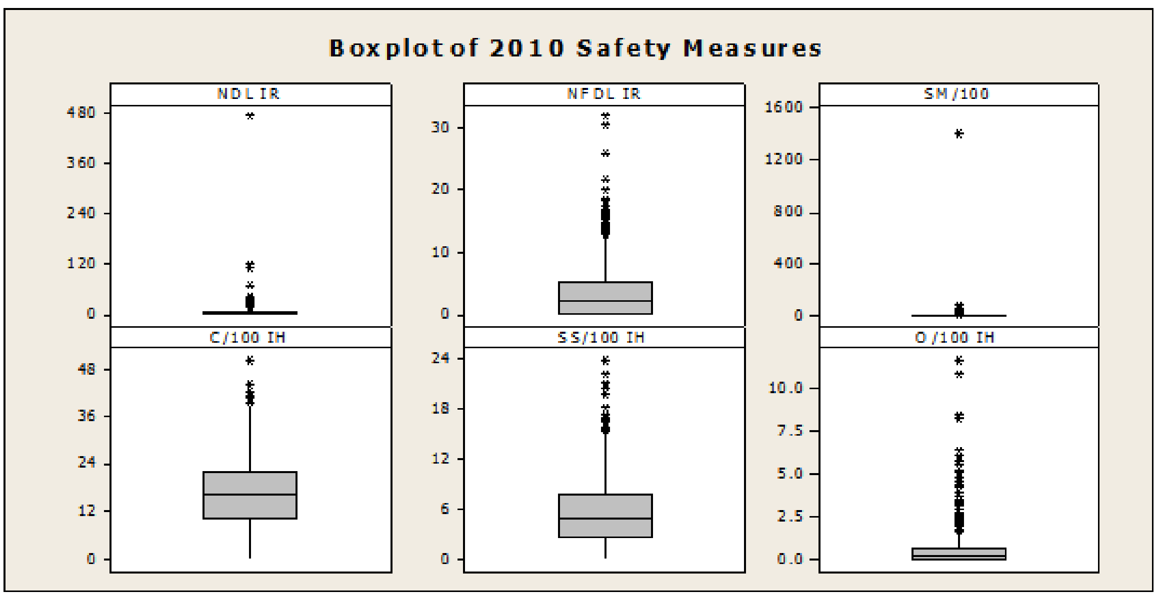

Figure 3-4. Boxplot of 2010 safety measures

In this paper, extreme outliers are identified and excluded from the process of determining the five equal intervals of values for each safety measure. However, the extreme values are included when assigning the risk value, and they were assigned a very high risk value

(5). For each mine's safety measures, based on the interval values for each safety measure, a corresponding risk value is assigned to convert it to a risk measure. The new risk measure has values ranging from 1 (very low risk) to 5 (very high risk). To form the risk index for a mine, the weights 0.05, 0.15, 0.30, 0.05, 0.15, and 0.30 are used as pre-multipliers for RNDL, RNFDL, RSM, RC, RSS, and RO, respectively, which are symbols for the no days lost risk, the non-fatal days-lost risk, the severity measure risk, the citation risk, the S&S-designated citation risk, and the types of orders risk, respectively, and the products are summed. The weighting factors vary according to the severity of the various measures; for example, orders are the most severe citations that can be issued by inspectors, thus they get the highest weighting factor. Note that the sum of the weighting factors equals 1, appropriately, and the sum of weights for the injury experience (three measures) and the citation experience (three measures) are each 0.5. The opinion is that the injury experience and the citation experience should have equal weights for a mine safety performance index to be well-balanced. This method represents a traditional risk-analysis approach using a new risk measure that embraces frequency and severity in the final equation.

An in-depth explanation on criteria for choosing the six safety measures and the corresponding weighting factors to form the SPI was given in earlier papers. In this paper, the same methodology is used to calculate the SPI of each mine for the years 2007 to 2010 which are then compared to the results of the risk-index analysis. It is noted that the West Virginia Coal Association (WVCA) and Arch Coal Company have given statements at regulatory hearings on the POV process in support of using the SPI. Arch Coal's Tony Bumbico "noted that MSHA should consider SPI, a holistic measure that more equitably blends injury and enforcement data" (Sharpe, 2011). The SPI methodology was also explicitly proposed in the U.S. House of Representatives' bill H.R. 5788 to target "poor" mine safety performances.

Chapter 4

RESULTS AND DISCUSSIONS

Introduction

In this chapter, the results obtained from the methodologies explained from the 4 papers are discussed. Also, an overview of the underground coal mine safety performance over the decade is discussed last.

Paper 1: A methodology for assessing underground coal mines for high safety related risk

In analyzing the SPI results for the 107-mine sample, comparisons of various metrics were made among the top 10% (best-performing), middle 10% (average-performing), and bottom 10% (worst-performing) mines. The best-performing 10% SPI mines, shown in Table **4-1**, are characterized as follows:

- All of them had an NFDL IR and SM/100 much less than the averages for all mines.
- Ten of 11 of them had a SS/100 IH and all of them had an O/100 IH much less than the averages for all mines.
- Ten of the 11 mines had no withdrawal orders or unwarrantable failure citations.
- Five pilot mines and six longwall mines were in the list.
- Significantly, only one mine on the MSHA list of targeted mines for special inspection made the list.

Table 4-1. Top 10% SPI Best-Performing Mines.

Mine ID	SPI	NDL IR	NFDL IR	SM/100	C/100 IH	SS/100 IH	O/100 IH
Pilot Mine 3	99.7	0.00	0.00	0.00	1.00	0.00	0.00
LW-19	96.9	7.14	0.00	0.00	0.50	0.51	0.00
LW-26	96.7	0.32	0.62	0.60	1.76	0.81	0.00
LW-25	96.4	0.40	0.38	0.07	2.31	1.50	0.32
LW-14	95.0	2.61	1.33	0.13	2.47	1.74	0.00
Pilot Mine 14	94.4	11.70	0.00	0.00	1.16	1.32	0.00
Pilot Mine 12	94.0	3.97	0.00	0.00	4.21	3.25	0.00
LW/Pilot Mine 28	92.3	2.52	1.44	1.82	2.51	0.91	0.00
LW-18	92.3	3.71	3.20	0.63	1.44	1.51	0.00
MB-17	91.9	3.42	0.00	0.00	6.07	4.92	0.00
Pilot Mine 27	91.1	5.00	1.91	0.09	4.20	3.70	0.00
Scaled Averages	73.2	5.00	5.00	5.00	5.00	5.00	5.00

The average-performing 10% SPI mines, shown in Table **4-2**, have expected characteristics. They are characterized as follows:

Table 4-2. Middle 10% SPI Average-Performing Mines.

Mine ID	SPI	NDL IR	NFDL IR	SM/100	C/100 IH	SS/100 IH	O/100 IH
LW-6	74.9	2.51	3.83	0.86	3.44	2.71	7.43
LW-11	74.4	9.77	6.45	1.98	5.09	3.10	3.59
MB-13	74.2	5.61	7.13	1.15	6.32	5.54	3.45
ML-15	73.7	4.49	8.55	2.05	5.33	6.63	1.85
LW-7	73.6	3.17	12.08	4.58	6.08	2.07	0.00
ML-8	73.2	1.75	0.00	0.00	7.04	6.14	8.86
MB-28	72.4	12.18	7.26	1.46	7.23	9.10	0.93
ML-22	72.2	4.43	0.00	0.00	5.81	4.88	9.75
LW-9	72.2	2.96	4.70	0.96	5.54	2.70	7.83
MB-1	70.9	5.74	3.52	0.91	6.21	6.82	6.50
MB-25	70.5	0.93	0.00	0.00	6.07	6.34	10.42
Scaled Averages	73.2	5.00	5.00	5.00	5.00	5.00	5.00

- Three mines (LW-7, MB-25, and MB-28) had a single measure that was more than two times the scaled mean of a metric, but in each case two or more metrics were significantly lower than the other metrics, including some with higher weighting factors.
- In one case (MB-1), the mine had four metrics that were 15–36% higher than their means, but one metric with the highest weighting factor was very low, thereby keeping the mine near average.
- Three mines (LW-6, LW-9, and ML-22) had four or five metrics below their respective means, including one in a highly weighted metric that offset another highly weighted metric that was significantly above its respective mean.
- In one case (ML-8), the mine's injury metrics were all excellent, and offset the citation metrics that were somewhat higher than their respective means.
- In the final three mines (LW-11, MB-13, and ML-15), somewhat elevated but lower-weighted metrics were offset by the highest-weighted metrics that were significantly lower than their respective means.
- Intuitively, these are the types of performances expected in the middle 10% group. Trade-offs among metrics occurs, but there are no highly weighted metrics that have values much higher than their means.

The worst-performing 10% SPI mines, shown in Table **4-3**, are characterized as follows:

- For six of the mines (LW-22, LW-31, MB-2, MB-14, and MB-20), a very high rate for SS/100 IH and/or O/100 IH got them on the list.
- For five of the mines, a very high rate for SM/100 got them on the list.
- Four mines had five elevated metrics versus the means for the metrics, while three mines had four elevated metrics versus their means.

Table 4-3. Bottom 10% SPI Poorest-Performing Mines.

Mine ID	SPI	NDL IR	NFDL IR	SM/100	C/100 IH	SS/100 IH	O/100 IH
LW-22	51.4	4.65	8.87	3.04	5.99	3.51	13.30
LW-31	45.0	4.84	5.54	1.17	6.57	7.81	17.77
MB-22	42.7	5.50	10.49	2.07	6.10	9.50	14.63
MB-16	39.7	4.89	4.66	23.63	4.86	2.88	1.11
ML-2	30.9	4.31	6.02	21.98	7.26	7.07	4.10
MB-12	29.1	4.30	7.56	27.60	3.52	4.45	0.55
MB-9	28.6	1.96	8.10	27.46	4.07	4.72	0.84
MB-14	2.6	3.85	14.69	1.02	8.37	12.45	32.09
MB-2	0.0	18.92	18.04	0.36	16.52	24.45	61.35
MB-8	0.0	7.41	0.00	280.48	7.03	6.84	15.80
MB-20	0.0	8.27	5.26	0.07	14.17	21.48	88.86
Scaled Averages	73.2	5.00	5.00	5.00	5.00	5.00	5.00

Thus, poor performances on either the injury experience or the citation experience can lead to targeting for interventions, or several worse-than-average performances can earn greater scrutiny.

Following discussions with representatives from Congressman Miller's office and jointly with several vice presidents in charge of underground coal mine safety, the findings of the application of the Safe Performance Index and its ability to target poor-performing mines were given in testimony before the U.S. House Education and Labor Committee on July 13, 2010. A new screening method, designed to replace the existing POV process was included in the Robert C. Byrd Miner Safety and Health Act of 2010, which uses similar metrics, with weighting factors to be determined through interim rulemaking whenever the bill passes through the Congressional processes. At present, the bill has not been passed by the U.S. House of Representatives, and in early 2011 it was introduced in the U.S. Senate. The methodology to target truly poor-performing mines for heightened enforcement action would then be implemented and its effectiveness as a screening tool could be determined.

Paper 2: Assessing small underground coal mines for high safety-related risk

The accident and citation data for 2008 and 2009 pertaining to all mines were analyzed. The six safety measures were calculated separately for all the mines for 2008 and 2009, and then grouped according to their mine size as shown in Table **3-6**. The median and the mean of safety measures for different mine-size categories are shown in Table **4-4** and Table **4-5**.

Table 4-4. Safety Measures' Median for Different Mine-Size Categories: 2008 – 2009.

Safety Measures	***Very Small***		***Small***		***Medium***		***Large***	
	2008	2009	2008	2009	2008	2009	2008	2009
NDL IR	0.00	0.00	3.48	2.57	4.73	4.69	4.88	4.08
NFDL IR	0.00	0.00	3.36	3.01	4.36	4.06	3.71	3.29
SM/100	0.00	0.00	1.05	0.74	1.87	2.18	2.40	2.33
C/100 IH	18.18	15.89	18.69	17.33	19.10	17.95	16.73	15.53
SS/100 IH	4.90	4.14	5.56	5.28	6.00	4.87	4.83	4.29
O/100 IH	0.00	0.00	0.00	0.00	0.16	0.14	0.19	0.15

Table 4-5. Safety Measures' Mean for Different Mine-Size Categories: 2008 – 2009.

