Application of fatigue management systems: small mines and low technology solutions

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Abstract The impact of fatigue is seen not only in its effect on job performance of haul truck operators but also on the health of the operator and the productivity at the mine site. Its impact can even extend outside of the mine site to the health and well-being of the surrounding community (Fourie et al., 2010). In this paper, a case study of a small surface mining organization is presented. The goal is to highlight the fatigue risk management system implemented at the studied mine site. Mine safety personnel who were interviewed discuss the changes made to the infrastructure of the mine, to administrative areas such as the number of shifts and the use of vacation time, as well as the implementation of new technology into haulage vehicles. This paper reviews how these changes are supported in the research literature.

Introduction

Historically, mining has been one of the most hazardous work environments around the world. The number of fatal and nonfatal injuries is especially high for those in positions working in and around trucks. Md-Nor et al. (2008) reported 516 fatal injuries in the United States between 1995 and 2006 attributed to the general category of equipment. Of those fatal injuries, 113 (21.8%) were truck-related. A more recent review of data from the U.S. Mine Safety and Health Administration (MSHA, 2010) by Sun et al. (2010) reveals an additional 15 fatal injuries attributed to trucks from 2007 to 2009. There are many factors that contribute to the number of haul truck-related fatal and nonfatal injuries; some of these factors include lack of visibility, road conditions, truck driver behavior and operational conditions, as well as weather conditions (Groves et al., 2007). While the causes for truck related incidents and accidents can rarely be attributed to a single factor, they often involve a significant human performance component (Patterson and Shappell, 2010; Randolph, 1998). Driver fatigue, in particular, has been identified as a major factor contributing to crashes in haul truck traffic (Orchansky et al., 2010; Santos et al., 2010; Schutte and Maldonado, 2003).

One way to define fatigue is as the transitory period between awake and asleep; if fatigue goes uninterrupted, it can lead to sleep (Lal and Craig, 2001). A number of factors contribute to fatigue, including the amount and quality of sleep (Stutts et al., 2003), the disruption of circadian rhythms (Akerstedt and Wright, 2009) and sleep-related disorders (Connor et al., 2001). Driving for prolonged periods of time can also result in impaired concentration and reduced alertness, feelings of fatigue or drowsiness, and longer reaction time (Hakkanen and Summala, 2001; McDonald, 1984). As a consequence, drivers fall asleep with some regularity during a work shift, especially during the late night/early morning hours (Mitler et al., 1997).

The effect of fatigue extends beyond the driving behavior of the operator into areas such as the health and well-being of the operator and the functionality of the mining organization, as well as the productivity of the surrounding community (Fourie et al., 2010). Chronic sleep loss has been identified as a contributing factor to several health-related issues, including obesity and diabetes (Knutson and Van Cauter, 2003) and gastrointenstinal problems (Monk and Folkard, 1992). Organizations with overly fatigued mine employees can be affected by reduced productivity and morale and may even see an increase in accident rates (Dawson et al., 2000). Fatigue can also impact the economy of a community; some researchers have estimated the costs of workplace fatigue to be as high as $18 billion per year in the United States alone (Caldwell, 2001).

There has been a recent effort by the mining industry to implement fatigue risk management systems to manage fatigue. The goal of these systems is to, first, detect and monitor changes in driver fatigue levels and, then, either change the drivers' working environment to limit burdens that may increase fatigue or to provide some type of feedback so the driver can safely work through the fatigue. Several reports have recently been published discussing the importance of fatigue risk management for workers (Lerman et al., 2012) performing driving-related tasks (Fourie et al., 2010). In 2008, Edwards et al. published an *Operator Fatigue Detection Technology Review* in order to review existing and emerging fatigue detection technologies. Twenty-one products were included in the review. The reviewed products monitor such traits as eye closure (e.g., percent eye closure), reaction time, steering behavior and skin conductance, ranging in price from $10 to approximately $9,000 per unit to install. More recently, Goodbody (2013) provides an updated review of available technology, as well as suggestions for attributes mining companies should take into consideration when choosing a fatigue-monitoring/detection technology. The majority of the fatigue monitoring/detection technologies reviewed by Edwards et al. and Goodbody were highly technical and require at least one of the following to install and implement the technology: a change to the mine-wide communication infrastructure, a large capital investment and/or a commitment from mine management and the work force. While the consensus of both reports is that a number of technologies are rated highly and are recommended, it is not possible and, in some cases, not necessary, for all surface mining operations – especially those with a smaller number of employees – to adopt one of the reviewed systems.

