Increasing Haul Truck Safety through the use of Virtual Pre-Shift Inspection Training

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ABSTRACT

On average, there are approximately ten fatal haul truck accidents per year in the United States. The most common causes for haul truck accidents include mechanical problems, inadequate training, and insufficient road/berm maintenance. Due to the frequency and magnitude of haul truck accidents, new training methods are being investigated. With the widespread availability of inexpensive and powerful computers and newer information technology, the ability to incorporate computer based training for miners is becoming more of a possibility. Computer based training is as effective in knowledge acquisition as traditional lecture, and computer based training can also lead to a significant increase in the retention of material. Studies have also shown that more engaging training methods lead to much more effective knowledge acquisition.

A computer-based virtual environment training system was developed to supplement current new miner training and address the common causes of fatal accidents. The new training system is a virtual pre-shift inspection of a haul truck, and will train the beginner haul truck operator to identify parts which look defective compared to how the parts look normally. The training will increase the operator's ability to recognize problematic parts and correctly identify the corrective action needed. Increasing the quality of training by providing a very engaging simulated hands-on environment will lead to safer behaviors by the trainees, and ultimately fewer accidents and fatalities.

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Chapter 1 – Introduction

In the past twelve years there have been 108 fatal haul truck accidents which have accounted for 110 deaths. From 2000 through 2006, haul truck fatalities accounted for 14% of the total fatalities in the surface mining industry (NIOSH 2006). Figure 1.1 details the categories of fatal accidents in the surface mining industry. The contributing factors for fatal haul truck accidents include mechanical problems, lack of training, seatbelt misuse, road/berm problems, and lack of communication. Mechanical failures and lack of training contributed the most to fatal accidents.

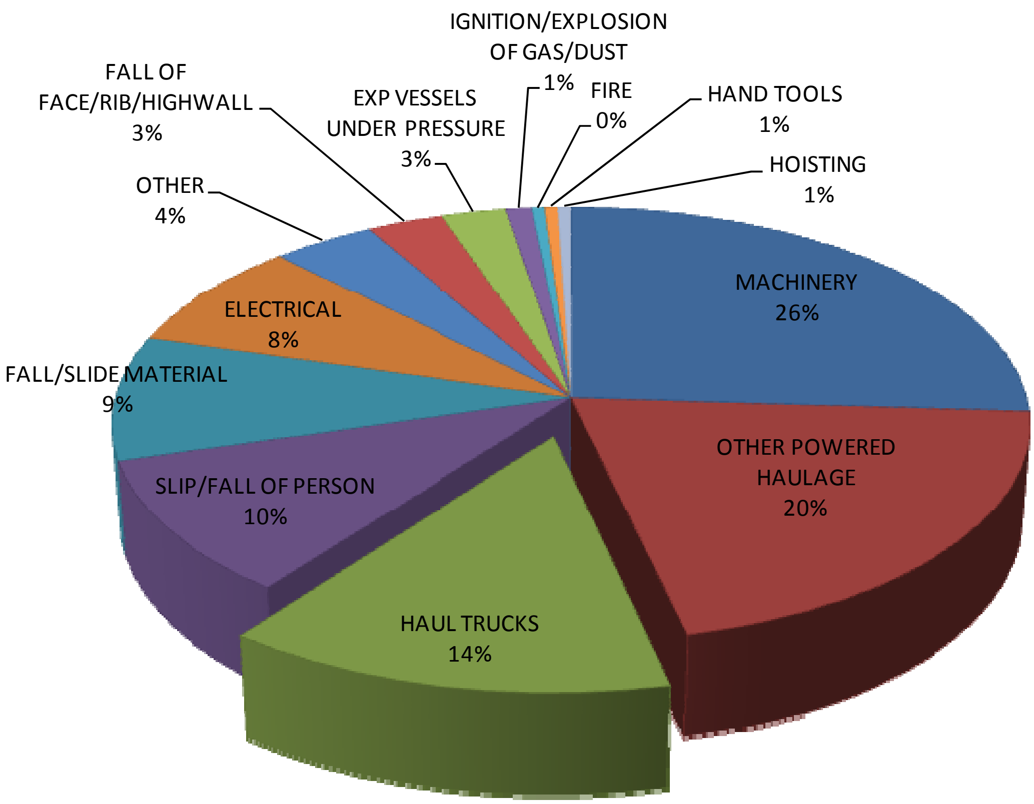

Figure 1.1 - 2000 through 2006 surface mining fatal accidents by category (NIOSH 2006)

Currently, haul truck safety applications are more focused on collision avoidance. Devices such as dump point proximity alerts and haul truck tracking systems are designed to reduce the chance a haul truck crashes into another truck, or falls over the highwall. Collision avoidance systems do not address the two most common contributing factors to fatal accidents, mechanical problems and lack of training. Current systems focus more on preventing the accidents where lack of communication and road/berm problems are the contributing factors. To address the more common contributing factors to fatal accidents, a supplemental training system was developed. The training system is a virtual pre-shift inspection of a haul truck and will contain three main sections. First, the user will be guided through the proper process of conducting a pre-shift inspection. Second, the user will need to conduct a pre-shift inspection within the virtual environment. Third, the user will be shown an animation of any part missed in the pre-shift inspection failing in a worst case scenario. The training system will work to encourage miners to perform a proper pre-shift inspection on the haul truck prior to operation. Identifying mechanical problems before the truck begins operation will reduce the number of fatal accidents which are caused by mechanical failures.

1.1 – Haul Tucks

Haul trucks are among the most common pieces of equipment found at any mining site and can be rather large. Since haul trucks are such a common piece of equipment, numerous accidents involving haul trucks occur. From 1995 through 2006, there were 108 haul truck accidents which resulted in a fatality. The physical dimensions of haul trucks are rather bulky. The length, width, and height of haul trucks can range upwards of 48, 33, and 23 feet respectively. Capacities of haul trucks can be upwards of 380 tons (797b Haul Truck). Fully loaded haul trucks have an added safety concern because the added weight requires longer distances for the truck to fully stop. To illustrate the true height of a haul truck, Figure 1.1 displays the height of a tire on a CAT 797B haul truck. The 797B uses a “standard tire 59/80R63” which has a 63 inch radius (797b Haul Truck). Operators of such large trucks have their eyesight upwards of 20 feet above the ground. The huge size combined with the height of the operator generates a very big blind spot all around the haul truck. It is essential that everyone who works around haul trucks know and understand the blind spots and the need to actively communicate with the operator.

Figure 1.2 - Diameter of a Tire on a CAT 797 Haul Truck

driver makes throughout their shift. Haul trucks often interact with other mobile equipment and stationary dumping stations. The mobile equipment often includes shovels, front-end loaders, and pickup trucks. Shovels and loaders, being large in size, can easily be seen. Pickup trucks can hide in the blind spots of haul trucks when they are close to one another.

It is necessary for miners to be sufficiently trained to operate haul trucks. It is also important that miners who do not operate haul trucks to be aware of the safety hazards which they impose. Miner training for surface operations is outlined in 30 CFR Part 48 Subpart B. It is also important that all miners understand that the maintenance and upkeep of haul trucks is important for their safe use. All equipment should be checked prior to use to ensure the machine is in good working order. If the haul truck does need maintenance, only qualified persons should perform the repair.

1.2 – Virtual Environments

Virtual environments (VE) provide an environment which a user can be fully immersed. Caird defines virtual environments as "three-dimensional graphic images that are generated by computers for the expressed purpose of cognitive and physical interaction" (Caird 1996). Immersive environments are accomplished by allowing the user to interact with the three-dimensional objects on the screen. While inside the virtual environment, the user can travel and look at any object freely. While the terms "virtual reality" and "virtual environments" can often be used interchangeably, this paper will use "virtual reality" when discussing non interactive systems and "virtual environments" when discussing interactive systems.

The principal causes of fatal haul truck accidents needs to be identified before any development of a safety program can begin. Chapter 2 identifies the significant contributing factors for haul truck fatalities.

Chapter 2 – Contributing Factors of Haul Truck Fatalities

From 1995 through 2006, there were 108 haul truck accidents which resulted in a fatality. This number of fatal injuries sustained from haul truck accidents can be reduced with increased training. The virtual pre-shift inspection training will work to reduce the occurrence of fatal accidents by better training operators to identify possible hazards, and realize the appropriate steps to ensure both their safety and the safety of the personnel around them. To ensure that the training system will positively affect the occurrences of fatalities, two studies were completed to identify the principal causes of haul truck accidents and fatalities. The first study completed was an analysis of all fatal accidents since 1995, and a statistical analysis to confirm the significant causes of haul truck fatalities. The second study looked at the relationship between experience and haul truck accidents (which may or may not have resulted in fatal injuries).

2.1 – Fatalgram Analysis

To determine the most common causes for fatal haul trucks accidents, the fatal accident reports and fatalgrams from MSHA were analyzed for every fatality involving haul trucks since 1995. It became apparent that mechanical failures, inadequate training, seatbelt misuse, and insufficient berms were the four most common problems. Mechanical failures were accidents where there was a mechanical problem with the haul truck. Inadequate training was specified for accidents where either the operator, or another employee involved in the accident was not sufficiently trained to operate or be around mobile equipment. Seatbelt misuse was classified for accidents where the driver was not wearing a seatbelt. Insufficient berms were classified for accidents where the haul truck came into contact with the berm, but it was either improperly constructed or did not meet MSHA standards. The berm classification was also given to accidents where haul trucks went over a highwall where no berm was present. A spreadsheet was created with each accident classified into four categories listed above. Other factors were listed, but no other cause contributed to more than five accidents.

From 1995 through 2006, there were 108 haul truck accidents which resulted in a fatality (MSHA "Fatalgrams"). Each accident report was read to find the underlying causes; the results are illustrated in Figure 2.1. Mechanical problems were present more frequently than all other factors.

Figure 2.1 - Contributing Factors to Fatal Accidents from 1995 to 2006 for All Mines (MSHA "Fatalgrams")

When looking just at haul truck accidents in metal/nonmetal mines there were 67 accidents which resulted in a fatality. The distribution of the common haul truck problems can be seen in Figure 2.2. Unrelated causes were more prevalent than any of the most common problems. The accidents which were classified as 'other' consisted mostly of lack of communication, alcohol and drug use, improper use of parking breaks and chocking tires, and visibility/blind spots. Lack of communication was listed for four of the accidents, which makes it the most prevalent problem listed under the 'other' classification. Aside from the 'other' classification, inadequate training had the greatest impact on haul truck fatalities in metal/nonmetal mining.