Safety Measures	***Very Small***		***Small***		***Medium***		***Large***	
	2008	2009	2008	2009	2008	2009	2008	2009
NDL IR	5.45	4.81	5.57	4.80	6.00	5.57	6.14	4.99
NFDL IR	3.48	3.59	4.69	5.33	5.05	5.13	4.64	4.23
SM/100	2.25	17.02	5.86	19.28	4.08	5.94	3.76	4.19
C/100 IH	19.80	18.10	19.84	18.46	19.51	18.48	17.49	16.13
SS/100 IH	6.29	5.60	6.41	5.92	6.16	5.77	5.45	4.90
O/100 IH	0.71	0.68	0.45	0.81	0.37	0.40	0.33	0.30

There were few major differences in the median and mean values for the very small mines between years. In 2008 and 2009, the median of NDL IR, NFDL IR and SM/100 was zero, as 75% of the very small mines did not have a lost-time accident. Similarly, the O/100 IH median was zero, as 63% of the very small mines and 53% of the small mines did not have an order. However, the mean values of these safety measures were not zero. Comparison of the mean and median (2009) values of SM/100 for very small and small mines indicates a heavy influence of very severe injuries in a number of mines. Before comparing the safety measures of different mine-size categories, the same mine-size categories were compared for statistical differences in their respective safety measures, for the years 2008 and 2009, as shown in Table **4-6**. As expected, the safety measure results within the same mine-size category were not significantly different in 2008 and 2009, except for NDL IR in the large mines. This indicates that each mine-size category had a similar performance in 2008 and 2009, except for NDL IR in the large mines.

Table 4-6. Statistical Comparison of Safety Measures for Same Mine-Size Categories: 2008 – 2009.

Safety Measures	**Test**	***V Small - V Small***		***Small - Small***		***Medium - Medium***		***Large - Large***	
		p-value	Signi-ficant	p-value	Signi-ficant	p-value	Signi-ficant	p-value	Signi-ficant
NDL IR	Not equal	0.0618	No	0.2538	No	0.9352	No	*0.0306*	*Yes*
NFDL IR	Not equal	0.8026	No	0.8022	No	0.7834	No	0.2747	No
SM/100	Not equal	0.6847	No	0.8330	No	0.2136	No	0.8063	No
C/100 IH	Not equal	0.1163	No	0.1335	No	0.5131	No	0.1167	No
SS/100 IH	Not equal	0.0988	No	0.1755	No	0.2598	No	0.1790	No
O/100 IH	Not equal	0.9361	No	0.3036	No	0.6900	No	0.4202	No

Note: p-values are adjusted for ties; level of significance 'α' = 0.05

The statistical comparison results for 2008 data of very small and small mines versus medium and large mines are shown in Table **4-7**. A statistical comparison of the six safety measures (2008 data) for very small mines, versus medium and large mines, indicates that the medians for the four safety measures (NDL IR, NFDL IR, SM/100 and O/100 IH) were significantly lower for the very small mines. The small mines' accident rates (NDL IR, NFDL IR and SM/100) were significantly lower than those of medium and large mines. The order rate (O/100 IH) of small mines was significantly lower, but the citation and the SS rates (C/100 IH and SS/ 100 IH) were significantly greater than those of large mines. The small mines had relatively poorer safety compliance for the citation and the SS rates compared to the large mines.

Table 4-7. Statistical Comparison of Safety Measures For Different Mine-Size Categories: 2008.

Safety Measures	**Test**	***V Small - Medium***		***V Small - Large***		***Small - Medium***		***Small - Large***	
		p-value	Signi-ficant	p-value	Signi-ficant	p-value	Signi-ficant	p-value	Signi-ficant
NDL IR	Less than	0.0000	Yes	0.0000	Yes	0.0129	Yes	0.0011	Yes
NFDL IR	Less than	0.0000	Yes	0.0000	Yes	0.0297	Yes	0.0342	Yes
SM/100	Less than	0.0000	Yes	0.0000	Yes	0.0046	Yes	0.0000	Yes
C/100 IH	Less than	0.4520	No	0.0953	No	0.4836	No	0.0448	Yes
SS/100 IH	Less than	0.1319	No	0.4828	No	0.4728	No	0.0408	Yes
O/100 IH	Less than	0.0116	Yes	0.0003	Yes	0.1658	No	0.0249	Yes

Note: p-values are adjusted for ties; level of significance 'α' = 0.05

Test: Greater than

A similar statistical comparison of the safety measures (2009 data) of very small and small mines versus medium and large mines is shown in Table **4-8**. Consistent with 2008 results, very small and small mines' accident rates (NDL IR, NFDL IR and SM/100) were significantly lower than those of medium and large mines. The very small mines' SS/100 IH and O/100 IH were less than those of medium and large mines, respectively. These results may be attributed to the relatively small mine size physically, fewer inspection hours and 31 (22%) of the mines having fewer than nine employees; such was the case in 2008. Consistent with 2008 results, the order rate of the small mines was significantly lower and the citation and the SS rates were significantly greater than those of large mines, which may be attributed to high inspection hours in the large mines. The SM/100 and O/100 IH mean values of very small and small mines were greater than those of medium and large mines.

Table 4-8. Statistical Comparison of Safety Measures for Different Mine-Size Categories: 2009.

Safety Measures	**Test**	***V Small - Medium***		***V Small - Large***		***Small - Medium***		***Small - Large***	
		p-value	Signi-ficant	p-value	Signi-ficant	p-value	Signi-ficant	p-value	Signi-ficant
NDL IR	Less than	0.0000	Yes	0.0000	Yes	0.0001	Yes	0.0008	Yes
NFDL IR	Less than	0.0000	Yes	0.0000	Yes	0.0188	Yes	0.0497	Yes
SM/100	Less than	0.0000	Yes	0.0000	Yes	0.0003	Yes	0.0000	Yes
C/100 IH	Less than	0.1407	No	0.2672	No	0.2927	No	0.0442	Yes
SS/100 IH	Less than	0.0169	Yes	0.1859	No	0.4764	No	0.0345	Yes
O/100 IH	Less than	0.0544	No	0.0043	Yes	0.0750	No	0.0078	Yes

Note: p-values are adjusted for ties; level of significance 'α' = 0.05

Test: Greater than

Paper 3: Tracking mine safety performance trends to assess the risk for a fatality

The underground coal mines with fatalities during 2007-2010 were analyzed using the accident/injury data and citation data from 2005 to 2010. In 2007, there were 10 mines with a fatality and a total of 19 fatalities, whereas in 2008, the number of mines with a fatality increased to 12, but the total number of fatalities decreased to 12, and, in 2009, a record low 6 fatalities occurred in 6 mines. The years 2008 and 2009 were disaster-free years. In 2010, there were fatalities at 12 mines, with a total of 41 fatalities, 29 of which resulted from a single major disaster. The SPI was constructed for each year separately and the mines' SPI was divided into four quartiles from I to IV. The maximum, minimum and median for each quartile were determined as shown in Table **4-9**. This table is helpful in categorizing mine safety performance and tracking the SPI trends over the years to assess the risk for a fatality.

Table 4-9. SPI quartile distribution from 2005 to 2010

SPI	Q1			Q2			Q3			Q4		
	Max	**Min**	**Med**	**Max**	**Min**	**Med**	**Max**	**Min**	**Med**	**Max**	**Min**	**Med**
2005	100	90.26	94.98	90.21	80.72	85.37	80.72	63.86	74.83	63.61	0	42.14
2006	100	90.67	94.76	90.64	81.73	86.86	81.60	68.33	76.04	68.28	0	52.20
2007	100	89.75	93.88	89.72	79.19	84.77	79.19	65.59	72.90	65.47	0	48.35
2008	100	88.39	89.50	88.37	77.54	83.27	77.51	62.45	71.59	62.43	0	43.77
2009	100	90.79	94.42	90.77	82.87	86.50	82.76	70.16	77.57	70.00	0	54.82
2010	100	89.48	94.00	89.46	82.05	85.72	82.04	67.50	76.22	67.37	0	46.12

During analysis, a mine in 2007 and one in 2010 did not have two prior years' records and were not considered for further analysis. In total for the years 2007 to 2010, there were 38 mines with fatalities and 76 fatalities in total. Regarding the number of mines, there were 19 mines (50%) with trends that could have assisted in predicting the conditions supporting serious injuries or a fatality, and there were 19 (50%) that lacked sufficient information to predict a fatality. Regarding the number of fatalities, there were 56 fatalities (74%) associated with predictable fatality mines and 20 fatalities (26%) associated with unpredictable fatality mines. Statistics for sample mines with single or multiple fatalities are listed from 2007 to 2010 in Table **4-10**. The six safety measures and the SPI of the mines with fatalities and the two years preceding the occurrence of the fatality are tabulated as shown in Table **4-10**. The 13 sample mines in Table **4-10** were chosen to represent each of the mine safety performance-tracking categories. Accordingly, three 'P' mines, 'SP' mines, A/F/U with clues and A/F/U with no clues were chosen for the analysis, but there was only one 'BA' mine in the entire set of mines with fatalities. The analysis of mines from the predictable category to the unpredictable category is given next.

First, the 'P' (predictable) mines #8, #12 and #13, selected from the years 2009 and 2010, were analyzed. Mine #8 had a fatality in 2009, making 2008 and 2007 the two preceding years. As shown in Table **4-10**, the mines' scores on the six safety measures and the SPI from 2007 to 2009 were tabulated. The mine's SPI was in quartile II in 2007 and deteriorated to quartile IV in 2008. This drop occurred because of a steep increase in NDL IR, NFDL IR and O/100 IH and a moderate increase in C/100 IH, and all were above the mean of 5.00. Due to their seriousness, the O/100 IH has the highest weight and the NFDL IR has the second-highest weight; together with the two lower-weight measures these scores made the mine predictable for a fatality. In the case of Mine #12, the SPI was in quartile IV from 2008 to 2010. All the safety measures were well above the mean of 5.00 in 2008 and four safety measures (NFDL IR, C/100 IH, SS/100 IH and O/100 IH) had an increasing trend in 2009. The mine ended up as predictable due to the serious nature of the safety measures. Similarly, Mine #13's SPI was in quartile IV from 2008 to 2010; five safety measures were above the mean 5.00 in 2008, and four of them had a very high value in 2008 and 2009. These gave compelling evidence that the mine was predictable for a fatality.

Table 4-10. Tracking Categories for Sample Fatality Mines: 2007 – 2010.

MINE	NDL IR	NFDL IR	SM/100	C/100 IH	SS/100 IH	O/100 IH	SPI	Year	Category
1	0.00	0.00	0.00	0.60	0.00	0.00	99.80	2005	$F_{with\ clue}$
	2.63	5.81	3.57	3.78	5.52	0.00	79.40	2006	
	3.10	12.57	63.46	3.46	3.62	11.29	0.00	2007	
2	1.75	3.53	0.33	6.25	10.25	0.00	82.89	2005	SP
	7.84	2.02	0.28	4.79	8.02	4.51	76.17	2006	
	12.39	3.31	32.78	7.12	9.52	9.22	0.00	2007	
3	2.59	2.09	1.59	3.90	3.12	0.00	89.45	2005	SP
	0.00	1.89	0.28	5.95	5.65	6.36	77.20	2006	
	2.39	25.79	546.08	3.10	3.75	10.17	0.00	2007	
4	2.75	2.81	1.00	6.65	7.12	10.09	64.76	2006	BA
	1.55	4.85	2.03	4.91	5.04	9.74	64.41	2007	
	1.08	7.68	18.97	4.28	4.28	8.90	30.51	2008	
5	2.36	2.24	0.30	11.34	15.94	29.92	16.82	2006	$F_{with\ clue}$
	3.29	0.00	0.00	6.31	8.37	0.00	88.43	2007	
	3.11	0.00	126.97	7.72	8.74	14.42	0.00	2008	
6	3.29	4.98	1.47	1.93	1.52	0.00	88.83	2006	$F_{with\ clue}$
	6.00	8.90	2.91	0.89	1.37	0.89	79.83	2007	
	4.32	5.58	64.72	1.00	1.03	0.65	0.00	2008	
7	5.51	1.34	0.30	6.01	3.73	3.28	83.92	2007	SP
	6.59	0.00	0.00	5.42	5.57	5.61	79.20	2008	
	6.39	2.30	25.26	3.28	3.67	0.00	40.28	2009	
8	2.74	3.32	2.16	4.69	4.40	2.95	79.58	2007	P
	6.95	5.39	0.61	5.09	4.81	13.63	57.33	2008	
	3.95	5.70	30.56	3.34	4.15	1.79	23.03	2009	
9	7.47	2.80	1.50	4.05	6.09	0.96	82.33	2008	$U_{no\ clue}$
	8.37	4.16	0.94	3.52	4.50	0.33	84.83	2009	
	5.34	5.20	22.46	3.51	3.50	0.72	41.98	2010	
10	2.56	0.00	0.00	3.22	2.02	0.00	96.05	2008	$U_{no\ clue}$
	1.56	0.85	0.07	2.84	1.67	0.00	95.87	2009	
	1.02	2.03	41.62	3.83	2.85	1.75	6.75	2010	
11	0.70	3.44	2.45	4.34	4.01	2.43	81.11	2008	$U_{no\ clue}$
	2.02	2.92	0.94	4.52	5.12	2.57	82.76	2009	
	2.17	4.56	10.73	4.36	4.55	1.82	63.61	2010	
12	6.50	10.22	7.98	7.63	6.16	6.47	50.01	2008	P
	3.91	11.54	2.96	8.21	7.48	8.56	53.90	2009	
	4.30	9.44	14.96	6.33	5.65	3.69	44.06	2010	
13	23.90	6.21	3.13	12.60	14.78	35.64	0.00	2008	P
	26.25	4.21	0.46	9.96	13.96	10.05	48.73	2009	
	7.94	2.44	51.15	6.25	6.91	8.08	0.00	2010	