The primary goal of this paper is to present a case study of one surface mine facility that has implemented a fatigue risk management system. One of the features of case study research is the assumption that "examining the context and other complex conditions related to the case [in this case the surface mine operation] being studied are integral to understanding the case" (Yin, 2011). Thus, a detailed description of the surface mine site, mine workers and equipment is provided to establish a context. Moreover, the steps that mine safety personnel took to change the working environment, as well as miner behavior, in order to increase the health and safety of the mining site for the employees will be discussed.

A secondary goal of this paper is to show that mine safety personnel who are choosing to independently implement fatigue risk management systems are making changes at the mine site that are based on scientific principles and theories. In this case study, we highlight specific examples from the studied surface mine. For each example, the pre-change condition at the mine is described. This is followed by a discussion of the changes implemented, along with evidence and references from the research literature that support the changes made. This paper can also be used as a tool by mine safety personnel at other surface mining operations of a similar size, that employ approximately the same number of miners and are interested in implementing a fatigue risk management system that is focused more on making changes to the work environment and work schedule. Likewise, a mine that chooses a high technology solution can also benefit from this case study in terms of the implementation of fatigue abatement solutions.

Table 1

General mine site questions included on the pre-interview questionnaire.

General worksite questions
What type of mining work do you do?
Who are your typical clients?
How many facilities do you operate and where are they located?
How many employees work at the mine site?
What is the average age of those employees?
What is the average amount of time employees have worked for the company? Please indicate a range: (0-5 years) (6-10 years) (11-20 years) (21-30 years) (31 or more years)
Is the company union or nonunion?
What types of equipment do your employees most often use?
What types of training do your employees take part in throughout the year?
How do shifts typically run at the mine site?
Do you offer any wellness programs? If yes, what wellness programs do you offer?
Do employees typically take part in these wellness programs?
Do you have any issues with employee obesity?
Do you ask employees to be tested for sleep apnea?

Case study: methodology

The study is based on data collected from one surface mining operation. The case study is descriptive in nature, as it involves the collection of observations and information from the mine, which were then compared to pre-existing theories related to fatigue and fatigue management. All data collected from the surface mine operation was qualitative in nature; therefore, no statistical tests were applied. A summary and synthesis of the collected data is reported in this paper. Specific changes made to the work schedule, the infrastructure of the mine and other aspects of the mine environment are also discussed.

Data collection techniques. Ob-

Table 2

A sample of the planned, open-ended questions included in the interview.

Interview questions
What is your safety record at the mine site?
Within the past 10 years, how many fatalities have you experienced?
Within the past 10 years, can you estimate how many accidents and injuries you have experienced that resulted in lost time?
Do you think your employees experience fatigue while they are working? If yes, how and why have you come to this conclusion? • Can you provide one specific example of how fatigue affects your employees' work? • Do you attribute any of these events (fatalities, accidents or injuries) to fatigue? • Approximately how many errors would you attribute to fatigue?
When did you decide to implement a fatigue risk management system (FRMS)? Was there a reason you chose to do this?
What did you choose to focus on or change with the FRMS that was implemented? • Did you make changes to the employees' work schedule? • Did you make changes to the mine site environment? • What else have you chosen to change?
Why did you decide to focus on the identified components? Can you give me an example to highlight why you chose a component?
How have you chosen to implement the system?
How did you introduce the system to your employees?
How much time was there between the decision to use the FRMS and the implementation of the system?
Did you choose to implement the system all at once or did you phase in the system?
Was there new training implemented to introduce employees to the FRMS?
How did your employees react to the implementation of the system?
How did you measure success with the FRMS you implemented?