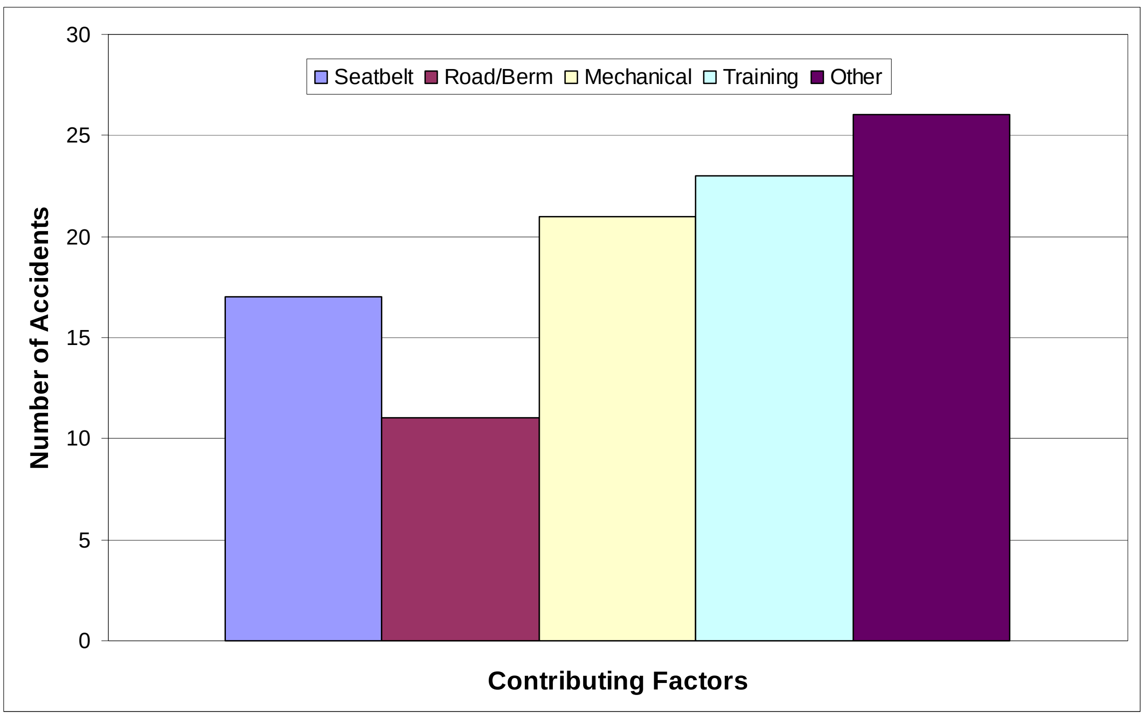

Figure 2.2 - Contributing Factors to Fatal Accidents from 1995 to 2006 for Metal/Nonmetal Mines (MSHA "Fatalgrams")

The majority of fatal accidents involving haul trucks can be reduced by simply supplying adequate training, keeping the haul truck in good mechanical order, and having a sufficient berm. Improving training can also improve some of the mechanical and seatbelt problems. While none of accidents were caused by the driver not wearing a seatbelt, the severity of the sustained injuries could have been lessened if one had been worn.

2.2 – Statistical Determination of Significant Causes

To identify the primary causes of fatal haul truck accidents, a t-test was conducted on the data collected from the fatalgram analysis. The statistical analysis was completed using the software program JMP (SAS 2006). For the test, the top five causes of fatal haul truck accidents were used and treated as different factors and interactions of training and seatbelt misuse, lack of communication, and mechanical failures were initially accounted for. Using a confidence coefficient of $\alpha = 0.05$, an analysis of variance (ANOVA) model was fit to the data. The t-test uses the null hypothesis that the coefficients of the factors in the model were zero (indicating that the factors could be ignored). The alternative hypothesis was that the coefficients of the factors were not zero (indicating that the factors could not be ignored in the model). The first model that was fit to the data indicated that the interaction effects between training and both lack of communication and seatbelt misuse were not significant (their p-values were 0.126 and 0.605 respectively). A second model was then fit, disregarding the insignificant interaction effects. All factors were found to be significant, with the p-value for all factors (except lack of communication) less than 0.0001. The p-value for lack of communication was determined to be 0.038, and the interaction between training and mechanical failures obtained a p-value of 0.0004.

The factors which were determined to be significant are the most likely causes for haul truck fatalities. The model predicts that haul truck accidents in the future will likely have these contributing factors. The interaction between the lack of training and mechanical failures indicates that training and mechanical failures are related. For many of the fatal accidents involving either training or mechanical failures, the other factor was present. This interaction is a sign that improving the quality of training, and reducing the number of accidents due to lack of training will also work to reduce the frequency of accidents which occur due to mechanical failure. This is further emphasized since the added virtual pre-shift training program will train operators to identify and correct mechanical problems on haul trucks before they begin operation for the shift.

Other factors which caused (or contributed to) fatal accidents do exist, but they were not tested due to their infrequent occurrence. Alcohol use had the highest occurrence for the factors not included and accounted for five of the total number of fatalities (the same amount as lack of communication), but was not included because training employees against working under the influence is beyond the scope of the training program. The table of accidents and their causes can be found in Appendix A.

2.3 – Age and Experience Effects on Haul Truck Accidents

Considering the analysis performed on fatal accidents involving haul trucks, it could be assumed that experience is an important factor in all haul truck accidents. The effects of experience are hypothesized to relate to the occurrence of accidents (including only fatal and serous injury) haul truck accidents. Age was also considered a possible factor in accident occurrence.

All the data for the analysis of age and experience effects on accident frequency was collected from the MSHA part 50 database (NIOSH). The data was filtered so that only data that was classified as “ore haulage trucks – off highway and underground” and "powered haulage." To reduce the amount of data in the database, only accidents that resulted in death or serious injury were used. This process was completed for data from the years 1994 through 2004. Three types of experience were reviewed; total mining experience, experience at the current mine, and experience at the current job. When looking at the data, the units of time could not easily be determined. Several entries could either have been in weeks or years, and a small portion of the data contained work experience in weeks which is either longer than the miner has lived or could have reasonably worked. Because the units of time could not be sufficiently determined, statistical analysis was not completed to look at the effects of age and experience. The data was deemed unreliable for quantitative study, but reasonable assumptions were made in regards to the units of time and the analysis was completed qualitatively.

Focusing on total mining experience, more than half of all haul truck accidents occur within the first two years of the operator working in the mining industry. The data also indicates that the accident frequency becomes smaller as total experience increases. When looking at all haul truck accidents from 1994 to 2004, roughly one third of all accidents occurred within the first year of the workers total mining experience.

Disregarding total mining experience and focusing on experience at the current mine, the frequency of haul truck accidents was reviewed. More than two-thirds of all truck haulage accidents occurred at the mine where the worker was first employed. It is apparent that the accident frequency for workers with less than one year of experience at the current mine is much greater than the frequency for the same time of total mining experience.

Only focusing on the experience from operating haul trucks, the accident frequency was once again reviewed. Similar to total experience, roughly one third of all haul truck accidents occur within the first year of the operator working at a mine. This comparison disregards experience other than the current job. Similar to the current and total mine experience, the majority of the accidents occur with little experience.

The trend of all types of experience with accident frequency for haul trucks shows that the majority of all accidents occur with less than a year of experience. For the total mining experience and the current job experience, there were fewer accidents with five or less weeks than ten to five weeks. This could partly be due to the training which often requires an experienced worker to ride along with a new worker. The sudden rise in accidents could be the result of the worker becoming comfortable with operating the haul truck and becoming less thorough during pre-shift safety inspections. To effectively address haul truck safety, continued training and emphasis on safety needs to be emphasized. Keeping the worker focused on safety will help to reduce the number of accidents with haul trucks.

When looking at accident frequency with age, it appears that there is little age effects. Once again this data is unreliable (some miners had an age of zero), but there did appear to be a rough normal distribution of accidents with the mean around 42 years. Further analysis cannot be conducted without knowledge of the ages of haul truck drivers in the workforce.

2.4 – Summary of Accident Causes

There are many contributing factors to fatal haul truck accidents. Experience, mechanical malfunctions, lack of berms, communication, and blind spots are the leading causes of haul truck accidents. There are solutions currently in place to help reduce the number of haul truck accidents. The solutions range from simple worker training to new technology which aids the equipment operator.

There is a trend for more accidents to occur with less experience. The lack of experience leads to other contributing factors to accident causes. Someone with little to no experience might have trouble identifying hazards while driving, or simply not know enough about the haul truck to know if there is something not working properly. Training is the most effective solution to lack of experience.

The majority of haul truck accidents are caused by some mechanical malfunction. It was found that in most fatalities with a mechanical cause, lack of training was also a contributing factor. The major downfall of pre-shift inspections is that if the operator has never seen damaged equipment, then they might not be able to recognize mechanical problems when they see it. Once again better training in recognizing possible mechanical problems might reduce the occurrence of accidents which mechanical malfunctions are the cause.

Berms are a necessary safety measure which will keep haul trucks from traveling over a highwall. If the berm is not properly constructed or not there entirely, then there is nothing preventing a haul truck from traveling over a highwall. The only solution for inadequate berms is to construct berms which meet MSHA standards. The current MSHA standard for berms is located in 30 CFR Part 56.9202.

Accidents which occur due to lack of communication between the driver and other personnel in the area result in accidents which usually result in the driver having little to no injury. It does, however, lead to accidents where a haul truck runs over a worker or another smaller vehicle. Blind spots coincide with communication problems in haul truck accidents. Most workers do not know exactly the blind spots of larger equipment if they have never operated them. Providing sufficient communication between vehicles and equipment will help reduce the haul truck and vehicle collisions. Ensuring that all workers know and understand the blind spots of larger equipment will also help reduce the accidents where communication is a cause. The safety hazards of larger equipment could be covered in miner training so that all mine workers are aware of the hazards of haul trucks. New technology is being developed and is already available which helps reduce accidents involving blind spots. Currently, there are more technological solutions to blind spots than any other cause of accidents.

Knowing the principal causes of fatal haul truck accidents, the currently available techniques to increase safety needs to be identified. Chapter 3 identifies the current haul truck safety techniques to determine which of the contributing factors for haul truck fatalities are not specifically addressed.

Chapter 3 – Current Measures to Increase Haul Truck Safety

To determine what can be done to reduce the number of fatal haul truck accidents, the current measures to increase haul truck safety needs to be reviewed. The current literature and federal regulations about haul truck safety was reviewed to determine what is currently available for haul truck safety. It was found that there are many areas which are currently being addressed to reduce fatal haul truck accidents. Federal regulations, miner training, and haul truck safety systems are currently available measures which work to reduce fatalities. While current measures do increase safety and work to reduce fatalities, they do not fully address the two principal contributing factors to haul truck fatalities (lack of training and mechanical problems).