The second category analyzed was 'SP' (somewhat predictable) mines #2, #3 and #7 that were selected from the years 2007 and 2009. Mines #2 and #3 had SPIs in quartile II in 2005, which deteriorated to quartile III in 2006, whereas the mine #7 SPI stayed in quartile II for 2007-08. In the case of mine #2, two safety measures (C/100 IH and SS/100 IH) were above the mean in 2005 and NDL IR and SS/100 IH, which had the second highest and the lowest weights, respectively, were above the mean in 2006. For mine #3, all violation safety measures (C/100 IH, SS/100 IH and O/100 IH) increased above the mean in 2006, but the accident/injury safety measure values were very low compared to the mean. In the case of mine #7, there were two safety measures (NDL IR and C/100 IH) with the lowest weights above the mean in 2007-08, and two of the violation safety measures (SS/100 IH and O/100 IH) with the second-highest and the highest weights got added in 2008.

The third category was 'BA' (below average) and only contained one mine (#4). The SPI of the mine was below the average (66.65) in the years 2006-07. The violation safety measures were above the mean in 2006, but in 2007, there were only two violation safety measures above the mean of 5.00 in 2008, and they had a decreasing trend. The accident/-injury safety measures were much below the mean, but the NFDL IR (second highest weight) safety measure had an increasing trend.

The fourth category is AFU_{wc} (average/fluctuating/ unpredictable) with clues. Mines #1, #5 and #6 were selected from the years 2007-08, and they had a fluctuating safety performance but offered some clues to assess the risk. Based on the SPI and safety measures, it appears that mine #1 had an excellent safety performance in 2005, but this was not the case, as the production level was 7% and the employee hours were 3.5% in 2005 compared to 2006-07. The SPI deteriorated to quartile III, which represents the actual mine safety performance under full production, and two safety measures (NFDL IR and SS/100 IH) of second-highest weight were above the mean in 2006. Mine #5 had a poor performance in 2006, as the SPI was in quartile IV and all the violation safety measures were significantly above the mean. But, the SPI improved (to quartile II) and only two of the violation safety measures were above the mean in 2007, with a decreasing trend. The accident/injury incidents were well below the mean in 2006–07 and no lost-time accident occurred in 2007. In the case of mine #6, the SPI stayed in quartile II in 2006–07, but two accident/injury safety measures (NDL IR and NFDL IR) were above the mean in 2007. All violation safety measures were much below the mean in 2006–07.

The fifth and final category is AFU_{nc} (average/ fluctuating/ unpredictable) with no clues. Mines #9, #10 and #11 were selected from the year 2010. The SPI of the mines did not deteriorate from the preceding years (2008-2009) and stayed in quartile I or II. Mine #9 had two safety measures above the mean in 2008 and only one, of the lowest weight factor (NDL IR), in 2009. In the case of mine #10, none of the safety measures were even near the mean of 5.00 in 2008-09. Only one safety measure was above the mean in 2009 for mine #11. These mine safety performances made it almost impossible to predict the risk for a fatality in the mine.

Paper 4: Evaluating equivalence of the Safe Performance Index (SPI) to a traditional risk analysis

The SPI results were evaluated to determine how well the SPI methodology emulates a traditional risk analysis approach, as represented by the risk-index methodology. The values of the upper quartile, interquartile range, and extreme outliers for all the six safety measures for the years 2007-2010 are shown in Table **4-11**. The C/100 IH measure did not have any extreme outliers, except in 2009. In 2007, there were 12 extreme outliers in NDL IR, 4 in NFDL IR, 22 in SM/100, 2 in SS/100 IH, and 35 in O/100 IH. The extreme outliers of each risk measure for the years 2008, 2009, and 2010 are shown in Table **4-11**. The constructed risk ranges for each normalized safety measure for the years 2007-2010 are given in Table **4-12**, Table **4-13**, Table **4-14** and Table **4-15**, respectively.

Table 4-11. Safety Measures' Interquartile Range, Upper Quartile, and Extreme Measures: 2007 – 2010

Measures	Box Plot											
	2007			2008			2009			2010		
	Inter Quartile Range	Upper Quartile (Q_3)	Extreme Outliers (nos.)	Inter Quartile Range	Upper Quartile (Q_3)	Extreme Outliers (nos.)	Inter Quartile Range	Upper Quartile (Q_3)	Extreme Outliers (nos.)	Inter Quartile Range	Upper Quartile (Q_3)	Extreme Outliers (nos.)
NDL IR	7.77	7.77	31.08 (12)	6.82	6.82	27.28 (15)	6.54	6.54	26.16 (12)	7.70	7.70	30.80 (13)
NFDL IR	7.57	7.57	30.28 (4)	5.91	5.91	23.64 (8)	6.47	6.47	25.88 (8)	5.12	5.12	20.48 (4)
SM/100	4.32	4.32	17.28 (22)	3.20	3.20	12.80 (25)	4.11	4.11	16.44 (29)	1.88	1.88	7.52 (29)
C/100 IH	15.34	27.33	73.35 (0)	12.76	25.33	63.61 (0)	11.89	23.32	58.99 (2)	11.37	21.96	56.07 (0)
SS/100 IH	6.06	9.43	27.61 (2)	4.87	8.08	22.69 (3)	4.43	7.32	20.61 (3)	5.09	7.88	23.15 (1)
O/100 IH	0.60	0.60	2.40 (35)	1.15	1.15	2.00 (31)	0.42	0.42	1.68 (38)	0.65	0.65	2.60 (28)

Table 4-12. Safety Measures' Risk Level Scheme: 2007

Measures	Risk Level				
	Very Low 1	**Low 2**	**Medium 3**	**High 4**	**Very High 5**
NDL IR	0.00 - 6.21	6.22 - 12.43	12.44 - 18.64	18.65 - 24.86	24.87 - 31.07
NFDL IR	0.00 - 6.05	6.06 - 12.11	12.12 - 18.16	18.17 - 24.22	24.23 - 31.27
SM/100	0.00 - 3.45	3.46 - 6.91	6.92 - 10.36	10.37 - 13.82	13.83 - 17.27
C/100 IH	0.00 - 12.81	12.82 - 25.62	25.63 - 38.43	38.44 - 51.24	51.25 - 64.05
SS/100 IH	0.00 - 5.52	5.53 - 11.04	11.05 - 16.56	16.57 - 22.08	22.09 - 27.60
O/100 IH	0.00 - 0.48	0.49 - 0.96	0.97 - 1.43	1.44 - 1.91	1.92 - 2.39

Severity ↓

Note: ↓ Indicates increasing severity of accident/injury measures and citation measures

Table 4-13. Safety Measures' Risk Level Scheme: 2008

Measures	Risk Level				
	Very Low 1	**Low 2**	**Medium 3**	**High 4**	**Very High 5**
NDL IR	0.00 - 5.45	5.46 - 10.91	10.92 - 16.36	16.37 - 21.82	21.83 - 27.27
NFDL IR	0.00 - 4.73	4.74 - 9.45	9.46 - 14.18	14.19 - 18.90	18.91 - 23.63
SM/100	0.00 - 2.56	2.57 - 5.12	5.13 - 7.67	7.68 - 10.23	10.24 - 12.79
C/100 IH	0.00 - 11.97	11.98 - 23.94	23.95 - 35.91	35.92 - 47.88	47.89 - 59.85
SS/100 IH	0.00 - 4.54	4.55 - 9.07	9.08 - 13.61	13.62 - 18.14	18.15 - 22.68
O/100 IH	0.00 - 0.40	0.41 - 0.80	0.81 - 1.19	1.20 - 1.59	1.60 - 1.99

Severity ↓

Note: ↓ Indicates increasing severity of accident/injury measures and citation measures

Table 4-14. Safety Measures' Risk Level Scheme: 2009

Measures	Risk Level				
	Very Low 1	**Low 2**	**Medium 3**	**High 4**	**Very High 5**
NDL IR	0.00 - 5.23	5.24 - 10.46	10.47 - 15.69	15.70 - 20.92	20.93 - 26.15
NFDL IR	0.00 - 5.17	5.18 - 10.35	10.36 - 15.52	15.53 - 20.70	20.71 - 25.87
SM/100	0.00 - 3.29	3.30 - 6.57	6.58 - 9.86	9.87 - 13.14	13.15 - 16.43
C/100 IH	0.00 - 11.80	11.81 - 23.59	23.60 - 35.39	35.40 - 47.18	47.19 - 58.98
SS/100 IH	0.00 - 4.12	4.13 - 8.24	8.25 - 12.36	12.37 - 16.48	16.49 - 20.60
O/100 IH	0.00 - 0.33	0.34 - 0.67	0.68 - 1.00	1.01 - 1.34	1.35 - 1.67

Severity ↓

Note: ↓ Indicates increasing severity of accident/injury measures and citation measures

Table 4-15. Safety Measures' Risk Level Scheme: 2010

Measures	Risk Level				
	Very Low 1	Low 2	Medium 3	High 4	Very High 5
NDL IR	0.00 - 6.16	6.17 - 12.32	12.33 - 18.47	18.48 - 24.63	24.64 - 30.79
NFDL IR	0.00 - 4.09	4.10 - 8.19	8.20 - 12.28	12.29 - 16.38	16.39 - 20.47
SM/100	0.00 - 1.50	1.51 - 3.00	3.01 - 4.51	4.52 - 6.01	6.02 - 7.51
C/100 IH	0.00 - 10.06	10.07 - 20.12	20.13 - 30.18	30.19 - 40.24	40.25 - 50.03
SS/100 IH	0.00 - 4.63	4.64 - 9.26	9.27 - 13.88	13.89 - 18.51	18.52 - 23.14
O/100 IH	0.00 - 0.52	0.53 - 1.04	1.05 - 1.55	1.56 - 2.07	2.08 - 2.59

Severity ↓

Note: ↓ Indicates increasing severity of accident/injury measures and citation measures

Risk Indices

The final risk index values for mines range from one to five. A risk index value of one implies a very low-risk mine, > 1 but ≤ 2 is a low-risk mine, > 2 but ≤ 3 is a medium-risk mine, > 3 but ≤ 4 is a high-risk mine, and > 4 is a very high-risk mine. The numbers of very high-risk and high-risk mines for the years 2007-2010, as per the risk-index are shown in Table **4-16**. In 2007, there were 8 mines with very high risk (> 4) and 27 mines with high risk (> 3), whereas in 2008, there were 4 mines with very high risk (> 4) and 28 mines with high risk (> 3). In 2009, there were 7 mines with very high risk (> 4) and 29 mines with high risk (> 3), and in 2010, there were 3 mines with very high risk (> 4) and 25 mines with high risk (> 3). The average risk index for all the mines was 1.65, 1.67, 1.69, and 1.66 in 2007, 2008, 2009, and 2010, respectively. The average risk index for all mines for the four years was at the low-risk level and 6% of the mines were at the high/very high risk levels.

Table 4-16. Very High- and High-Risk Mines as per Risk Analysis and SPI: 2007 – 2010.