servations of the surface mine operation were collected by personnel from the U.S. National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR). Several data collection techniques were used in this case study, as follows:

- A brief pre-interview questionnaire was given to mine safety personnel prior to the interview. This questionnaire was emailed to mine safety personnel and included general mine site questions as well as general questions related to fatigue at the mine site (Table 1). The questionnaire responses were used to guide the formation of the questions included in the interview.
- An interview was conducted with mine safety personnel. A series of questions were prepared for the interview that lasted approximately two hours. The majority of prepared questions included in the interview were open-ended, and the interviewee was asked to answer the questions as completely as possible (Table 2). Additional, unprepared questions were asked as well, in order to gather as much information as possible during the interview. The interviewee was also given the opportunity to provide any additional information pertinent to the questions provided.

Case study: surface mining operation

The focus of this case study is a surface mining operation located in the northeast region of the United States. The company is family owned and operated; there are currently family members from several generations working in various departments at the mine site. The operation has been mining sand, stone and gravel for approximately 50 years from the same quarry. There are approximately 60 employees working at the mine site. The majority of employees have worked for the company for at least 11 years, many have 20+ years of service, and the average employee age is 50 years old, which is slightly higher than the current average age of a stone miner (approximately 43 years old; McWilliams et al., 2012). The workforce is reported to be mostly married men with children and the overall community is religious and values strong family commitments. Because of the family presence and the length of time the company has been mining from the same quarry, there is also a strong relationship between the company and the surrounding community.

Initial mine observation. In the early 1990s, a fatality occurred at the mine site. The operator of a haul truck was assisting in the building of a stockpile. The pile was recently formed and not very tall; the operator inaccurately positioned the haul truck prior to dumping and backed a set of wheels through the side berm and hung the truck up. The operator then decided to jump from the truck, which caused the truck to slide down into the quarry and flip over, crushing the driver. The truck sustained minimal damage.

This particular surface mine's incident, accident, injury and citation rates had always been exemplary, as reported by mine safety personnel. The organization was compliant with regulations; however, the fatality illustrated to mine management that employees may not have been working as safely as possible. The senior staff began to look for ways to minimize the effect of human error at the mine site.

In an initial series of changes, haul roads were widened, berms were made higher and set further back, and "best practices" safe work procedures were made a strong priority. In addition, a safety committee was formed. This committee includes representatives from mine management and mine safety personnel, as well as the mining workforce. The safety committee was empowered to seek out areas with potential problems or hazards, and develop and present ideas for how to improve those problem areas. Overall, company effort was recognized and appreciated by employees.

The next series of important changes took place sometime later (approximately 10 years), when it was becoming evident that some employees were showing signs of fatigue. The number of hours worked was reviewed. It was determined that it was not unusual for some employees to work 65 to 80 hours per week. Further evaluation revealed that employees were not taking their paid vacation time. Rather, they chose to work through the entire year, in order to receive payment for vacation time not taken during the previous year.

Senior staff and mine safety personnel decided to widen the Federal Motor Carrier Safety Administration (FMCSA) hours of service rule to include their mining workforce. At the beginning of the next benefit year, the vacation utilization policy was changed to a "use it or lose it" approach. That year, 100% of vacation time was taken as time off. That approach continues to this day.

In retrospect, mine safety personnel realized that a hidden benefit to these changes was a reduction in domestic issues and the number of divorces reported by employees. It is interesting to note that, overall, divorce is not as common in the small, religious community. The effect of divorce on the workforce is not confined to mood and morale; it also impacts the safety of the operators. Research shows an increase in driving accidents for those drivers experiencing marital conflict and divorce; this increase is present up to six months after the divorce has concluded (Norris et al., 2000).