3.1 – Current Federal Regulations on Mine Haul Truck Safety

Due to the inherent safety risks involving mining, the Mine Safety and Health Administration has defined regulations concerning the required safety training that each miner must go through. For newly hired inexperienced miners, a total of 24 hours of training is required (four of which needs to occur before the miner begins working). Until the 24 hours has been reached, the miner must work alongside an experienced miner who can observe that the new miner is working safely. Specific subject areas which are required to be covered in the miner training is covered in the Code of Federal Regulations as 30 CFR § 46.5. Similarly to new miners, newly hired experienced miners must also undergo training. Training for newly hired experienced miners is focused more on site-specific characteristics and reinforcing the miner's statutory rights (newly hired experienced miner training is defined under 30 CFR § 46.6). Similar to the training for newly hired miners, when a miner changes jobs they must have new task training. New task training is required for any miner who has been reassigned to a task in which they have no training (new task training is detailed under 30 CFR § 46.7). For all miners, 8 hours of annual refresher training is required. The annual refresher training will reinforce the key health and safety hazards miners are exposed to at the mine (annual refresher training is listed under 30 CFR § 46.8). The required training exists to ensure that all workers in the mine have knowledge of the health and safety risks they are exposed.

Federally mandated training does have drawbacks. The content of the necessary training is not expressly detailed, and left to the individual mine operators to determine the necessary training content. By mandating training based on time rather than content could lead to trainers to spend more time focusing on the hours of training remaining, and not cover enough material. There are also no mandated procedures for ensuring that the trainee learned any material.

3.2 – Current Miner Training

Current literature about available techniques for miner training was reviewed to determine what is being accomplished, and what can be accomplished through training. It was found that current training is not being conducted in an effective way, and that miners are not exposed to better training methods. Miner training is currently approached as a "one size fits all" model which is not appropriate. Differences in learning between younger and older workers are not addressed in current miner training, and the most effective method of training (hands-on training) is not commonly utilized.

Kowalski and Vaught performed a study on the principles of adult learning. The study showed that roughly 70% of all training consists of only an instructor and simple demonstrations, and that most mine "trainers frequently do not teach the way adults learn." It was found that adults respond best through "personal experience, group support, or mentoring"(Kowalski and Vaught 2002; Peters 2002). A five point checklist for developing a training curriculum was proposed and is outlined in Figure 3.1. It was shown that "adult learners are task-centered and problem-centered" which leads to the trainee becoming focused on a problem and "so are solution-driven." It was also determined that effective training programs for adults were "active and experienced-based" (Kowalski and Vaught 2002). These findings coincide with the results from the study conducted by Burke et al, which indicate that hands-on training to be the most effective for learning.

1. **Clear Goals** – What is the point of training? What are the expected outcomes of the training?

2. **Content** – What content will support the stated goals?

3. **Appropriate delivery mechanism** – What is the best delivery mechanism for the chosen content? Will the delivery mechanism add or subtract to the value of the lesson?

4. **Assessment** – How will you determine if the trainee has learned the content? How will you know if the goals have been achieved?

5. **Remediation** – If the trainee does not grasp the content, what will the intervention be?

Figure 3.1 - Checklist for developing a curriculum adapted from (Kowalski and Vaught 2002)

The studies reviewed show that hands-on training is superior to traditional training methods. By analyzing 95 studies (with roughly 21,000 total participants) from 1971 to 2003, Burke et al. identified that "the most engaging methods of safety training are, on average, approximately three times more effective than the least engaging methods in promoting knowledge and skill acquisition." It was also shown that "the most engaging methods of safety training are, on average, most effective in reducing negative outcomes such as accidents." Burke defined "most engaging methods" as hands-on training and behavioral modeling, "moderately engaging" was defined as instruction with direct feedback, and "least engaging" was defined as lectures and videos (Burke, Sarpy et al. 2006).

For safety training, it is important that the trainee's learn and understand the material presented to them.

Studies have also been conducted which analyze the effectiveness of computer based training (CBT). One such study was conducted by Williams and Zahed, and focused on the effectiveness of computer based training. They concluded that computer based training was "as effective as the traditional lecture/discussion method" (Williams and Zahed 1996). The effectiveness of the training method was defined as knowledge acquisition. The study also concluded that "there was a significant difference in the level of retention between CBT and lecture, with the CBT group performing better overall one month following the training" (Williams and Zahed 1996). By finding that the knowledge retention is greater with computer based training, the study shows that traditional lecture is not necessarily the best model for providing training. The results of the study also concluded that "computer anxiety had no impact on the level of knowledge acquisition within the CBT group" (Williams and Zahed 1996). With computer anxiety not impacting the computer based training program, it follows that computer training is acceptable to use on individuals who have little to no computer experience. Since participants using computer based training are also able to proceed at their own pace, the knowledge gained from computer training does not rely on the trainee having any computer experience. The Williams and Zahed study showed that computer based training is as effective as traditional lecture for knowledge acquisition, and significantly better in knowledge retention. These two factors indicate that computer based training is an effective training tool which should be utilized when creating a safety training program.

Two examples of utilizing virtual reality in miner training were reviewed. The first study was an incident recreation system which worked to promote "a strong safety culture … by accurate recreation of unsafe actions in the workplace, demonstrating explicitly how they resulted in a fatality or significant injury" (Schafrik, Karmis et al. 2004). By showing the user the exact consequences of unsafe actions, the user will be able to fully understand the consequences of unsafe actions. The major drawback of this system is that the user may interpret the recreations as videos and not an actual incident recreation. The second study utilizing virtual reality miner training reviewed was a virtual pre-shift inspection of a haul truck. In this study it was determined that a VR pre-shift inspection was "more flexible and cost effective than other available training methods" (Ennis, Lucchesi et al. 1999). This system required the user to learn how to use a six-axis controller and only presented a haul truck for inspection. Although there is some level of interactivity, forcing the user to learn a new controller would take away time the user could spend learning more about the content.

With 70% of all miners only experiencing the traditional lecture method of training, the other (and more effective) methods are not being utilized. Training is essential for safety, and should be the focal point of all safety measures. By not utilizing newer techniques for safety training, the effectiveness of the training is negatively impacted.

3.3 – Currently Available Haul Truck Safety Systems

Current techniques are in place to reduce the occurrence of haul truck accidents. The current safety techniques mostly focus on dump point proximity alerts, collision avoidance systems, and braking systems. The primary goal of all techniques is to reduce the number of haul truck accidents and increase safety.

Dump point proximity alerts consists of cameras and warning lights. Camera systems have a camera mounted in the rear of the truck and a monitor in the cab giving the driver the capability to see exactly what is behind him while the haul truck is in reverse (MSHA). Additional training usually coincides with the implementation of camera systems. The training allows the operators to better judge distances while looking through the monitor. Some camera systems have the monitor disabled while the haul truck is not in reverse. This is to lower the chance for the operator to become distracted by looking at the monitor. Warning lights consist of a laser and a light. When the haul truck backs into the dump point, the light comes on to notify the operator that they are at the dump point. Both camera and warning light systems are to be used in conjunction with adequate berms. In the event that the proximity alert malfunctions, training is needed so that operators will not solely rely on cameras and lights to determine the dump point.

Collision avoidance systems are primarily used to reduce the frequency of equipment collisions. Common collision avoidance systems include radar systems, radio frequency signal detection (RFID), global positioning satellite (GPS), and video camera systems (MSHA). Radar systems are a low-cost collision warning system. The fallback of using only a radar system is that rocks, highwalls, and loaders trip the alarm. It is most often recommended that a radar system be used in conjunction with video cameras, so that the driver can see exactly what sets off the alarm. RFID systems require that all equipment and miners wear RFID tags which broadcast a specific radio frequency. When two tags get too close together, a warning will sound. The major fallback of RFID is that the specific location of the other person/vehicle is not known. GPS systems require all vehicles to be mounted with a GPS receiver. Cost and coverage are the major fallbacks to a GPS system. Video based collision detection systems work by having cameras mounted on the haul truck and a monitor inside the cab. The driver is able to see the blind spots of the truck on the monitor. Fallbacks for video based systems include the possible distraction of the driver from looking at the monitor. While no one technology stands above the rest, combinations of the aforementioned systems and other technology do look promising. Combining radar systems or RFID with video cameras will allow the driver to see exactly where other people and equipment are located. Combining GPS and wireless networking technology allows real-time tracking of every piece of mobile equipment in a mine (Dagdelen and Nieto 2001).

Braking systems are a standard feature found on all mobile equipment. There are three main types of baking systems common to all haul trucks, the service brake, the secondary (emergency) brake, and the parking brake. The service brake serves as the main braking system used to stop the machine and hold it stationary, it acts much in the same way as the brakes in a car. The secondary (emergency) brake works as a backup in the event that the service brake does not work. Secondary brake systems often have less braking capacity than the service brake and should only be used in an emergency. The parking brake is only intended to hold a stopped machine. In the event that the parking brake is used to stop a machine, it must be tested for parking capacity before the machine can be used again. Some machines may come equipped with a retarder brake. The retarder brake is used only to control the vehicle's speed while traveling downgrades. All manufacturers include detailed instruction on the proper maintenance and inspection of braking systems. Should a problem in the braking system be found, only qualified and trained personnel are to perform maintenance (MSHA).

Currently driver training and braking system regulation are the only MSHA required techniques to increase truck haulage safety. The implementation and use of all other technologies is solely dependent on the mine operator. The use of collision avoidance and proximity detection systems are increasing as mine operators are noticing the cost effectiveness of prevention systems to the cost of haul truck accidents. While it is common for new technology to be used in accident avoidance, there is little technology readily available that currently exists for driver training.

After reviewing the current techniques to increase safety, it was determined that a pre-shift inspection training program would cover the significant contributing factors in haul truck fatalities. Chapter 4 details the development of the training program.

Chapter 4 – Development of the Training System

The training system developed addresses the common causes of haul truck accidents and fatalities defined in Chapter 2. The virtual pre-shift inspection training program will allow the user to gain a better understanding of what the parts need to be inspected for, and what the possible outcomes would be if the parts were left unchecked. With the added experience gained from the training program, the likelihood those accidents resulting from ignoring mechanical problems on trucks will be reduced.

Virtual environments were chosen as the training medium for multiple reasons. Due to the cost associated with removing a working truck from operation to practice pre-shift training, it may be impractical for newly trained operators to obtain experience on a haul truck. Immersive virtual environments were chosen over two-dimensional point-and-click methods because the level of interactivity is greatly increased when the user needs to navigate to the parts to inspect, and look under, on the side, and behind the inspection parts (which would not be easily accomplished in two-dimensional methods). X3D was chosen as the modeling standard to create the virtual pre-shift inspection due to its status as a widely accepted open standard.