Years	**Risk Index (RI)**		**SPI**	
	> 4	> 3	0.00's	< 40
2007	8	27	30	59
2008	4	28	27	64
2009	7	29	15	40
2010	3	25	24	52

Safe Performance Index Results

The final SPIs of the mines range from 100 to 0 (zero). An SPI of 100 implies a very good safety performance mine, an SPI less than 40 implies "below average" or "poor" safety performance, and an SPI of zero indicates the worst safety-performance mines. The average SPI for all mines was 66.66 each year due to the intrinsic design of the methodology (see Appendix C), which is a valuable and consistent marker for average performance. As shown in Table **4-16**, there were 30 mines with zero SPI and 59 mines with an SPI less than 40 in 2007. Similarly in 2008, there were 27 mines with zero SPI and 64 mines with an SPI less than 40, whereas in 2009, there were 15 mines with zero SPI and 40 mines with an SPI less than 40. In 2010, there were 24 mines with zero SPI and 52 mines with an SPI less than 40.

Correlation of SPI to the Risk Index

Based on the analysis of results, an opinion is that the mines with a very high risk level should be targeted for improvement and immediate action should be taken to reduce the risk. Likewise, the mines with zero SPI should be targeted and immediate interventions should be taken to improve the safety performance. Mines with high risk or with an SPI less than 40 should take action to remediate their poor safety performance.

Table 4-17. Correlation of Risk Index and SPI Results: 2007 – 2010

Years	Correlation (RI – SPI)	p-value (α = 0.05)
2007	-0.913	0.000
2008	-0.922	0.000
2009	-0.905	0.000
2010	-0.898	0.000

The risk index results and the SPI results were tested for correlation using the *Minitab* statistical software with a level of significance (α) of 0.05. The risk index and SPI correlations are shown in the Table 4-17 for the years 2007-2010. The negative correlations of the risk index with the SPI were expected, as a high risk index indicates a high-risk mine, whereas, the SPI was constructed as a positive safe performance indicator. The correlations of the risk index with the SPI were –0.913, –0.922, –0.905, and –0.898 for the years 2007, 2008, 2009, and 2010, respectively. The correlations between the risk index and the SPI for each year were excellent as well as significant (based on the p-value). This indicates that the SPI methodology effectively emulates the risk index developed using the traditional risk approach. Using the SPI approach does have the advantage over the use of the risk index, because in the risk index approach, the range of values for each risk measure is generally unknown in deciding what intervals to create. Analysis of the data is required to construct an appropriate risk interval for each measure. Also, because of the normalized measures incorporated, the SPI is an understandable approach (no learning curve) for mine operators as well as federal and state enforcement agencies, and it would likely be more compatible with MSHA's enforcement tools.

Underground coal mine safety performance in the past decade

The decade 2001-2010 had its high and low moments all the way due the mine disasters and its impacts had a profound effect on safety, enforcement, production, employment and productivity. A steady decline in safety statistics was marred in four of 10 years, with the following multiple-fatality major-hazard events, with impacts noted in some detail:

- In 2001, the Jim Walter Resources No. 5 mine explosion that caused 13 fatalities, the usual high-impact visibility was overshadowed by the media coverage of the aftermath of 9-11, and thus no new mine safety legislation was initiated.
- In 2006, the Sago mine, Aracoma Alma No. 1 mine and Darby No. 1 mine disasters resulted in 12 fatalities, two fatalities, and five fatalities, respectively. Following these disasters, Congress passed the Mine Improvement and New Emergency Response (MINER) Act which led to dramatically increased fines, new technology implementation, mandatory new training, while other provisions took hold, and it took until the end of 2008 for enforcement impacts to be fully realized.
- In 2007, the Crandall Canyon mine disaster resulted in nine fatalities. This event heightened the already high scrutiny on underground coal mines and prolonged the transition time on stabilization.
- In 2010, the Upper Big Branch Mine-South explosion, the worst in 40 years, resulted in 29 fatalities. Congress pursued new legislation, but with multiple investigations pending, none was passed. However, because of Congressional and media scrutiny of this worst disaster, MSHA took action by implementing impact inspections, a new potential pattern of violations (PPOV) process, POV rulemaking, and the Rules to Live By initiative.

Table 4-18. Data on Mines, Employees, Production and Productivity.

Year	Mines	Miners	Employee Hours	Production	Hours/Miner	Tons/Hour
2001	717	38,538	80,463,014	379,933,950	2088	4.72
2002	655	37,015	75,809,652	357,106,504	2048	4.71
2003	579	34,580	73,946,735	352,487,486	2138	4.77
2004	583	35,812	78,504,123	366,510,326	2192	4.67
2005	606	39,029	86,144,899	368,611,500	2207	4.28
2006	654	41,067	91,098,700	358,985,414	2218	3.94
2007	563	40,325	89,874,950	351,789,934	2229	3.91
2008	583	42,972	97,622,797	357,645,482	2272	3.66
2009	540	43,827	95,932,679	332,055,422	2189	3.46
2010	497	43,867	100,271,309	337,348,524	2286	3.36

As shown in Table **4-18**, the number of mines declined over the decade from 717 to 497, by 30.7%, but the number of employees increased from 38,538 to 43,867, by 13.8%; however, the low point occurred in 2003 with 34,580 employees. Total production declined by 42.6 million tons, and productivity decreased from 4.72 in 2001 to 3.36 in 2010, a 28.8% reduction, while the average number of hours worked per year per employee increased from 2,088 to 2286, a 9.5% increase. Now approximately 50% of the workforce has five or fewer years' experience. This is, however, only partially the answer for the dramatic decrease in productivity.

Table 4-19. Accident Data

Year	Fatality	NDL	NFDL	Days Lost	FD-Days	SI-Days
2001	31	2812	3080	425,442	260,128	151,725
2002	12	2523	2930	281,205	121,915	147,712
2003	13	2401	2545	287,700	125,810	152,194
2004	15	2552	2443	293,309	139,750	142,981
2005	14	2583	2407	290,311	145,092	134,964
2006	36	2695	2383	413,329	278,506	123,898
2007	20	2859	2317	298,535	165,918	118,280
2008	12	2697	2256	222,669	99,963	110,222
2009	6	2201	2085	244,808	114,269	120,722
2010	41	2336	1951	405,967	288,348	106,179

Overall statistics on accidents are given in Table **4-19**, but with separate statistics presented on fatalities and disabilities (F-D, including partial disabilities) and serious injuries (SI, defined as lost or restricted days of 20 or more). These statistics are used to calculate normalized safety measures.

Table 4-20. Normalized Accident Measures

Year	Mines	Fatal IR	NDL IR	NFDL IR	SM	FD-SM	SI-SM
2001	717	0.077	6.99	7.66	1057.48	646.58	377.13
2002	655	0.032	6.66	7.73	741.87	321.63	389.69
2003	579	0.035	6.49	6.88	778.13	340.27	411.63
2004	583	0.038	6.50	6.22	747.24	356.03	364.26
2005	606	0.033	6.00	5.59	674.01	336.86	313.34
2006	654	0.079	5.92	5.23	907.43	611.44	272.01
2007	563	0.045	6.36	5.16	664.33	369.22	263.21
2008	583	0.025	5.53	4.62	456.18	204.79	225.81
2009	540	0.013	4.59	4.35	510.37	238.23	251.68
2010	497	0.082	4.66	3.89	809.74	575.14	211.78

Table **4-20** reveals a steady and noticeable decline in the NFDL IR (49.2% reduction), the NDL IR (33.3%) and the SI-SM (43.8%). The Fatal IR reached a record low of 0.013 in 2009, with a record low six fatalities, but was marred greatly by very high IRs in 2001, 2006, 2007 and 2010. The elimination of disasters remains the underground coal sector's greatest challenge, and unfortunately, the events impact all sectors of the mining industry.

Table 4-21. Citation and Penalty Data

Year	**Citation**	**S&S**	**Order**	**Pro-Penalty**	**SS-Penalty**	**O-Penalty**
2001	47671	18592	904	$ 10,125,736	$ 7,989,423	$ 1,828,780
2002	39270	14101	772	$ 9,657,185	$ 7,712,808	$ 2,585,534
2003	39825	14614	790	$ 9,966,665	$ 8,003,386	$ 2,554,289
2004	45734	18038	1047	$ 11,944,915	$ 9,515,625	$ 2,886,938
2005	50407	18608	1007	$ 13,775,385	$ 11,093,766	$ 3,079,779
2006	58832	22170	1753	$ 25,213,423	$ 20,827,106	$ 8,135,836
2007	63072	20540	1708	$ 78,752,974	$ 60,137,356	$ 26,687,941
2008	82748	25308	1699	$ 87,766,875	$ 65,774,937	$ 22,454,615
2009	79036	23204	1688	$ 79,316,287	$ 58,126,166	$ 16,825,190
2010	77748	25470	2272	$ 95,727,892	$ 79,440,320	$ 29,881,861

Table **4-21** shows the statistics that highlight the heightened enforcement. Beginning in 2006, and extending through 2008, the number of citations, S&S-designated citations, and orders increased severely, by 64.2%, 36% and 68.7%, respectively, over 2005 levels. The number of inspection hours increased by 53% and the total proposed penalty assessments rose by 637% over 2005. Similarly, the proposed penalty assessments for S&S-designated citations and orders rose by 49.3% and 62.9%, respectively. Table **4-21** also reveals that 2009 enforcement actions and penalties dropped significantly from 2008, but because of the Upper Big Branch Mine-South disaster in 2010, S&S-designated citations and orders rose significantly, even beyond the highest levels realized in 2008.

Table 4-22. Normalized Citation Measures, % S&S and % Orders.

Year	Mines	C/100 IH	SS/100 IH	O/100 IH	%S&S	%Orders
2001	717	13.72	5.35	0.26	39.00%	1.90%
2002	655	12.04	4.32	0.24	35.91%	1.97%
2003	579	12.71	4.67	0.25	36.70%	1.98%
2004	583	14.51	5.72	0.33	39.44%	2.29%
2005	606	16.12	5.95	0.32	36.92%	2.00%
2006	654	19.43	7.32	0.58	37.68%	2.98%
2007	563	19.33	6.30	0.52	32.57%	2.71%
2008	583	19.10	5.84	0.39	30.58%	2.05%
2009	540	17.46	5.13	0.37	29.36%	2.14%
2010	497	16.26	5.33	0.48	32.76%	2.92%

In spite of the significant increases in total citations and inspection hours as well as numbers of citations, Table **4-22** shows that the citations per 100 inspection hours (C/100 IH), S&S-designated citations per 100 inspection hours (SS/100 IH) and orders per 100 inspections hours (O/100 IH) peaked in 2006. The rates decreased significantly through 2009, by 16.3% (through 2010), 29.9% (through 2009) and 36.2% for C/100 IH, SS/100 IH, and O/100 IH, respectively. Because of the Upper Big Branch Mine-South disaster, the SS/100 IH and O/100 IH rates increased in 2010. It is useful to note the percent S&S citations and percent orders also decreased similarly through 2009, and increased in 2010. This indicates there is a strong correlation between the occurrence of a disaster in a particular year and the level of enforcement in reaction to it; however, as demonstrated in the period following 2006, these enforcement levels tend to moderate as industry addresses the additional scrutiny, apparently through greater diligence in maintaining compliance with major hazard-related regulations, which tend to get more elevated citations. This may be an indication of a growing movement by many mining companies to change the safety culture in their workforces to one of diligence and prevention.

Table 4-23. Normalized Proposed Penalty Measures

Year	PP/C	PP/SS	PP/O	PP/100 IH
2001	$ 212	$ 430	$ 2,023	$ 2,914
2002	$ 246	$ 547	$ 3,349	$ 2,961
2003	$ 250	$ 548	$ 3,233	$ 3,182
2004	$ 261	$ 528	$ 2,757	$ 3,790
2005	$ 273	$ 596	$ 3,058	$ 4,406
2006	$ 429	$ 939	$ 4,641	$ 8,327
2007	$ 1,249	$ 2,928	$ 15,625	$ 24,137
2008	$ 1,061	$ 2,599	$ 13,216	$ 20,262
2009	$ 1,004	$ 2,505	$ 9,968	$ 17,519
2010	$ 1,231	$ 3,119	$ 13,152	$ 20,016

Table **4-23** shows the normalized fiscal impact of efforts to reduce enforcement actions. The average proposed penalty assessments on citations and elevated citations also diminished significantly from 2007 through 2009, by 19.6%, 14.4%, 36.2% and 27.4%, respectively, for average proposed penalty per citation (PP/C), average proposed penalty per S&S-designated citation (PP/SS), average proposed penalty per order (PP/O) and average proposed penalties per 100 inspection hours (PP/100 IH). Following the Upper Big Branch disaster, the trend was reversed, as would be expected.