Clearly, the mine chose to implement a targeted fatigue risk management program to increase the well-being, health and safety of the miners at the mine site. Management did this by analyzing how the mine was currently operating and considering worst-case scenarios. Mine safety personnel also spent time talking with the miners to assess their safety concerns. Because of the nature of the mine and the workforce, open, honest and respectful communication between employees and management has always been encouraged by mine management, who believes it is necessary for the miners to feel safe at the work site in order to be productive.

Work schedule. The average number of hours worked per week by a miner at the case study surface mine was previously not limited. Miners were permitted to work as many hours of available overtime as they wanted; in some cases, this amounted to 40 hours of overtime in one week. The structure of the work schedule was a shift work schedule; during one period, a typical schedule included three shifts that lasted between 8 and 12 hours per shift. While the most heavily populated shift was the day shift (scheduled between 7 am and 4 pm), miners did work the evening and night shifts as well.

In the United States, 40 or more hours at the work site is considered a normal workweek and comes out to roughly 2,000 hours worked per year. The average mine worker at the studied mine, therefore, worked a considerable number of overtime hours. Within the research literature, there is ample evidence that associates overtime and extended work schedules with increased levels of fatigue (Duchon and Smith, 1994; Rosa, 1995), cardiovascular disease (Buell and Breslow, 1960; Liu and Tanaka, 2002), the onset of musculoskeletal disorders (Bergqvist et al., 1995; Dembe et al., 2005), as well as psychological issues such as stress (Kircaldy et al., 1997) and depression (Proctor et al., 1996). All of these factors can lead to accidents, injuries and even death.

Shift work also has adverse effects on physical and mental health. Frequent shift work can result in a decoupling of the internal circadian pacemaker from external, environmental factors such as the light/dark cycle (Shen et al., 2006). This decoupling can lead to disruptions in the normal sleep-wake rhythm (Costa, 2003) and cause workers to be vulnerable to work-related fatigue because there is a mismatch between a person's desired sleep-wake schedule and the shift work schedule (Hossain et al., 2003). Altogether, shift work can cause high subjective fatigue (e.g., a person's experience of fatigue), which increases the possibility of falling asleep while on the job and, therefore, increases the risk of workplace accidents (Akerstedt et al., 2002).

When the mine implemented the fatigue risk management program, one of the first changes mine management made was to the work schedule. Consistent with the FMCSA standards, the number of permissible hours worked per week was capped at 60 and the shift work schedule was eliminated (there are instances when multiple shifts are run, e.g., weather emergencies such as blizzards and floods). Instead of running three shifts, the mine consolidated the work schedule so that all employees worked the day shift. The exception to this schedule was the maintenance shift, which runs from 2 pm until 10:30 pm for approximately nine months of the year. The miners working this shift revert to the day shift during the winter months. While limiting the number of possible overtime hours was initially an unpopular decision, mine management made the decision to change the work schedule to ensure that some miners were not working around the clock. By changing the work schedule, the mining operation took steps to accommodate sleep schedules and gave miners the opportunity to spend time with family.

Within the fatigue risk management program, the mining operation also mandated breaks, a mid-morning break and a lunch break. During these breaks, miners have the opportunity to stretch, relax, eat a snack or meal or use the restroom. All of these activities are different from typical work-related tasks and give the miner time to relax or re-energize. There is also research indicating that performing moderate exercise (e.g., stretching or taking a short walk) leads to reports of increased energy and decreased levels of tiredness for a longer period of time, compared to results following eating a sugary snack, which initially increases energy and decreases levels of tiredness but causes the exact opposite effect pattern just one hour later (Thayer, 1987). Stretching and moderate exercise can, therefore, be used as a tool to moderate fatigue more effectively than some foods and beverages.

While mine management mandated breaks and mine safety personnel encouraged the use of stretching and moderate exercise, the mining operation has not made recommendations on weight or diet. The mine recognizes that there are a number of instances of obesity at the mine site — this is a common characteristic across those in the truck driving industry – however, it is not a characteristic the mine chooses to regulate. The mine does provide an unlimited supply of cold beverages during the summer months and an effort is made to provide a variety of types of beverages (e.g., water, sports drinks, soda, etc.) so that employees have a choice.