It should be noted that the training system developed should not be used as a replacement for current training, but to complement the training new operators already receive. Due to the variations between haul trucks from different manufactures, the model attempts to identify the major inspection points on a generic truck. Because of the generic model, it is essential that new operators have experience with pre-shift inspections on the actual haul trucks they will be operating. It is also recommended that the first few pre-shift inspections completed by a newly trained worker be overseen by a competent person to ensure that the proper procedure is being followed. Complementing conventional training with virtual pre-shift inspection training will reduce the number of accidents which have mechanical failures, seatbelt misuse, and lack of training.

4.1 – Modeling in X3D

The modeling language used to create the model was X3D. X3D was chosen since it is a well established standard for 3-dimensional web content and extensive documentation for creating models are widely available online. Officially, "X3D is an open standard for 3D content delivery" (Web3D "X3d Faq"). Due to its status as an open standard, content viewers are widely available (most of which are freely available). X3D is designed to be scalable to the specific application, only including the details necessary to complete the specific model. The scalability is defined in the first few lines of code as the "profile" (Web3D "X3d, H-Anim, and Vrml97 Specifications"). The different profiles available are interchange, interactive, immersive, and full. Figure 4.1 illustrates the different profile levels, and includes some of the components available at each level. The training program developed uses the immersive profile due to the use of the interactive menus and audio playback.

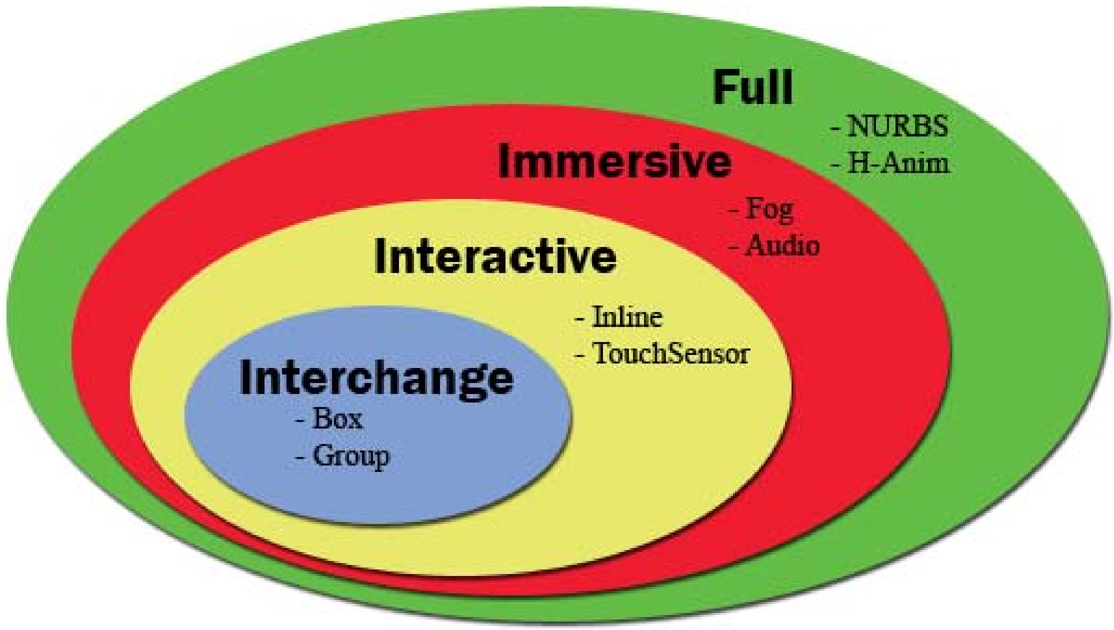

Figure 4.1 - X3D Profiles adapted from (Web3D "What Is X3d?")

To create X3D content, the easiest way is to use a modeling program. To create the model for the pre-shift inspection training, the program Flux Studio from Media Machines was used and is freely available for academic and non-commercial use. Within the Flux Studio program, parts could be created or imported into the scene and allowed simultaneous views from different angles or cameras within the scene. Basic X3D models include objects, lights and cameras which are all referred to as nodes. All nodes can be grouped so that they can be translated, rotated, scaled, or modified together. Other features included in X3D models include the animation of any node and environmental effects such as fog. Animations are created by setting the translation, rotation, and scale for nodes, at keyframes along the animation timeline. The X3D code stores the placement of the objects at each keyframe which the content viewer uses to create the animation and display to the user. Camera effects in animations are included by animating the camera node itself. Occasionally, it is convenient to have one long animation separated into multiple animation nodes which automatically trigger one another. Setting up multiple animations will allow for changing the camera, and greater synchronization with audio. When set up properly, the user will not notice the change from one animation to another. Fog effects are available within the immersive profile, but were not included in the training model.

The X3D file is an XML (extensible markup language) ASCII file which contains the code to generate the 3D model. Figures 4.2 and 4.4 show the code for a cube, and the modeled cube respectively. The cube (like cylinders, cones, and spheres) is a native object in X3D. The code for Figure 4.2 and 4.3 were generated by the modeling program (Flux Studio). Native objects are built into the X3D standard and require less code to model than objects stored as an indexed face set (IFS). The IFS code for the same cube is included as Figure 4.3. Indexed face set objects are broken into triangles, whose coordinates are stored in the code. The IFC code in Figure 4.3 shows that there were twelve triangles which made the cube. As it can be seen, the code to store a single IFC object is much larger than the code to store a native object. Although a simple cube modeled as an IFC needs more code, there are added advantages when working with textures and lighting. Larger and more complicated objects actually are more efficiently stored as single IFC objects, rather than the multiple native objects which would be required to create it. For the training system, most objects were stored as indexed face sets, due to the complex nature of the parts being modeled.

```
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 <meta name='ExportTime' content='19:23:56'/>
 <meta name='ExportDate' content='4/11/2007'/>
</head>
<Scene>
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 translation='1 2 3'>
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  <Appearance
   containerField='appearance'>
   <Material DEF='Red'
    containerField='material'
    ambientIntensity='0.200'
    shininess='0.200'
    diffuseColor='1 0 0'/>
  </Appearance>
  <Box DEF='GeoBox1'
   containerField='geometry'
   size='1 1 1'/>
 </Shape>
</Transform>
</Scene>
</X3D>
```