After a flat productivity record during 2001-2004, with 2004 seeing a modest decrease, productivity began a dramatic, steady decline thereafter. There was a relatively large increase in the number of employees from 2004 to 2005 and there was a distinct increase in the citation and S&S-designated citation rates. Of course in 2006, these rates and the order rate increased even more dramatically, as did the proposed penalty assessments. Thus the more intense level of enforcement, coupled with large changes in mines to implement new provisions of the MINER Act, could have had a significant impact on productivity. Although the intensity of enforcement action rates subsided during 2008 and 2009, after reaching a peak in 2007, productivity continues to decline as the workforce transition continues. We now await realization of the next round of legislative action and finalization of several rules in various stages of rulemaking. The record year in 2009 for all of the incident rates was excellent. The normalized citation measures similarly decreased. The underground coal industry is in large part responsible for building the safety cultures across their mines that can sustain that level of performance, and MSHA must maintain the scrutiny over mines to ensure that 'bad players' don't disrupt this trend again. At this point, the industry and MSHA are focused on the same outcomes, which are driven by the goals of zero fatalities and zero lost-time accidents. In 2009, the goal of zero fatalities was so close.

Chapter 5

SUMMARY AND CONCLUSIONS

During 2007 to 2009, a random, stratified pilot sample of 31 underground coal mines was used to develop the Safe Performance Index, which uses Mine Safety and Health Administration injury data and citation data to assess the relative safety-related risk of mines. Using 2009 data, the database was expanded to 107 mines, which is a 30% sampling of all underground coal mines producing 10,000 tons or more. Analyses demonstrated that the methodology can be used to assist companies, MSHA, or state agencies in targeting mines with high risk for serious injuries and elevated citations for remediation of their violation and/or injury experience. The results of analyses were presented at a hearing conducted by the U.S. House Education and Labor Committee, and if the legislation is passes, a similar methodology is now planned to be used for targeting poor-performing mines for elevated enforcement action. The U.S. House of Representatives' bill H.R. 5788 proposed explicitly the use of the SPI, and it incorporated a benchmarking rehabilitative process for targeting "poor" safety performances, particularly aimed at changing a mine's safety culture over a one-year probationary period.

Generally, based on the historically elevated fatality rate, safety experts in the industry believe that small mines have a relatively poor safety record as compared to the large mines; however, the results from this study indicate that the opposite is likely true. In fact, the accident rates (NDL IR, NFDL IR and SM/100) of very small and small mines in 2008 and 2009 were less than those of medium and large mines. Even though all of the accident/injury measures (NDL IR, NFDL IR and SM/100) were significantly lower for very small and small mines than those of medium and large mines in 2008 and 2009, the SM/100 mean values in 2009 were much greater than the mean values of medium and large mines. This indicates a heavy occurrence of very severe injuries in a number of very small and small mines. The impact of frequent and thorough mine inspections, both by MSHA and a company, and of on-site safety expertise, on improving the overall safety performance is evident from the results. Consistent with 2008 results, the order rate of the small mines was significantly lower and the citation and SS rates were significantly greater than those of large mines, which may be attributed to high inspection hours in the large mines. The SM/100 and O/100 IH mean values of very small and small mines were greater than those of medium and large mines.

The underground coal mines with fatalities from 2007 to 2010 were analyzed for mine safety performance trends to assess the risk for a fatality using a semi-quantitative risk-based methodology. Based on mine safety performance trends, the mines with fatalities were categorized as predictable or unpredictable regarding the ability to predict the fatality. During the period 2007-2010, 50% of the mines with fatalities had sufficient information to identify a safety-performance trend that could have predicted the need to address problems that may have led to the fatality, while 50% did not. However, the mines with sufficient trending information accounted for 74% of the fatalities. It appears that 26% of the underground coal mine fatalities did not have safety-performance trends that could have triggered preventive action. In these cases, predicting such fatalities will remain a real challenge for the industry and regulatory agencies. On the other hand, 74% of the underground coal mine fatalities could likely have been predicted by tracking the mine safety performance trends using this or a similar risk-based methodology. Based on results, the methodology developed in this paper may be used to assess the risk for a possible fatality by tracking mine safety performance trends and taking action to improve them. This methodology may prove useful to the mine operator and federal and state agencies in mitigating the risk for a possible fatality.

A traditional risk approach was used to develop a risk index that embraces frequency and severity in the final equation for assessing the safety performances of U.S. underground coal mines based on six prominent normalized safety measures. The risk index ranks the mines' relative safety performances on a risk scale that ranges from very low risk to very high risk. In order to explore the equivalence of a traditional risk analysis approach with the SPI, the mines' safety performances were also calculated using the previously developed Safe Performance Index methodology. The risk index and SPI results for each mine for the years 2007- 2010 showed a correlation coefficient of –0.89 or more between the results of these two methodologies. Thus the application of the SPI methodology effectively emulates a traditional risk analysis. Either can be used to assist companies, the U.S. Mine Safety and Health Administration, or state enforcement agencies in targeting mines with high risk for serious injuries and elevated citations for remediation of their injury and/or violation experience. The SPI is, however, a transparent, understandable, and reproducible approach for mine operators and federal and state agencies, with a quick learning curve, and it is likely more compatible with MSHA's enforcement tools than a formal risk analysis.

Also, the underground coal mine safety performance in the past decade (2001 to 2010) was analyzed and reviewed using the data from 2001 to 2010. The number of miners and employee hours worked has increased noticeably and, contrary to that, the production and productivity have decreased significantly. Also, the accident measures such as NFDL IR and NDL IR have reduced significantly. Due to the new legislation (MINER Act of 2006) and heightened enforcement, the inspection hours, the number of violations cited and fines associated with them also increased drastically. However, the normalized citation measures indicate that rates decreased significantly from 2006 to 2009. The citation data also indicated that there is a strong correlation between the occurrence of a disaster in a particular year and the level of enforcement in reaction to it.

In conclusion, the four research papers developed a balanced methodology and some application tools, which can be used as a risk management system to monitor the safety performances of underground coal mines, comparing the safety performances of underground coal mines by mine type and size, as well as to track safety performances of underground coal mines and to assess a mine's relative risk for a fatality. The SPI methodology has been proved to be a semi risk-based methodology that emulates the results of a quantitative risk-based methodology. The elimination of disasters remains the underground coal sector's greatest challenge, and unfortunately, the events impact all sectors of the mining industry; the need for systematic risk analysis and targeting of poor-performing, high-risk mines is important.

Future Research

This research can be extended to other commodities, if required, with minor modifications. These methodologies can also be used for studying mines based on the geographical locations (state, county, etc.) or any other classification or categorization. The study can be adopted by an operator or regulatory agencies to evaluate and benchmark the superior safety performances of any mine of a company, or between various mines belonging to different companies. Formal risk analysis may be carried out along with these methodologies wherever necessary (in case of major hazard-related citations, injuries due to slips and falls, etc.). It may also be used to evaluate whether there is any bias from one inspector to another in identifying and issuing citations to address the subjectivity. Analyses may be done by linking the inspector's ID with the standards cited during the inspection for a mine in a district, county, or state. If a citation issued by an inspector can be cited by the location underground where the violation had occurred, then, using the citation data with its location in a mine, a study could be done on whether an accident/incident occurred in the same location, section, or unit, where an accident-related violation was cited prior to the referred accident/incident. This might help regulatory agencies and operators to know whether there is any relation between the violations cited and the accidents that occurred in the respective location or section. These analyses might help to reduce the existing difference of opinion between the operators and regulatory agencies on some of the issues.

A graphic user interface (GUI) can be developed that can be used by operators, regulatory agencies and researchers evaluate the safety performance of the mines and as well as predict the safety performance levels. Also, GIS can be utilized to explore the feasibility of predicting a major hazard-related incident(s) in a mine using the leading indicators such as citation database.

The methodology developed in the Paper 3 was developed using the mines with a single or multiple fatalities. However, a study can be done for all underground coal mines using the five categories developed (in Paper 3) as a leading indicator for addressing emerging problems with actions that may able to prevent high-risk conditions, the fatality, and/or other serious injuries. Also, this future study can be helpful in establishing the realistic potential of the methodology as a leading indicator for certain number of problematic mines.

In the future, if the overall safety performance of the underground coal mines improves drastically to the level of zero fatalities and no or very few lost- time accidents, targets set by CORESafety (2012), then, there may be a situation where the SPI scaled meaning factor (5) and the PI normalizing factor (15) need to be remodeled. Also, a study could be done in more depth in-terms of modifying and interpreting the PI normalizing factor (15) differently in the SPI methodology.

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Appendix A

Sample SQL Code using PHP for Data Retrieval

Number of Employees

```
?php
$link = mysqli_connect("instructdb1.aset.psu.edu","username","password","accessid");

$sql = "SELECT MCPUG_06.MINE_ID
      FROM MCPUG_06;";

$result = mysqli_query($link,$sql);
if ($result != 0) {
   header("Content-type: text/xml");
   echo '<shapes>';

   $num_results = mysqli_num_rows($result);
   for ($i=0;$i<$num_results;$i++) {
      $row = mysqli_fetch_array($result);
      $mineid = $row['MINE_ID'];

      echo '<poly MINE_ID="' .$mineid. '">';

      $sql = "SELECT SUBUNIT_CD, AVG_EMPLOYEE_CNT  FROM SPI_Mines_06
                  WHERE MINE_ID='" .$mineid. "' ORDER BY ID;";

      $coords = mysqli_query($link, $sql);
                  $empl = 0;
      if ($coords != 0) {
         $num_coords = mysqli_num_rows($coords);
           for ($j=0;$j<$num_coords;$j++) {
                              $rec = mysqli_fetch_array($coords);
            $x = $rec['AVG_EMPLOYEE_CNT'];
            $y = $rec['SUBUNIT_CD'];
          if ($y == 1 || $y == 2) {$empl = $x + $empl; }
           }
            echo '<v Avg_Empl="' .$empl. '" />';
      }   echo '</poly>';
   }   echo '</shapes>';
}
?>
```

Accident Data

```
<?php
$link = mysqli_connect("instructdb1.aset.psu.edu"," username","password","accessid ");

$sql = "SELECT SPIUG_07.MINE_ID
      FROM SPIUG_07;";

$result = mysqli_query($link,$sql);
if ($result != 0) {
   header("Content-type: text/xml");
   echo '<shapes>';

   $num_results = mysqli_num_rows($result);
   for ($i=0;$i<$num_results;$i++) {
      $row = mysqli_fetch_array($result);
      $mineid = $row['MINE_ID'];

      echo '<poly MINE_ID="' .$mineid. '">';

      $sql = "SELECT SCHEDULE_CHARGE, DAYS_RESTRICT, DAYS_LOST
          FROM SPI_Acc_UG07 WHERE MINE_ID="' .$mineid. '" ORDER BY ID;";

      $coords = mysqli_query($link, $sql);
                  $drdl = 0;
                  $ndl = 0;
                  $nfdl = 0;
      if ($coords != 0) {
         $num_coords = mysqli_num_rows($coords);
           for ($j=0;$j<$num_coords;$j++) {
                  $rec = mysqli_fetch_array($coords);
                  $sc = $rec['SCHEDULE_CHARGE'];
                  $dr = $rec['DAYS_RESTRICT'];
                  $dl = $rec['DAYS_LOST'];

          if ($sc == NULL && $dr == NULL && $dl == NULL) {
               $ndl = $ndl + 1; }
                     else { $nfdl = $nfdl + 1; $drdl = $drdl + $sc + $dr + $dl; }
           }
            echo '<v NDL ="' .$ndl. '" NFDL ="' .$nfdl. '" DaysLost ="' .$drdl. '"/>';
      }  echo '</poly>';
   }  echo '</shapes>';
}
?>
```