Finally, the mine implemented a policy regarding days off. All miners are given paid benefit time, and it is mandated that miners have to take vacation time sometime during the year. The number of personal days available to the miners depends on the length of their service at the mine – this can range from zero to seven days. In addition, employees receive up to four weeks of vacation, depending on the length of their service. This paid benefit time is considered "use it or lose it" time because the miners have to use it by the end of the fiscal year or lose it. Prior to the implementation of the fatigue risk management system, miners had been permitted to save paid vacation time and then cash the unused vacation hours in for money. While this was initially an unpopular policy change, mine safety personnel believe it was important change to have made because it required workers to take time off from work, therefore giving miners the opportunity to relax, spend time with family and friends, schedule doctor and dentist appointments, etc. All of these factors contribute to the safety and well-being of the workforce.

Driving route. Surface mines are structurally dynamic; i.e., the number of intersections and driving routes regularly change to accommodate the location of the materials that must be mined and then transported. The list of potential cognitive demands (tasks that require some level of mental effort) an operator must juggle is not limited to routes and intersections, however. Operators must also be aware of drop-offs, watch for oncoming traffic, which sometimes moves too quickly and also comes in a variety of sizes, must be able to drive in a reverse driving pattern, must be able to keep track of vehicles that move in and out of the haul truck's blind spots, and handle unexpected muddy and icy ramps. Mine safety personnel at the studied mine report that rounds run between six and eight hours under ideal circumstances, but can last up to 10 hours. Driving a haul truck, therefore, requires a high level of cognitive effort because it requires the coordination of sustained vigilance, selective attention, complex decision-making and the occasional use of automatic perceptual-motor control skills.

MSHA offers recommendations for the construction of the infrastructure at surface mining operations. According to

Figure 1

Example of a haul road that an operator would travel from the load site to the dump site.

MSHA's *Haul Road Inspection Handbook* (PH99-I-4), haul roads with traffic moving in both directions should be three and a half times the width of the widest vehicle traveling on the road and two times the width of the widest vehicle for one-lane roads (Fig. 1). Berms must be maintained on the outside edge of all haul roads where there is a danger of a haul truck overturning; it is recommended that berms be at least mid-axle height to the largest equipment that uses the haul road. These recommendations are enforced to ensure that haul roads are as safe and maneuverable as possible. Even with these recommendations in place, there are still a large number of accidents, injuries and fatalities that occur on haul roads because trucks collide with other trucks and with walls, and because trucks drive off of roads into berms or into the pit (Santos et al., 2010).

Because of the complexity of the task a haul truck operator performs, there are several factors associated with the task that likely contribute to the number of accidents, injuries and fatalities occurring on haul roads. Haul truck operators need to be aware of oncoming traffic, proximity of the truck to the berm and vehicle traffic moving through intersections, as well as incoming information from dispatch. The operator must not only divide attention between these tasks but also make ongoing steering decisions. Attention is a limited-capacity resource (Wickens, 1984). In this case, driving is the primary task, and engaging in any additional task(s) diverts attention from the primary task and, therefore, comes at a cost. In research studies investigating drivers multi-tasking by using a cell phone, drivers talking on a cell phone while driving were more likely to fail to stop at a four-way interaction and were more likely to rear-end other vehicles than drivers not talking on cell phones (Strayer and Drews, 2006). Vigilance, or sustained attention, is also necessary and important during the haul cycle as drivers often drive for long periods of time (see Fig. 1 for an example of a driving route). Prolonged vigilance, brought on by an extended amount of time on task, has been shown to lead to increases in subjective reports of fatigue as well as decrements in driver performance, especially when the driving task is monotonous (Thiffault and Bergeron, 2003).