Figure 4.2 - X3D Code for the Native Cube

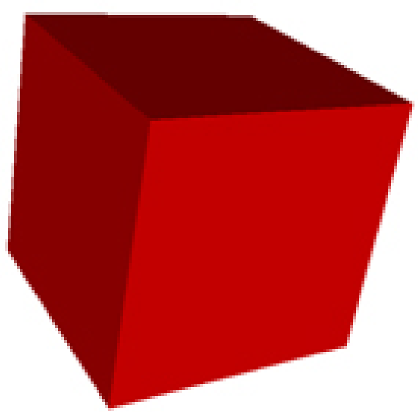

Figure 4.4 - X3D Model of a Cube

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  <Appearance
   containerField='appearance'>
   <Material DEF='Red'
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    ambientIntensity='0.200'
    shininess='0.200'
    diffuseColor='1 0 0'/>
  </Appearance>
  <IndexedFaceSet DEF='Box1_Geo'
   containerField='geometry'
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   coordIndex='
     0 1 2 -1
     0 2 3 -1
     1 5 6 -1
     1 6 2 -1
     2 6 7 -1
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     3 7 4 -1
     3 4 0 -1
     0 4 5 -1
     0 5 1 -1
     6 5 4 -1
     6 4 7 -1'>
   <Coordinate DEF='Box1_Coord'
    containerField='coord'
    point='
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     -.5 .5 .5
     .5 .5 .5
     .5 .5 -.5
     -.5 -.5 -.5
     -.5 -.5 .5
     .5 -.5 .5
     .5 -.5 -.5'/>
  </IndexedFaceSet>
 </Shape>
</Transform>
</Scene>
</X3D>
```

Figure 4.3 - X3D Code of the IFS Cube

4.2 – Modeled Inspection Parts

4.2.1 - Headlights

Haul truck headlights have two main purposes. They act to increase the visibility allowing the operator to better see the haul road, and they make it easier for other haul truck operators and personnel to identify the haul truck and avoid possible accidents. MSHA regulates that each mine create rules for "the use of headlights to assure appropriate visibility" (U.S. CFR 30 § 59.9100). Headlights need to be inspected so that any cracks, burnt bulbs, or broken connections are found and can be fixed prior to operation. In the event that the headlight is not properly checked during the pre-shift inspection, poor visibility can result in fatal accidents. Figures 4.5 and 4.6 illustrate real-life haul truck headlights, and the modeled headlights respectively.

Figure 4.5 - Actual Headlights

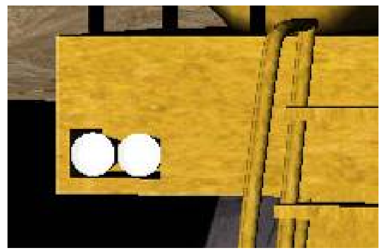

Figure 4.6 - Modeled Headlights

4.2.2 - Ride Cylinders

Ride cylinders on haul trucks act as shock absorbers for the front of the haul truck. When inspecting the ride cylinders during a pre-shift inspection, the bolts connecting the cylinder to the frame needs to be checked. If any bolts are missing, the truck should go out of service and be repaired. Steady leaks down the cylinder are also cause for immediate removal from service. In the event that the ride cylinder failed while in operation, the operator may loose control of the truck resulting in an accident. The ride cylinders on an actual truck and on the modeled truck are shown in Figures 4.7 and 4.8 respectively.

Figure 4.7 - Actual Ride Cylinder

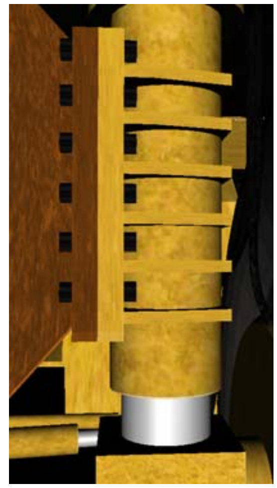

Figure 4.8 - Modeled Ride Cylinder

4.2.3 - Brakes

Brakes are of paramount importance on haul trucks. They serve to slow, stop, and prevent the haul truck from moving. MSHA minimum requirements for brakes are "self-propelled mobile equipment shall be equipped with a service brake system capable of stopping and holding the equipment with its typical load on the maximum grade it travels" (U.S. CFR 30 § 56.14101). There are also regulations regarding the use and capabilities of parking brakes (it should be noted that chocks should always be used when the truck is in park). MSHA also details testing procedures that are required for all mobile equipment brake systems. The brake system for a haul truck and the brake system used in the model are shown in Figures 4.9 and 4.10.

Figure 4.9 - Actual Brakes

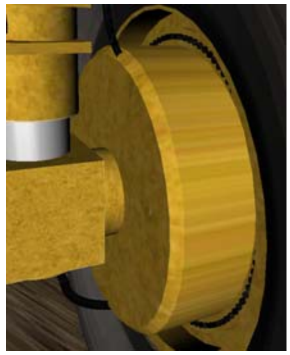

Figure 4.10 - Modeled Brakes

4.2.4 - Tires

Haul truck tires are composed of many different pieces which all need to be inspected prior to operation. The flange, or the "hub," of the haul truck tire supports the tire and provides the connection between the axel and the tires. The flange needs to be checked for cracks. The actual tires need to be checked on each wall, and on the tread. Lodged rocks and cracks need to be identified and may need immediate action prior to operation. Some small cracks in the tire rubber pose no immediate threat and can be resolved after the shift when discovered. Lastly, the lug nuts need to be checked to ensure that none are missing. Should two or more lug nuts be missing in any group of three, or if more than three total nuts are missing, the problem needs to be resolved before operation. Failure of any part in the tire system can lead to a blowout and the operator losing control of the truck. Figures 4.11 and 4.12 show the outside of the tire system in both a real haul truck and the modeled haul truck.

Figure 4.11 - Actual Tire

Figure 4.12 - Modeled Tire

4.2.5 - Hydraulic Hoses

Hydraulic hoses on haul trucks carry hydraulic oil to different components. Hoses need to be checked for cracks and leaks prior to operation. If a leak or crack is found the truck should be removed from operation until it is fixed. A leaking hydraulic hose will cause the oil pressure to drop, and some components (such as the brake systems) may not respond to the operators commands. Such a result would lead to accidents. Figures 4.13 and 4.14 illustrate the hydraulic hoses on a real truck and the modeled truck.

Figure 4.13 - Actual Hoses

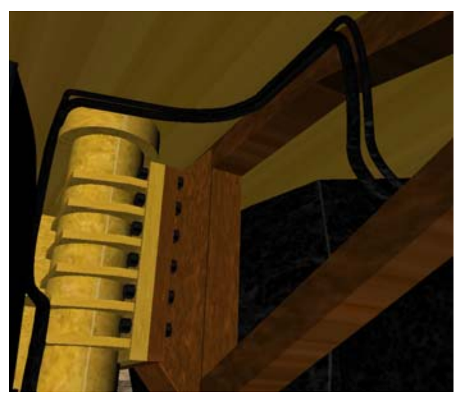

Figure 4.14 - Modeled Hoses

4.2.6 - Tie Rods

The tie rods of the haul truck act to steer the truck and transfer the motion from the bell crank to the wheel. The connections between the bell crank and wheel needs to be checked during the pre-shift inspection. In the event that one tie rod fails during operation, the operator will have no control over that particular wheel and would likely not have time to respond and stop the truck before it crashes. Tie rods for both an actual haul truck and the modeled haul truck are shown in Figures 4.15 and 4.16.

Figure 4.15 - Actual Tie Rods

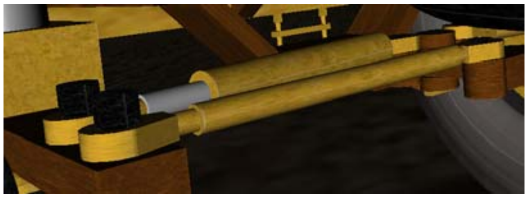

Figure 4.16 - Modeled Tie Rods

4.2.7 - Bell Crank

The bell crank on a haul truck transfers the actions from the steering wheel to the tie rods, and is the center of the steering system. The connections to the tie rods need to be checked, as well as the pin bracket below the bell crank. Any problems found with the bell crank needs to be remedied before the truck goes into operation. If the pin bracket fails, there is the chance that the entire bell crank would become dislodged making both front wheels unresponsive to any steering. Without the operator having control of the steering, there is a great risk for accidents. Figures 4.17 and 4.18 show the bell crank and pin bracket on a haul truck and on the modeled truck.


Figure 4.17 - Actual Bell Crank

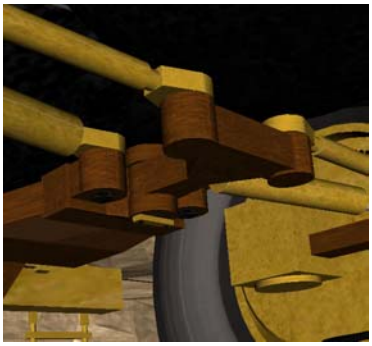
Figure 4.18 - Modeled Bell Crank

4.2.8 - Fuel Tank

The fuel tank on haul trucks holds the diesel fuel the truck uses during operation. During a pre-shift inspection, the tank needs to be checked for cracks, leaks, and the gauge needs to be checked for adequate fuel levels. If any cracks or leaks are found, they should be remedied prior to operation. Should a crack or leak go unnoticed, the tank would drain quicker than normally during operation, and may leave the haul truck out of fuel on the haul road. While this may not pose a serious safety risk, it will result in added frustration for the operator and other personnel who need to refuel the truck on the haul road. Figures 4.19 and 4.20 shows the haul truck fuel tank and the modeled fuel tank.

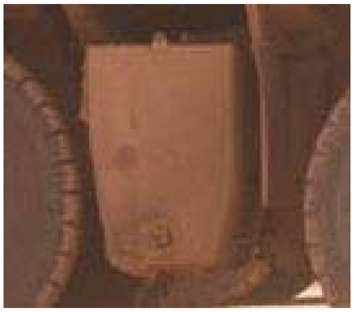
Figure 4.19 - Actual Fuel Tank

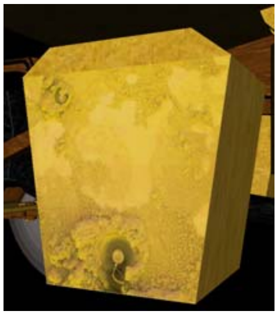
Figure 4.20 - Modeled Fuel Tank

4.2.9 - Mud Flaps

On haul trucks, mud flaps act to prevent mud and rocks from accumulating on top of the fuel and hydraulic tanks. If a mud flap is missing, it should be replaced as mud and rocks could build up on top of the tanks and cause them to collapse or detach from the truck due to the added weight. Mud flaps for a haul truck and the modeled truck are shown in Figures 4.21 and 4.22.

Figure 4.21 - Actual Mud Flaps

Figure 4.22 - Modeled Mud Flaps

4.2.10 - Bed Cylinders

The bed cylinders on the haul truck act to raise and lower the dump bed. They need to work in synchronization to ensure that the bed is raised leveled. The connections between the frame and the dump bed need to be checked as well as checking for steady leaks down the cylinder. If any connections problems, or leaks are found they need to be addressed prior to operation. If a problem goes unchecked, damage to the truck could result when raising the bed. In extreme cases the truck may tip over when only raising one side of the dump bed. Figures 4.23 and 4.24 show the bed cylinders on a haul truck and on the modeled truck.