Citation Data

```
<?php
$link = mysqli_connect("instructdb1.aset.psu.edu"," username","password","accessid ");

$sql = "SELECT AEPUG_10.MINE_ID
       FROM AEPUG_10;";

$result = mysqli_query($link,$sql);
if ($result != 0) {
   header("Content-type: text/xml");
   echo '<shapes>';

   $num_results = mysqli_num_rows($result);
   for ($i=0;$i<$num_results;$i++) {
      $row = mysqli_fetch_array($result);
      $mineid = $row['MINE_ID'];

      echo '<poly MINE_ID="' .$mineid. '">';

      $sql = "SELECT SIG_SUB FROM AEPVio_2010 WHERE MINE_ID='" .$mineid. "'
                    ORDER BY ID;";

      $coords = mysqli_query($link, $sql);
                    $cit = 0;

      if ($coords != 0) {
         $num_coords = mysqli_num_rows($coords);
           for ($j=0;$j<$num_coords;$j++) {
                            $rec = mysqli_fetch_array($coords);
            $x = $rec['SIG_SUB'];

          if ($x == N || $x == NULL || $x == Y) {
             $cit = $cit + 1;
             }
           }
            echo '<v Citations ="' .$cit. '" />';
      }
      echo '</poly>';
   }
   echo '</shapes>';
}
?>
```

Appendix B

Formulas

The formula used for calculating various incidence rates and forming the SPI is given below:

$$\text{NDL IR} = \frac{\text{Number of no lost-time reportable accidents/injuries x 200,000}}{\text{Employee hours worked}}$$

$$\text{NFDL IR} = \frac{\text{Number of non fatal days-lost incidents x 200,000}}{\text{Employee hours worked}}$$

$$\text{SM} = \frac{\text{Number of statutory, restricted, and lost work days x 200,000}}{\text{Employee hours worked}}$$

$$\text{C/100 IH} = \frac{\text{Number of citations x 100}}{\text{On-site inspection hours}}$$

$$\text{SS/100 IH} = \frac{\text{Number of significant and substantial citations x 100}}{\text{On-site inspection hours}}$$

$$\text{C/100 IH} = \frac{\text{Number of withdrawal orders x 100}}{\text{On-site inspection hours}}$$

$$\text{PI} = 0.05*\text{NDL IR} + 0.15*\text{NFDL IR} + 0.30*\text{SM}/100 + 0.05*\text{C}/100\ \text{IH} + 0.15*\text{SS}/100\ \text{IH} + 0.30*\text{O}/100\ \text{IH}$$

$$\text{Normalized PI} = \text{PI} \div 15$$

$$\text{SPI} = 100 - (100 * \text{Normalized PI})$$

Appendix C

Sensitivity Analysis

The sensitivity analysis to select appropriate and practical scaled mean value for the six normalized safety measures and associated normalizing factor for Performance Index (PI) was done on the 2009 data. Also, large mine size with employees greater than or equal to 100 was subjected to sensitivity analysis.

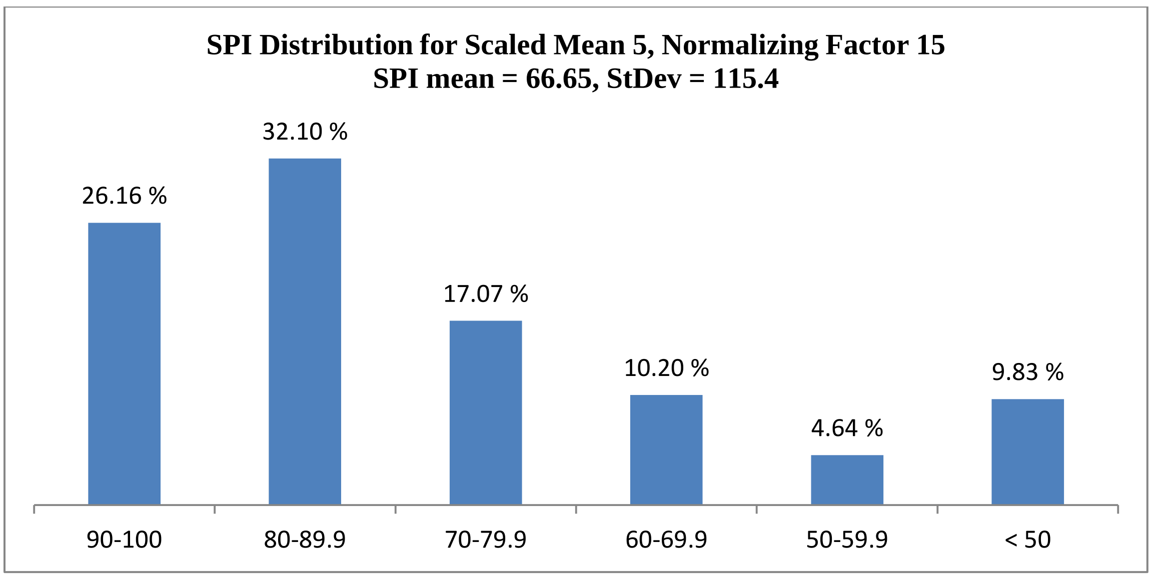

Figure 1: SPI Distribution for Scaled Mean 5 and Normalizing Factor 15

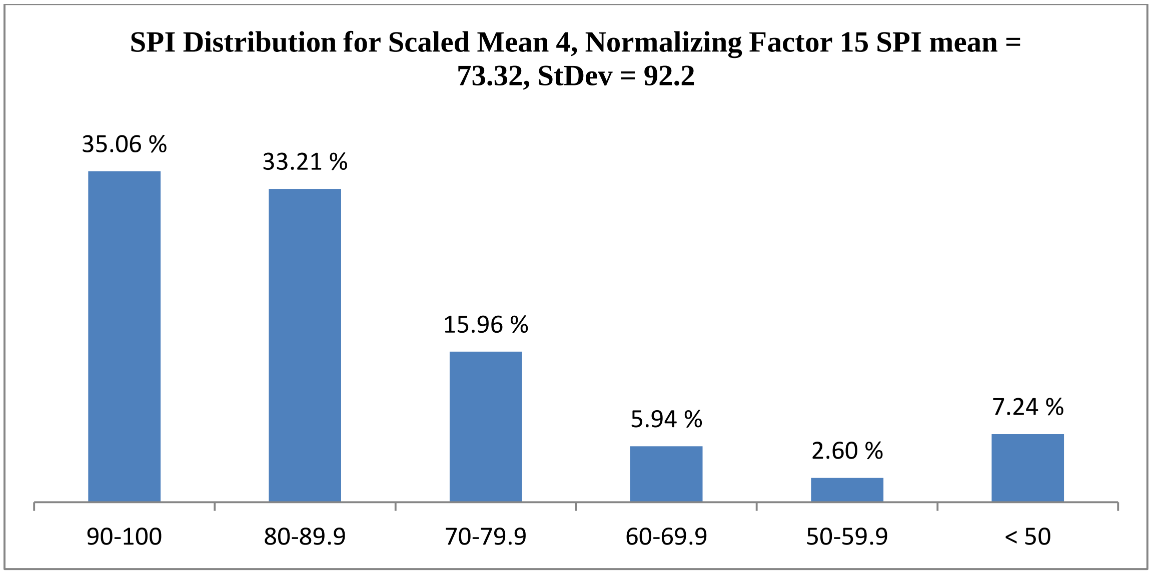

Figure 2: SPI Distribution for Scaled Mean 4 and Normalizing Factor 15

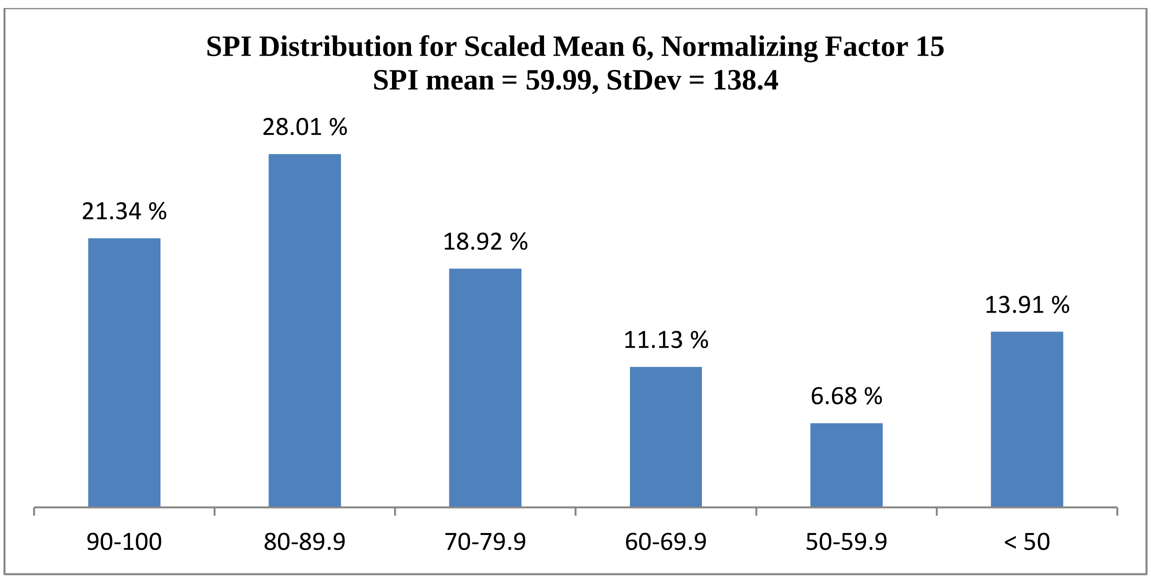

Figure 3: SPI Distribution for Scaled Mean 6 and Normalizing Factor 15

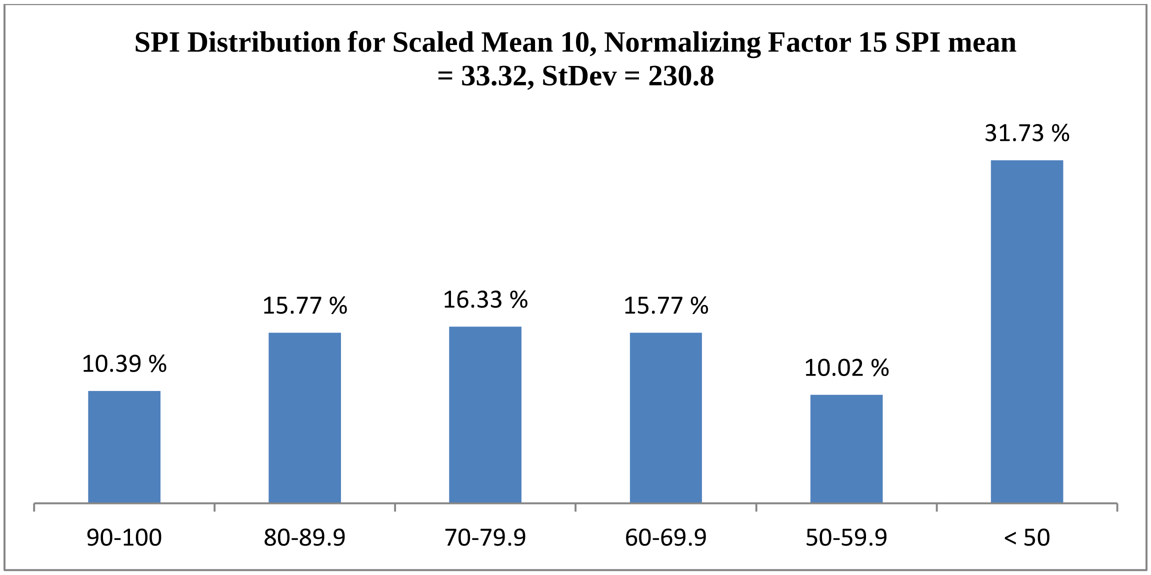

Figure 4: SPI Distribution for Scaled Mean 10 and Normalizing Factor 15

Figure 1 to Figure 4 shows the SPI distribution with different iterations on determining the practical scaled mean with fixed normalizing factor. Figure 1 represents the SPI distribution which comes close to a normal distribution with scaled mean of 5 and normalizing factor 15. Figure 3 with scaled mean of 6 would not be suitable as it has greater standard deviation and higher percentage of < 50 SPI mines compared to the scaled mean of 5 in Figure 1. The distribution in the Figure 2 and 4 were skewed and had higher standard deviations.