Driver stress and anxiety are also factors that contribute to the onset of fatigue and a decrement in driver performance. Driver stress can increase for a number of reasons: time pressure to complete a job, long work hours, personal

Figure 2

Example of a sign used at a surface mine site to warn operators of haul road traffic pattern.

situations, unpredictable and hazardous road conditions, and other truck traffic. All of these potential factors contribute to increases in driver stress. One explanation for the effect of stress on driving is that stress diverts attention away from the primary task (driving) through a process called cognitive interference. When an operator experiences cognitive interference, thoughts associated with a stressor intrude on task-related activities and work to reduce the quality and level of driving performance (Sarason et al., 1995). Operators who have experienced a recent stressful event are five times more likely to cause fatal accidents than unstressed drivers (Brenner and Selzer, 1969). Moreover, repeated exposure to stressful driving contexts during a haul cycle can lead to the onset of fatigue symptoms (Lal and Craig, 2001).

In order to reduce attention demands placed on operators, limit driver stress and minimize fatigue, mine safety personnel at this mine made several changes to the infrastructure and operation of the mine. One of these changes was to widen the haul roads beyond even the MSHA recommendation. The overall goal of widening the roads was to make the driving environment as safe as possible. By widening the haul roads, the mine decreased driver stress associated with such problems as vehicle collisions and the proximity of the truck to the berm. Widening the roads makes it possible for the driver to operate the vehicle further away from the berm, thus setting the vehicle back from the edge of the road and minimizing the risk of driving into the berm or off the road into the pit. Moreover, maintaining the quality and integrity of the haul roads not only eases psychological stress but also the physical stress put on the body from jolting and whole body vibration (Kittusamy and Buchholz, 2004).

Attending to haul truck traffic and being aware of the proximity of vehicles of varying shapes and sizes throughout the haul cycle can be cognitively demanding and, as a consequence, increase driver stress. To optimize the driving experience, some of the haul truck traffic patterns at the surface mine move in a reverse driving pattern so that the haul truck cab is closest to the outside of the haul road, on the opposite side of oncoming traffic (Fig. 2). Thus, while the truck moves, the cab runs parallel to the berm. The operator is able to more easily see the berm, which improves visibility of the location of the edge of the road and, therefore, decreases guesswork. Furthermore, if two haul trucks were to collide head-on or be involved in a sideswipe, the operator cabs would not collide. Driving in a reverse pattern can limit driver stress as well as the possibility of injury to the operator of the vehicle.

To further increase the visible area around the truck, vehicles at the mine site have been equipped with rear vision cameras. These cameras are mounted on vehicles to eliminate some of the more hazardous blind spots. In fact, one of the principal benefits of the rear vision camera is the elimination of the blind spot that occurs while driving in reverse. Mine safety personnel report that most operators are typically uncomfortable while driving in reverse because they are effectively driving blindly. By enhancing the "vision" of the operator with the rear vision camera, the mine increases pedestrian safety by decreasing the likelihood a haul truck will back over a person or smaller vehicle. Use of the camera, therefore, also limits one source of on-the-job stress.

After being trained to use the camera and operating the truck with it for some time, all operators not only use the camera but report that the camera makes their job easier. In fact, a spare truck at the site did not have a camera installed and operators expressed concern about using the truck without a rear vision camera.

Conclusion

The implementation of this fatigue risk management system was not without cost. First, changing the work schedule did limit the total number of hours worked per week and reduced the amount of product moved from the site. This means that employees may work fewer hours per week, but, in the long run, employee quality of work/home life has likely improved. Secondly, widening the haul roads required an initial investment, as did the installation of rear vision cameras on the fleet of vehicles. However, this investment is small relative to the cost of the loss of a life and the penalties associated with that loss. In fact, investing in these changes can lead to long-term savings because of a reduction in property damage and lower insurance payments.

The mine safety personnel interviewed for this analysis stressed the importance of implementing a fatigue risk management system that took into account mine-specific issues. Targeted changes can be made at a mine to increase the health, safety and happiness of the employees, but mine management needs to be in touch with the workforce to effectively implement and recognize the changes' value. ■

Disclosure

The findings and conclusions in this presentation are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

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