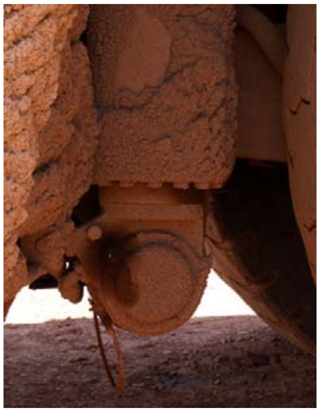
Figure 4.23 - Actual Bed Cylinder


Figure 4.24 - Modeled Bed Cylinder

4.2.11 - Rock Ejectors

On haul trucks that have double tires on rear wheels, rock ejectors are necessary to prevent rocks from becoming lodged between the tires. The rock ejectors hang from the dump bed in between the tires and will knock any lodged rock out of the tire. The connection between the rock ejector and the dump bed needs to be checked prior to operation. Should the rock ejector be missing, it should be replaced prior to operation. If the rock ejector is missing, a rock could become lodged between the tires and puncture one of the tires resulting in a blowout or deflation. Either case may result in the adjacent tire not being able to handle the increased pressure and failing as well. This would result in accidents involving the truck. The rock ejectors are shown on a haul truck as well as the modeled truck on Figures 4.25 and 4.26.

Figure 4.25 - Actual Rock Ejector

Figure 4.26 - Modeled Rock Ejector

4.2.12 - Pivot Joints

The pivot joints are the connection between the dump bed and the frame. They partially support the weight (along with the bed cylinders) of the dump bed during dumping. Cracks and missing pins need to be checked for prior to operation, and should be fixed immediately. If a pivot joint fails, the dump bed could slide off of the truck during dumping and cause severe damage to any equipment and personnel in the area. Figures 4.27 and 4.28 show the pivot joints on a haul truck and on the model.

Figure 4.27 - Actual Pivot Joints

Figure 4.28 - Modeled Pivot Joints

4.2.13 - Struts

Struts serve as the connection between the truck frame and the rear axle to prevent vertical movement. They help support the frame and should be regularly checked for leaks prior to operation. The connections on the Struts should also be checked, and any problem found should be resolved prior to the truck beginning operation. If one strut should ever fail, the entire frame could become twisted resulting in an inoperable truck. The struts on a haul truck and on the modeled truck are shown in Figures 4.29 and 4.30.

Figure 4.29 - Actual Struts

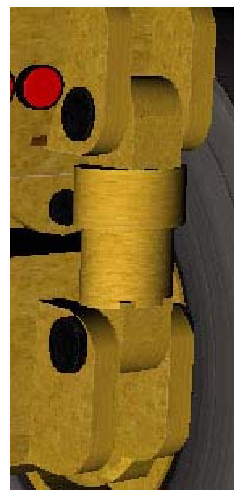

Figure 4.30 - Modeled Struts

4.2.14 - Rear Lights

The rear lights include brake lights on haul trucks, and act to signal vehicles behind the haul truck that it is braking. Similarly to headlights, they should be checked for burnt bulbs, cracks, or loose connections are found and fixed prior to operation. Broken brake lights could result in the rear collision of the haul truck and another vehicle, which would result in an accident. The rear lights of a haul truck and the modeled truck are shown in Figures 4.31 and 4.32.

Figure 4.31 - Actual Rear Lights

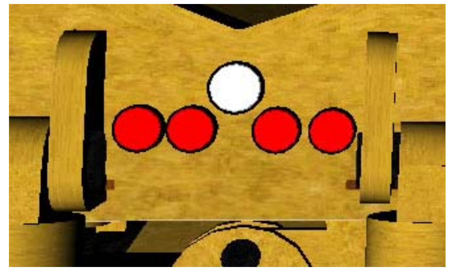

Figure 4.32 - Modeled Rear Lights

4.2.15 - Dog Bone

The dog bone acts as a connection between the rear axle and the frame preventing lateral movement. The dog bone should be checked for cracks and connections, and any problems found should be remedied immediately. Should the dog bone fail during operation, the entire rear axle could move independently from the frame and result in loss of control and accidents. Figures 4.33 and 4.34 show the dog bone on a haul truck and on the modeled truck.

Figure 4.33 - Actual Dog Bone

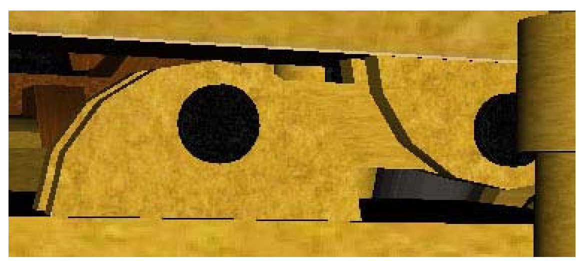

Figure 4.34 - Modeled Dog Bone

4.2.16 - Hydraulic Tank

The hydraulic tank stores the hydraulic oil the truck uses for various components such as the brake systems. The tank needs to be checked for any cracks and leaks, as well as the gauges checked for appropriate oil levels. If problems are left unnoticed, oil pressure could be lost during operation and components such as the brake system would become unresponsive to the operator which would end in an accident. The hydraulic tank of a haul truck and the modeled truck is illustrated as Figures 4.35 and 4.36.

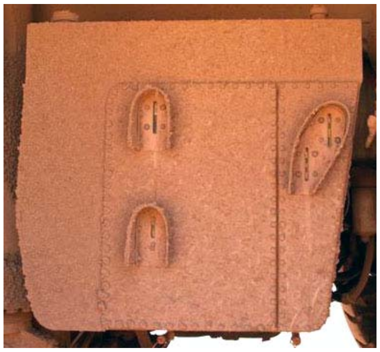

Figure 4.35 - Actual Hydraulic Tank

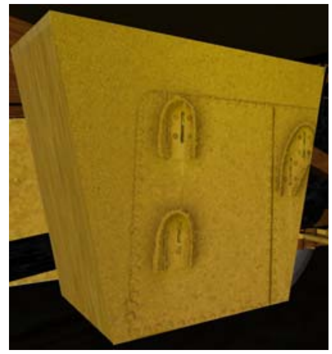

Figure 4.36 - Modeled Hydraulic Tank

4.3 – The Training System

The training system was developed in X3D and can be implemented over the internet, or as a standalone application. The complete system will contain three major parts: a virtual tour, a pre-shift inspection, and the results. The program was developed assuming that the user will have gone through the standard classroom-like safety training on haul trucks. To complete the program start to finish, the user can expect to spend roughly 30 minutes.

The virtual tour will take the user on a guided pre-shift inspection. The inspection points are shown and the corrective action is given. The inspection points were detailed earlier in section 4.2. There is the opportunity, within the tour, to go back and revisit parts which may have been unclear. The total tour lasts approximately ten minutes, and at the end the user has the ability to freely move around and look at the haul truck. The virtual tour only shows the correct working parts, leaving the user unfamiliar with what the failed parts will look like. It is in this part of the program where the user learns about the key components and what they need to inspect for. The following image, Figure 4.37, shows the hydraulic tank during the virtual tour. There is also a window displaying text (which accompanies the voiceover reading the same text) of what to look for, and what actions to take. The window for the hydraulic tank is shown as Figure 4.38.

Figure 4.37 – The Hydraulic Tank during the Virtual Tour

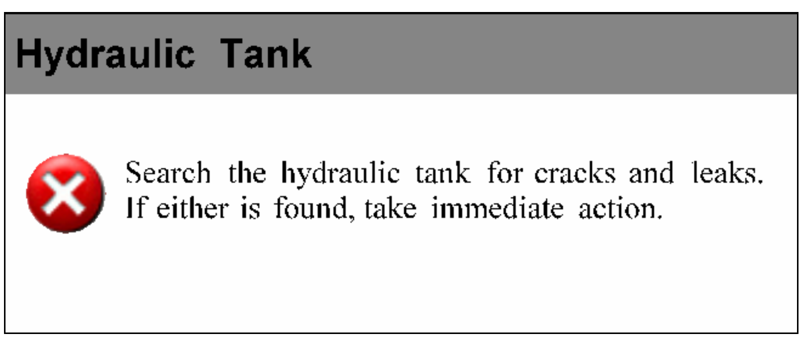

Figure 4.38 – Hydraulic Tank Virtual Tour Window

Once the virtual tour is completed, the user will then begin the second phase of the training (the virtual pre-shift inspection). During this phase the user will be presented with a broken haul truck, and asked to perform a pre-shift inspection. The broken parts will be positioned around the truck in a random manner. The most common problems (usually involving rocks lodged in tires) will occur more often than the less common problems (such as the bell crank pin bracket failing). There will be no more than three different parts broken during one pre-shift simulation. An example of the broken hydraulic tank is shown in Figure 4.39. To identify the part as needing action immediately, after shift, or no action at all the user will click on the part to see the action window. The action window will allow the user to select to take immediate action, take action after shift, or take no action. Each part which could fail will show an action window when clicked. It is up to the user to decide if there is a problem, and if there is what level of action needs to be taken.

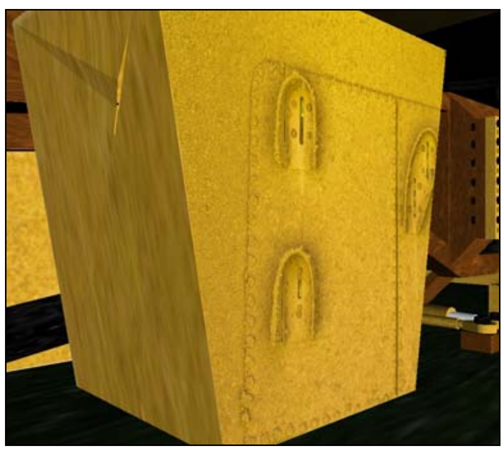

Figure 4.39 - Broken Hydraulic Tank in the Pre-Shift Inspection

After the user completes the pre-shift inspection, a resulting animation will play. If the user either missed a broken part, or identified a critical problem as an after shift problem, the animation will display that particular part failing. If the user missed more than one item, the animation will show the consequences of missing the more severe part. A screenshot from the animation for the broken hydraulic tank is shown as Figure 4.40.

Figure 4.40 - Failure Animation of the Hydraulic Tank Losing Oil

In the event that the user completes the virtual pre-shift inspection and successfully identifies all of the broken parts and does not misidentify any unbroken parts, a separate animation will be shown. This congratulatory ending conveys the operator driving his pickup home after another safe day at the mine. A message of congratulations appears as the pickup drives off into the sunset. Figure 4.41 shows the pickup driving off into the sunset.

Figure 4.41 - Congratulatory End Animation

Once the failure/ending animation completes, the user will be displayed with a list of what problems existed on the truck during the pre-shift inspection, and what the correct course of action would have been. This will also identify any parts that were mistakenly marked as broken or needing immediate action, when the parts were not broken or could have waited until after shift to fix. At this point the user will be given the opportunity to revisit the virtual tour, or attempt another pre-shift inspection. After the virtual tour is completed, it may be beneficial to evaluate the trainee. An example evaluation is included in Appendix B.