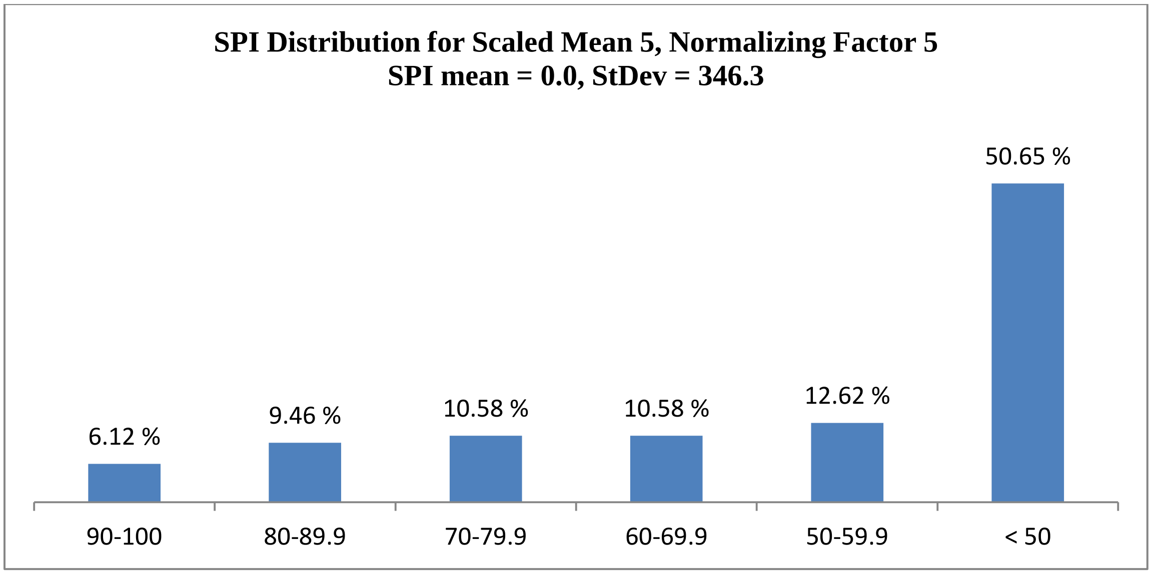

Figure 5: SPI Distribution for Scaled Mean 5 and Normalizing Factor 5

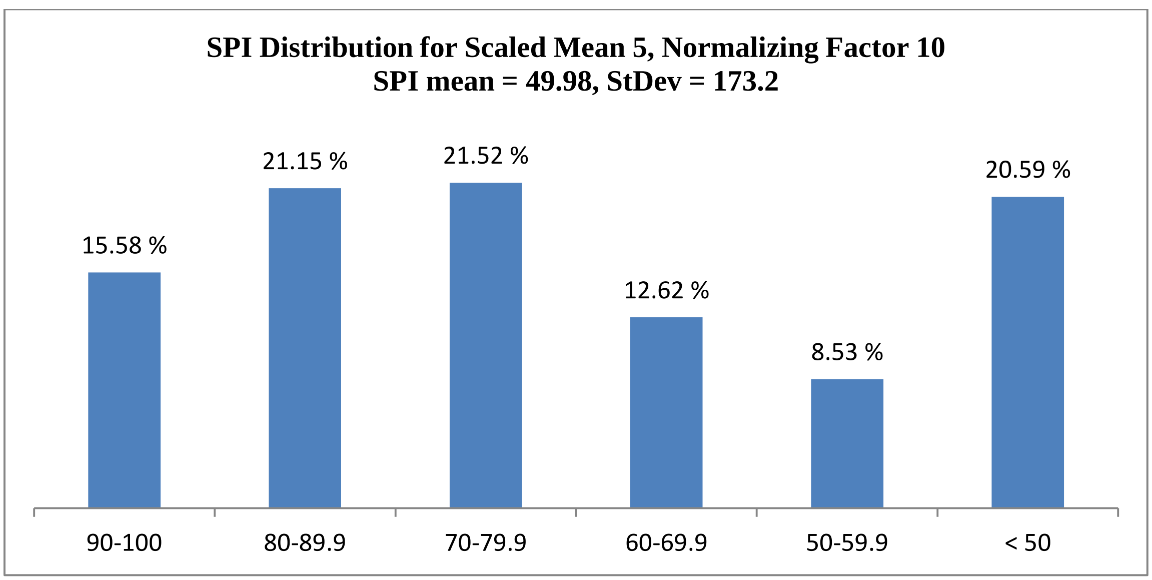

Figure 6: SPI Distribution for Scaled Mean 5 and Normalizing Factor 10

Figure 5, Figure 6, and Figure 7 shows the SPI distribution with different iterations on determining practical the normalizing factor with fixed scaled mean. Figure 5 and Figure 7 have skewed SPI distribution and Figure 6 indicates that SPI mean is less than 50 and greater number (20.59 %) of mines as poor performing mines.

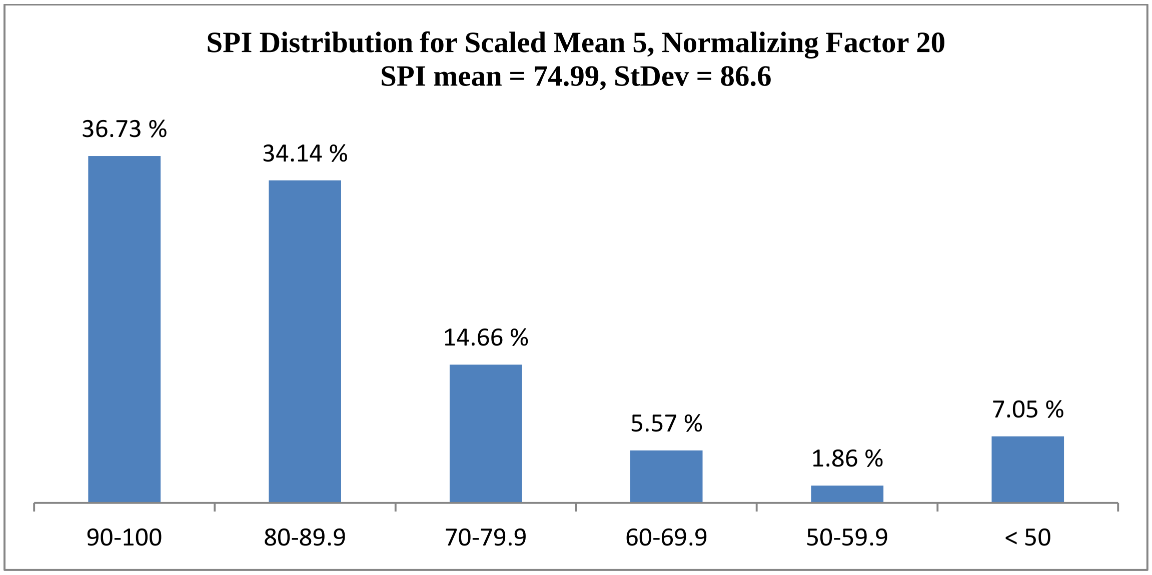

Figure 7: SPI Distribution for Scaled Mean 5 and Normalizing Factor 20

Similar distribution analysis was replicated using the large mine size (greater than 99 employees). The large mine size group data were the only one which could be transformed to normal distribution. Figure 8 to Figure 14 shows the SPI distribution with different iterations on determining the practical scaled mean and normalizing factor.

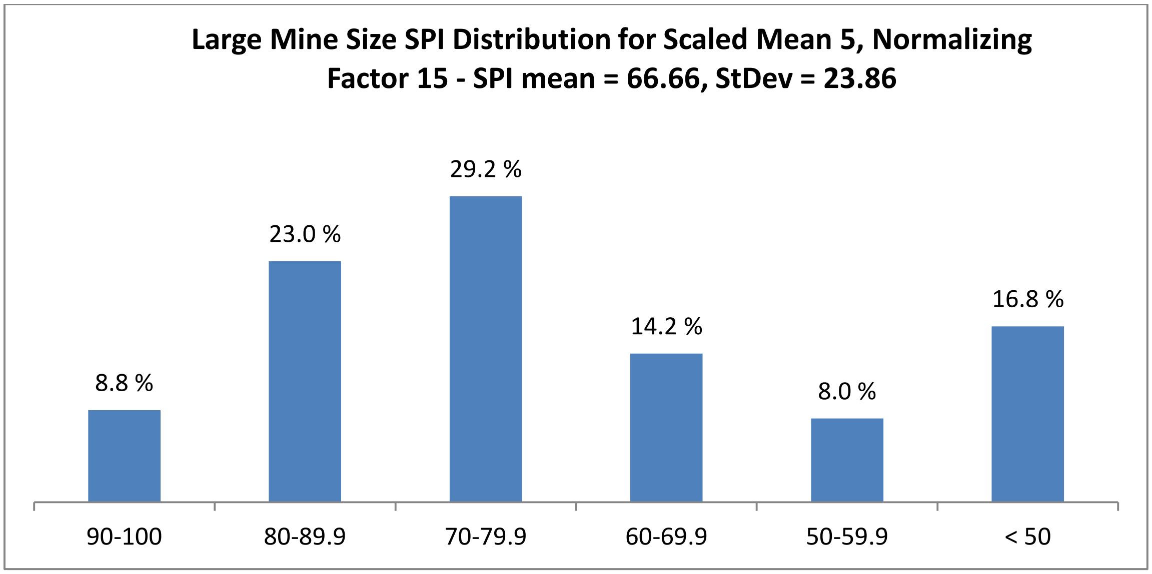

Figure 8: Large Mine Size SPI Distribution for Scaled Mean 5 and Normalizing Factor 15

The SPI distribution in Figure 8 and Figure 13 looks normal and rest of the iteration are skewed. However, the SPI mean of 66.66 from scaled mean 5 and normalizing factor 15 for the entire mines is more realistic than the SPI mean of 71.41 from scaled mean 4 and normalizing factor 14. As a future research work, chi-squared test of variance may be conducted on these distributions.

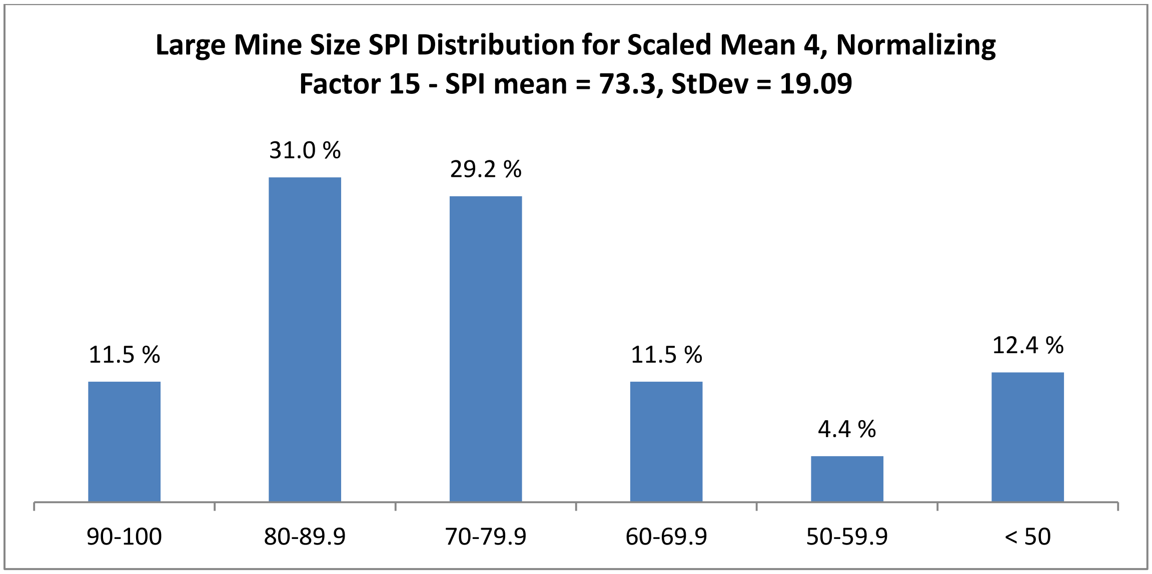

Figure 9: Large Mine Size SPI Distribution for Scaled Mean 4 and Normalizing Factor 15