4.4 – Testing the Effectiveness of the Training Program

A pilot study using a limited number of participants was conducted to determine if the training program was effective enough to begin testing with a larger population. The pilot group consisted of six participants with varying degrees of experience (from never having seen a haul truck to former haul truck operators) with haul trucks. All participants were presented with the same broken haul truck during the virtual pre-shift inspection portion of the training, and completed a post assessment survey of the training system.

The post-assessment survey's goal was to identify the strengths and weaknesses of the training program. The survey consisted of six simple questions which provided an outlet for the user to describe how effective they observed the training to be. The results of the survey were separated into each section of the training system and overall observations and comments of the system. The comments obtained from the surveys provided a good insight into what needs to be modified, and what is appropriate for further testing.

Chapter 5 – Conclusions

From 1995 through 2006, there were 108 fatal haul truck accidents in the United States. The current measures available for increasing haul truck safety focus more on collision avoidance, rather than prevention. With additional training to address some of the most common factors contributing to fatal accidents, the frequency of fatal haul truck accidents can be reduced.

All factors which contribute to fatal haul truck accidents must be considered when developing a new training program. The study from Burke et al indicated that the most effective training methods are hands-on training. It was determined by Kowalski and Vaught that following a checklist of five steps when creating a training program will make the training program more effective. Using this checklist, the training system was planned out. First is clear goals, the goal of the virtual pre-shift inspection training is to provide haul truck operators with additional training to successfully complete pre-shift inspections. Second is content, the information about which parts to inspect and the appropriate corrective action to take comprise the content for the training program. Third is the appropriate delivery mechanism, virtual environments were chosen to convey the content. Fourth is assessment, a post-test questionnaire will be given to the trainees to test their knowledge of haul truck parts and their corrective action. Fifth is remediation, if the assessment or completion of the virtual pre-shift inspection was unsatisfactory the trainee must restart the training program.

The trainee will begin training by completing the virtual tour of a pre-shift inspection. They will then complete a pre-shift inspection on a virtual haul truck. Based on their actions during the virtual pre-shift inspection, the appropriate consequence animation will play showing a report comparing the trainee's responses to the pre-shift to the actual parts which needed to be identified. The trainee will then complete an assessment which will test their knowledge of haul trucks and pre-shit inspections. If the responses are unsatisfactory, the trainee will return to training starting from the virtual tour. If the responses from the user were satisfactory, they will complete the virtual pre-shift inspection training and continue further with their standard training. Figure 5.1 diagrams the training programs process.

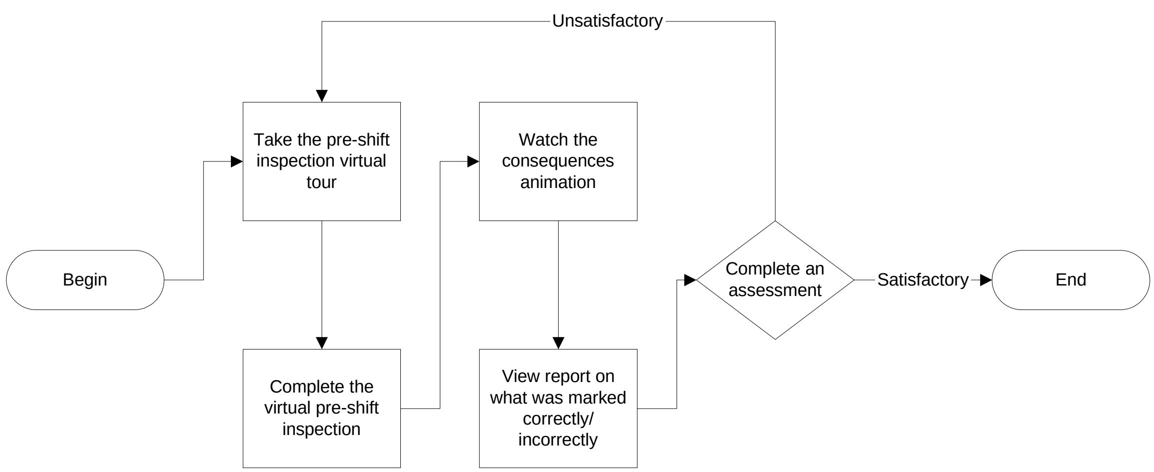

Figure 5.1 - Process of the Virtual Pre-Shift Inspection Training Program

5.1 – Results from the Pilot Test of the Training Program

The results of the survey were separated into each section of the training system and overall observations plus comments of the system. For the virtual tour the results indicated that some of the on-screen text was difficult to read, but was very thorough. The results concerning the virtual pre-shift inspection focused mainly on movement controls. The responses indicated that the navigation was somewhat difficult and "jumpy." The impressions from the consequence animation once again focused a little on the "jumpiness," but the responses also indicated that an explanation of the failure would greatly increase the effectiveness of this portion.

The "jumpiness" of the training program was determined to be caused by the lacking computer hardware. The test was completed on a low-end machine which resulted in the lagging performance. When the program was installed on a mid-range machine the "jumpiness" was drastically reduced and the movement controls were much easier. For the best performance, the program should be run on a current mid- to high-end computer.

Of the six users who tested the training program, all but one missed at least one part, with most missing the only part which did not require immediate action. The comments from the survey indicated that the most common part missed (the mud flap) was difficult to determine if it was missing. The results indicated that the training system in general was adequate to begin further testing with a larger test group. The responses from each of the six users in included in Appendix C.

5.2 – Future Work

From the comments obtained during the pilot study, the issues of the text being difficult to read can easily be addressed. Formal testing can then be completed to compare the effectiveness between traditional lecture and the virtual pre-shift training.

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Appendix A – Raw Fatalgram Data

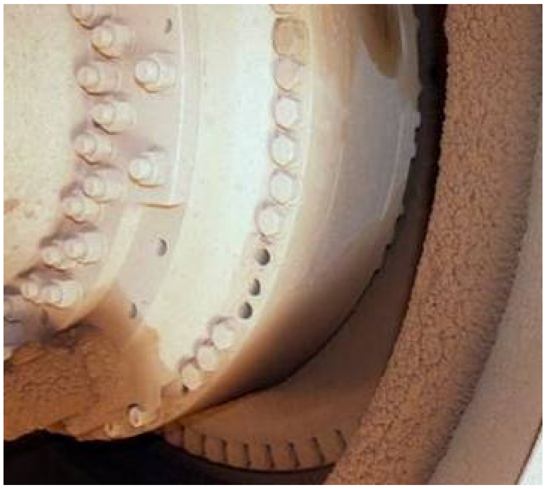
Year	Fatal Number	Seatbelt	Road	Mechanical	Training	Other (specify)
1995	M-1995-11	X			X	
1995	M-1995-12			X	X	
1995	M-1995-13				X	Lack of Communication
1995	M-1995-14			X	X	
1995	M-1995-16			X	X	
1995	M-1995-2					Lack of Communication
1995	M-1995-32		X		X	
1995	M-1995-35			X		
1995	M-1995-38				X	
1995	M-1995-4					Illumination Problems
1995	M-1995-45					Undetermined Cause
1995	M-1995-50					Alcohol
1995	C-1995-14					
1995	C-1995-28			X	X	
1995	C-1995-4	X	X	X		Drugs
1995	C-1995-45			X	X	
1995	C-1995-5	X		X		
1996	C-1996-16	X	X			
1996	C-1996-31	X			X	
1996	M-1996-2	X	X			
1996	M-1996-22	X	X	X		
1996	M-1996-25				X	
1996	M-1996-27			X	X	
1996	M-1996-42		X	X	X	
1996	M-1996-8					Lack of Communication
1997	M-1997-11				X	
1997	M-1997-12			X		
1997	M-1997-13	X				Alcohol
1997	M-1997-28	X				
1997	M-1997-33					Only a Lap Belt
1997	M-1997-41	X	X			
1997	M-1997-43					Power Line Clearance
1997	M-1997-44					Unstable Stock Pile
1997	M-1997-46					Alcohol
1997	M-1997-47					Hit by a Train
1997	M-1997-48					Hit by a Train
1997	M-1997-51			X	X	
1997	M-1997-8		X			
1997	C-1997-21	X	X			
1997	C-1997-24			X		
1997	C-1997-5				X	Power Line Clearance
1998	C-1998-10	X		X	X	
1998	C-1998-15					Lack of Communication
1998	C-1998-20			X	X	

Year	Fatal Number	Seatbelt	Road	Mechanical	Training	Other (specify)
1998	C-1998-21	X		X		
1998	M-1998-12			X		
1998	M-1998-24	X	X			
1998	M-1998-26					Operator Error
1998	M-1998-3	X				
1998	M-1998-43	X				Service Truck in Blind Spot
1998	M-1998-47	X			X	
1998	M-1998-7			X		
1999	M-1999-1					Visibility
1999	M-1999-11		X			
1999	M-1999-16				X	
1999	M-1999-2					Failure to Block Dump Doors
1999	M-1999-28	X		X		
1999	M-1999-40					Lack of Communication
1999	M-1999-47					Parking Break not Set
1999	M-1999-55				X	Pre-existing neck problems
1999	M-1999-7				X	Blind Spots
1999	C-1999-16			X	X	
1999	C-1999-2					Unstable Ground
1999	C-1999-9			X		
2000	C-2000-11	X				
2000	C-2000-15					Victim Intentionally walking behind truck
2000	C-2000-17	X		X		
2000	C-2000-36	X				
2000	C-2000-37				X	
2000	M-2000-22				X	
2000	M-2000-42			X		
2000	M-2000-45	X		X		
2000	M-2000-49					Driver left cab in loading area
2000	M-2000-6		X			
2001	M-2001-19			X	X	
2001	M-2001-22			X		
2001	M-2001-23	X		X		
2001	M-2001-3					Failure to set parking break
2001	C-2001-13					Failure to set parking break
2001	C-2001-35			X	X	
2002	C-2002-11			X	X	
2002	C-2002-16		X			
2002	C-2002-17					Alcohol
2002	C-2002-22		X			
2002	C-2002-8				X	
2002	M-2002-10			X		

Year	Fatal Number	Seatbelt	Road	Mechanical	Training	Other (specify)
2002	M-2002-24					Victim in blind spot
2002	M-2002-26	X	X	X	X	
2002	M-2002-35					Unstable dump site
2003	M-2003-26			X		