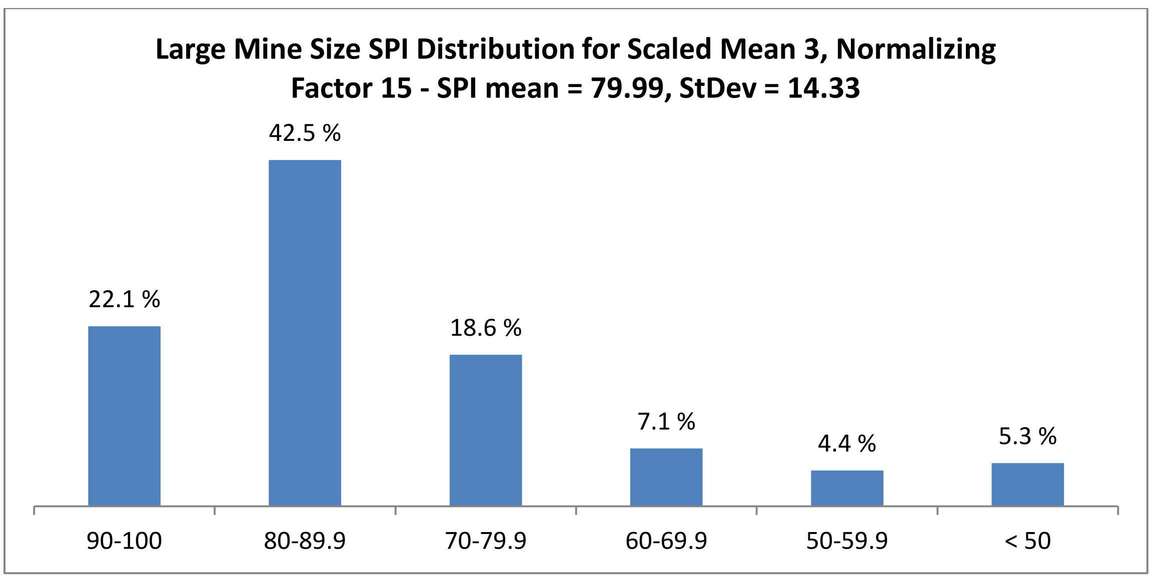

Figure 10: Large Mine Size SPI Distribution for Scaled Mean 3 and Normalizing Factor 15

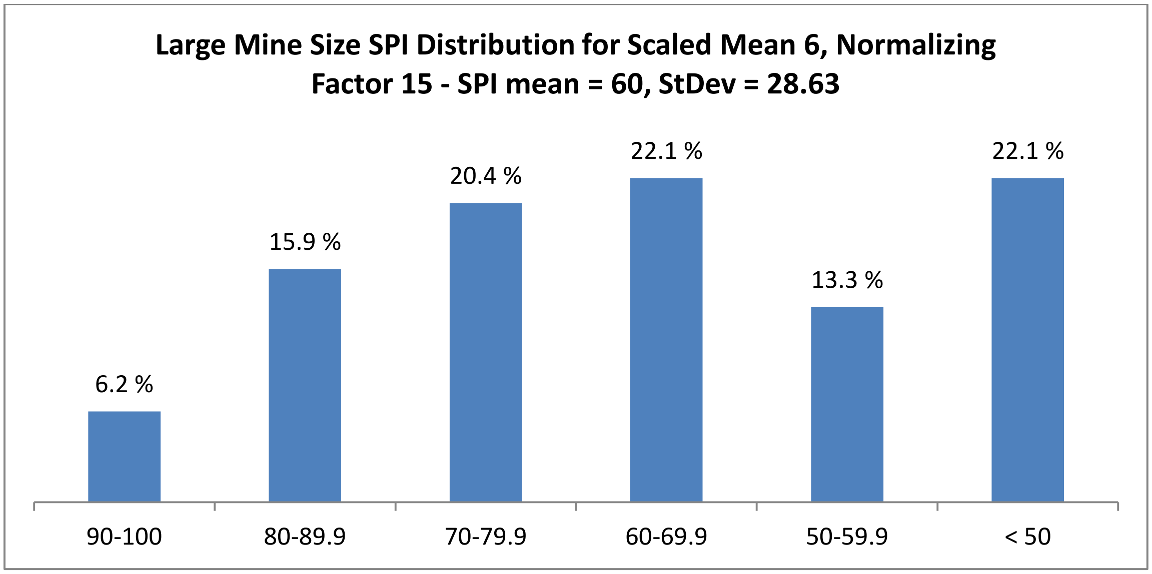

Figure 11: Large Mine Size SPI Distribution for Scaled Mean 6 and Normalizing Factor 15

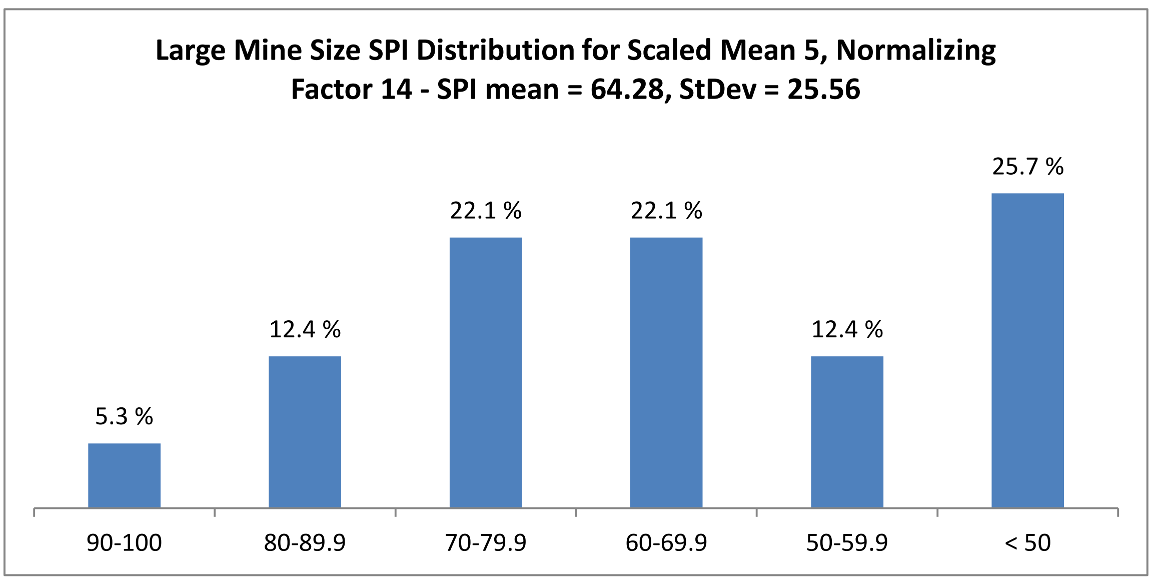

Figure 12: Large Mine Size SPI Distribution for Scaled Mean 5 and Normalizing Factor 14

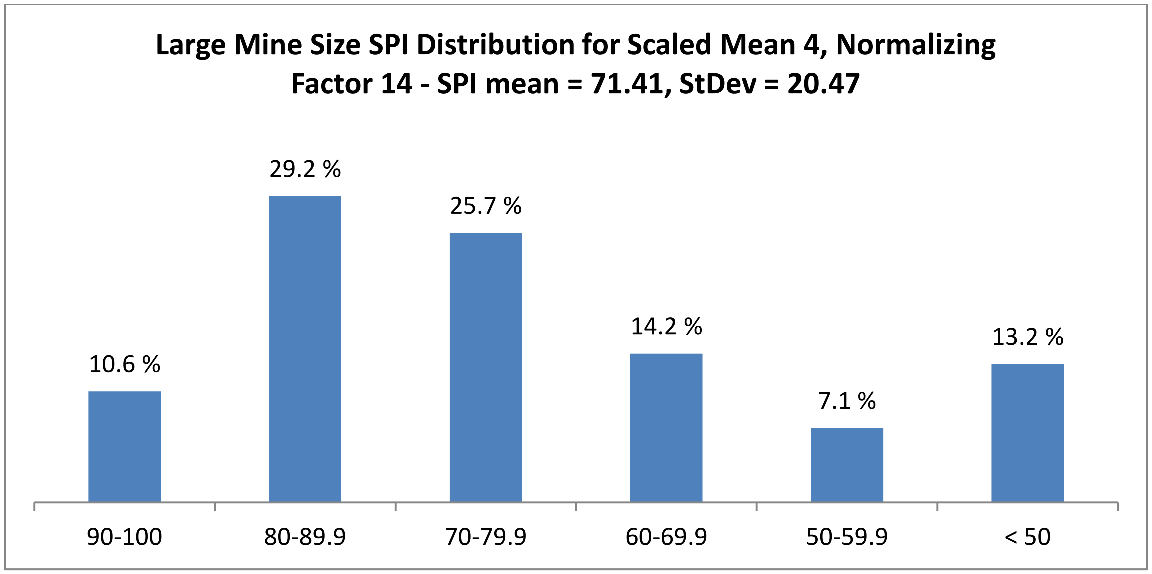

Figure 13: Large Mine Size SPI Distribution for Scaled Mean 4 and Normalizing Factor 14

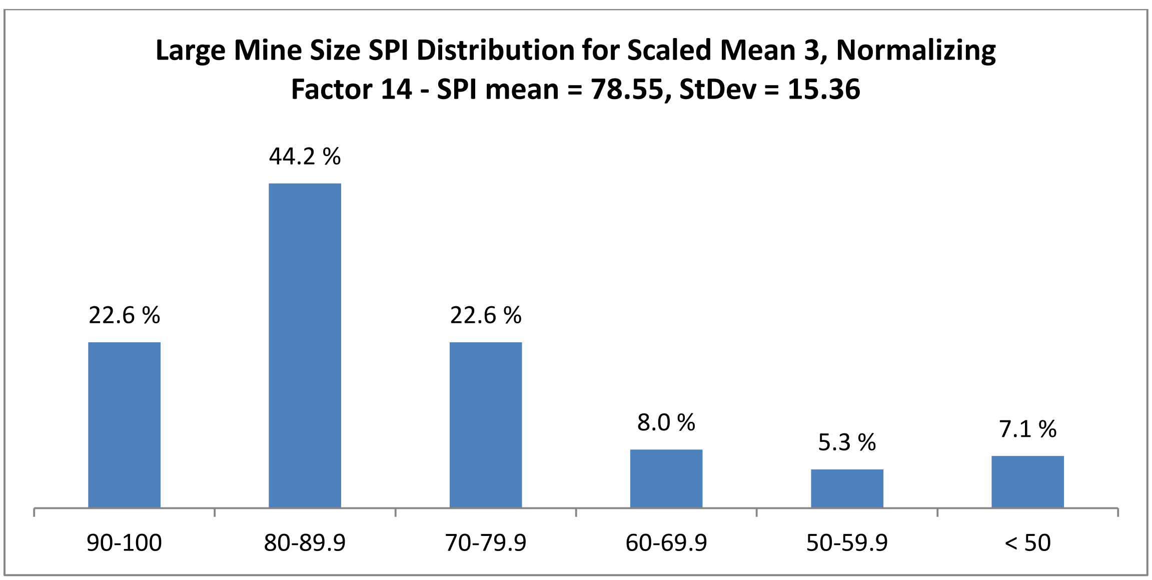

Figure 14: Large Mine Size SPI Distribution for Scaled Mean 3 and Normalizing Factor 14

Appendix D

Research Data

The research database files are available on request by sending an email to:

harisha.bhat@gmail.com

Appendix E

Peer-Reviewed Journal Articles

The peer-reviewed journal articles associated to this dissertation are available on request by sending an email to: harisha.bhat@gmail.com

VITA

Harisha Kinilakodi

Education

Doctor of Philosophy December 2012
Energy and Mineral Engineering, Mining and Mineral Processing Option.
The Pennsylvania State University, University Park, PA
Master of Science December 2009
Petroleum and Mineral Engineering, Mining and Mineral Processing Option.
The Pennsylvania State University, University Park, PA
Bachelor of Engineering October 2004
Mining Engineering
National Institute of Technology Karnataka (NITK), Karnataka, India

Work Experience

Project Manager – Liberty Mining Consultants, Inc., Kentucky, USA Apr’12 to Present

- Assisting mining experts in providing strategic improvement plans for the mining projects worldwide.
- Developing programs to improve production and reduce cost while maintaining high safety standards.

Deputy Manager – Materials, Kirloskar Ferrous Industries Ltd, India Jun’04 to Jun’07

- Cost analysis and feasibility reports on mining projects.
- Production scheduling in surface mines.
- Commercial operations, procurement, materials management, and vendor development.

Teaching Experience

Teaching Assistant Fall 2009
Fayette Campus, Pennsylvania State University, Uniontown, PA

Instructor – Mining Technology Program Spring 2010
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