2003	C-2003-10	X		X		
2003	C-2003-19		X			
2003	C-2003-25&26			X		
2003	C-2003-7	X		X		
2003	C-2003-8		X	X		
2004	C-2004-10			X		
2004	C-2004-11	X		X	X	
2004	m-2004-20	X		X		
2004	M-2004-8				X	
2005	m-2005-13				X	
2005	m-2005-19	X				Alcohol
2005	m-2005-21	X			X	
2005	C-2005-14-15				X	
2005	C-2005-18	X		X		
2006	C-2006-17	X		X		
2006	C-2006-32	X		X	X	
2006	C-2006-46			X	X	
2006	M-2006-17		X		X	

Appendix B – Example Evaluation Questionnaire

Evaluation Questions



What is wrong with the part shown in this picture?

What is wrong with the part shown in this picture?


What is wrong with the part shown in this picture?

What is wrong with the part shown in this picture?

What is wrong with the part shown in this picture?


What is wrong with the part shown in this picture?

This mudflap is missing. What should the corrective action be?

A. Take Immediate Action
B. Take Action After Shift
C. Take No Action

This hydraulic tank’s gauges read low oil. What corrective action should be taken?

A. Take Immediate Action
B. Take Action After Shift
C. Take No Action

This ride cylinder has a steady leak. What should the corrective action be?

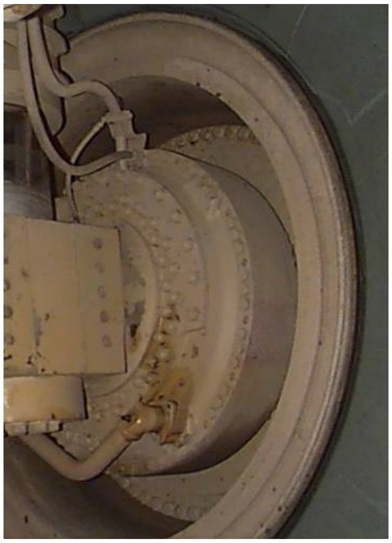
A. Take Immediate Action
B. Take Action After Shift
C. Take No Action


This transmission has a steady leak. What should the corrective action be?

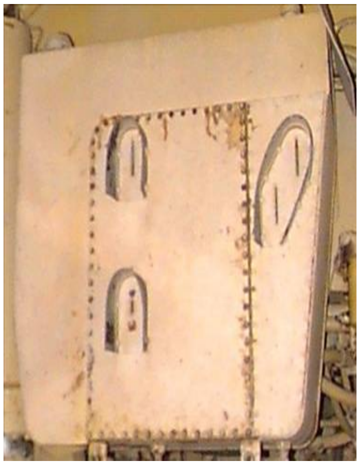
A. Take Immediate Action
B. Take Action After Shift
C. Take No Action

There are two missing lug nuts in a group of three. What should the corrective action be?

A. Take Immediate Action
B. Take Action After Shift
C. Take No Action



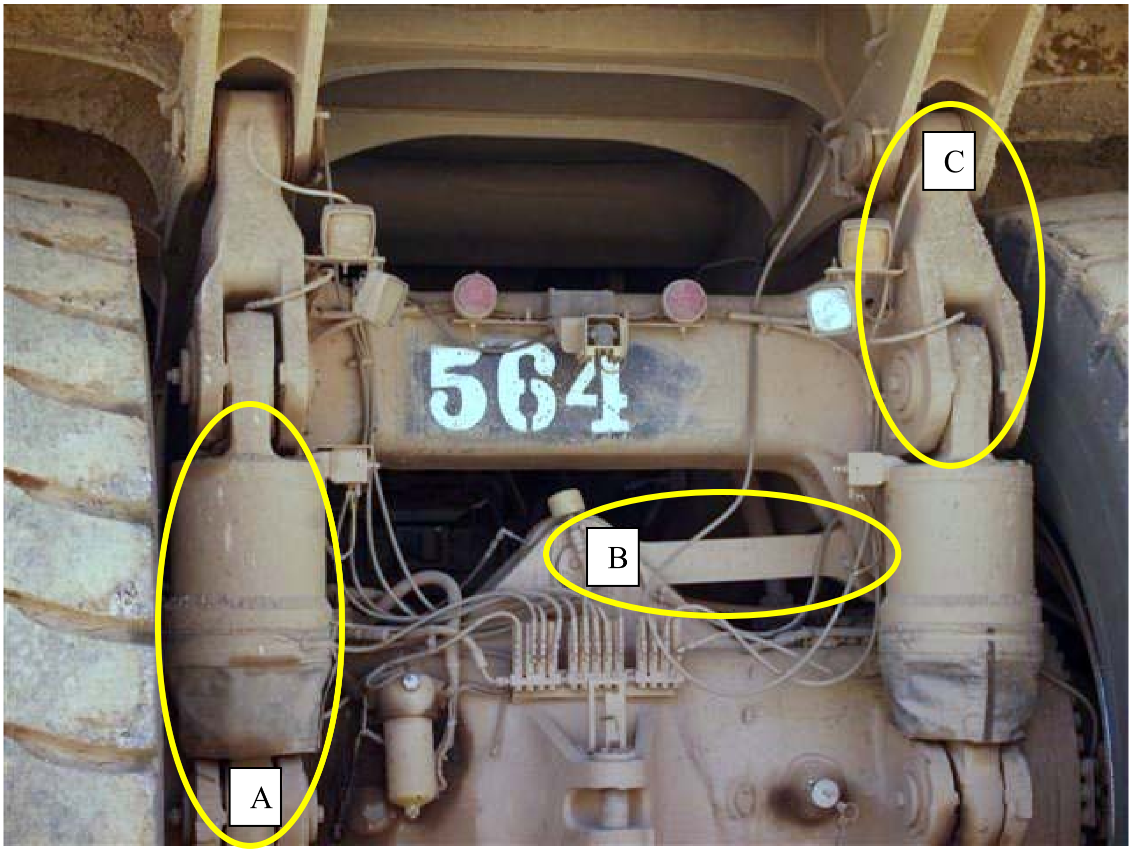
Identify this part. List all of the problems you should look for with this part, and the corrective action for each problem



Identify this part. List all of the problems you should look for with this part, and the corrective action for each problem.

Identify this part. List all of the problems you should look for with this part, and the corrective action for each problem.

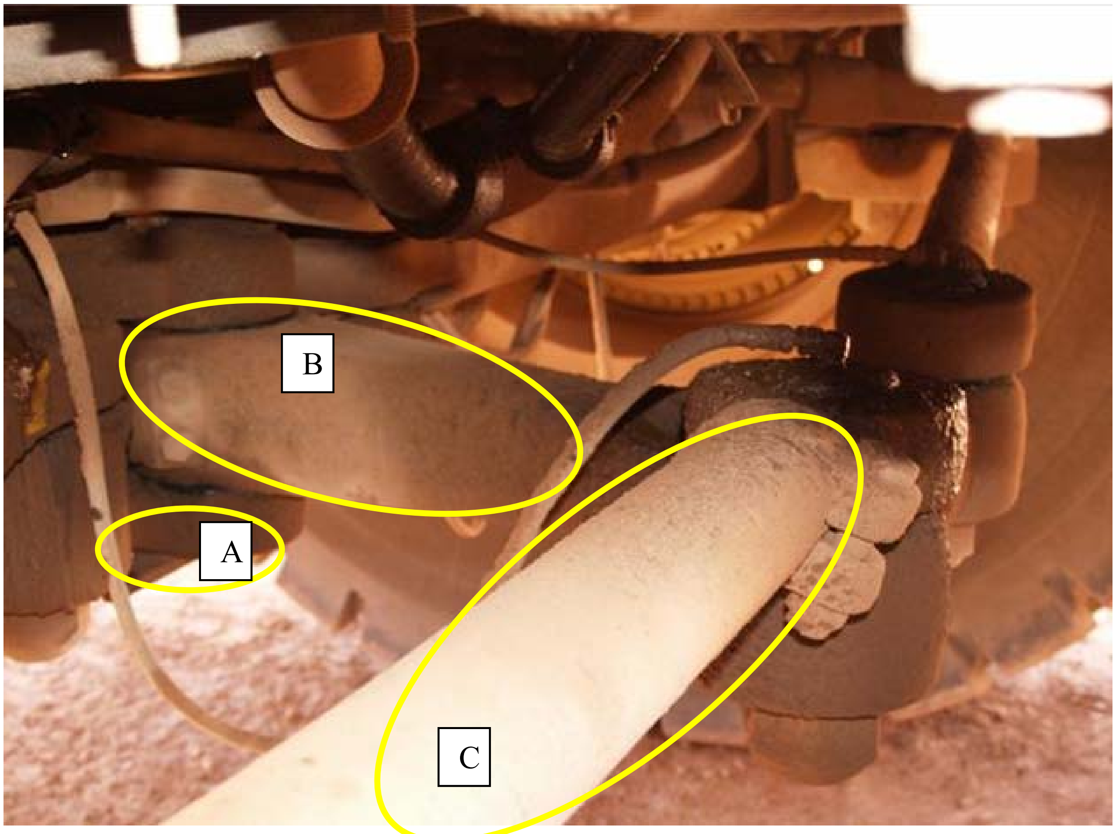
Identify this part (not the tires). List all of the problems you should look for with this part, and the corrective action for each problem.



For the following questions, answer A, B, or C:

In the picture above, locate a strut.

In the picture above, locate the dogbone.



For the following questions, answer A, B, or C:

In the picture above, identify a tie rod.

In the picture above, identify the bell crank.

In the picture above locate the bell crank pin bracket.

Appendix C – Pilot Testing Results

Exact text of user responses is included in italics below.

Concerning the virtual tour, what are your general impressions? Do you think the tour did an adequate job of conveying the information?

Pretty nice. Not Really, For example it doesn't say how many bolts should be there, or what necessary action should be taken. The pop-up windows disappear too quickly (ones we don't need to click "Next")

It may be helpful to make each piece that is referred to in the virtual tour change to red momentarily so that it stands out to the trainee.

Yes, some of the windows were hard to read, A visual as motion for areas to check would be ideal for a final product.

Some of the text is difficult to read. Also, for inexperienced haul truck drivers knowing the names of all the parts might present a problem.

The walkthrough is thorough and very similar to my personal training with pre-shift inspections. With my experience, EMS sheets were used with a check list of items to check on the truck, and all items that I recall are covered in this simulation.

The virtual tour give me a lot information

Concerning the virtual inspection, what are your general impressions? Was the navigation around the haul truck easy and intuitive? Were you able to locate the parts needed for inspection?

It's pretty tough to navigate. It's not rally intuitive. It takes time to understand the buttons. It would have been a lot easier using joy stick. No, I believe there are some parts that should be inspected, but have not option to be inspected.

Navigation was kind of difficult using the mouse and somewhat jumpy w/ the arrow keys. The "jumpiness" may be a result of the computer speed.

I was, the model was well done and navigation was easy to figure out.

Navigation around the outside of the truck is simple, however navigating inside/under the truck is more difficult.

The problem items were representative of issues I have encountered during pre-shift inspections.

Yes. I think so.

Concerning the consequence animation, what are your general impressions?

It looks pretty good, though it should be longer / has some explanation as to what went wrong.

I had some difficulty understanding exactly where I was located at times during the animation due to the "jumpiness" of the view. Overall, looking at 3D representations of the parts is much better than just seeing a 2D diagram.

[User identified all parts and didn't observe an animation]

I liked that it zoomed in on the part, but it should have some sort of text to tell you what happened to the part.

The resulting video after assessment is a "wake-up call" to the importance of checking every essential items without the threat of damaging equipment in the real world.

[NO RESPONSE]

Please add any additional comments or suggestions which may improve this training program.

Joystick would be great, so it will be a lot easier to navigate. Also virtual tour's messages are very general. Maybe will be better if there is help button to ask question regarding parts.

I think that the label for "Tie" rods and "Tire" rods changed from one side of the truck to the other during virtual tour.

On training – Highlight broken areas and what it might actually look like

Maybe add a list of parts and their definitions / locations for new users.

Model is sufficiently detailed for a realistic and practical simulation.

For a 3D interface, it should be much more convenient with mouse input.

Did you successfully complete the training program? What parts were missed in the virtual inspection? Can you list the parts to be inspected now?

No. I don't know the name of the parts (but I can show it where). Not all of them.

I thought I had checked both sides of the truck for missing mud flaps, but missed a missing mud flap. The result was a buildup of mud on the gas tank and the tank fell off. Tie rods, rock in tires, dogbone, fuel tank, bed supports, rock ejector parts, break lines, struts, lug nuts, flanges, hydraulic leaks, mud flaps.

I did. I select the wrong action for the ride cylinder.

No, something was leaking behind the front passenger tire. I could list or point out most parts, but as I said before I don't know the names of all the parts since I don't have any haul truck experience.

[user did not answer this question]

Yes.

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EDUCATION

Virginia Tech
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M.S. Mining and Minerals Engineering (Spring 2007)

B.S. Mining and Minerals Engineering (Spring 2006)

WORK EXPERIENCE

Graduate Research Assistant (May 15, 2006 – May 9, 2007)
Virginia Tech, Blacksburg, VA 24061

- Worked primarily on a NIOSH project through the Virginia Center for Coal and Energy Research
- Contributed to a Goodyear project in the area of telegeomonitoring (TGM)
- Assisted in preparing notes, teaching, and grading in various undergraduate courses in Mining and Minerals Engineering

Treasurer (May 2005 – May 2006)
Burkhart Mining Society, Blacksburg, VA 24061

- Implemented a new standard for keeping financial records
- Tracked the accounts for the student societies:
    - Burkhart Mining Society (Student chapter for SME)
    - Intercollegiate Mining Competition Team
    - International Society of Explosives Engineers (ISEE)
    - National Sand, Stone, and Gravel Association (NSSGA)
- Designed logos and assisted in the procurement of new merchandise

Mining Engineering Intern (May 15, 2005 – July 29, 2005)
Vulcan Materials, Hanover, PA 17331

- Performed quality control tests
- Assisted in checking screens
- Assisted in plant maintenance
- Performed miscellaneous clean-up tasks around the site

Mining Engineering Intern (June 1, 2004 – July 29, 2004)
Martin Marietta Aggregates, Boonsboro, MD 21713

- Assisted in mechanical shop work
- Carried out plant maintenance
- Performed minor clerical work on fuel usage data and on-shift hours
- Gained a variety of experience in the aggregates industry