A GPS Based System for Minimizing Jolts to Heavy Equipment Operators

R. E. Miller, N. T. Lowe
CDC, NIOSH, Spokane Research Laboratory

R. Thompson
University of Pretoria, South Africa

ABSTRACT

When two pieces of heavy equipment interact, jolting and jarring can occur. During haulage truck loading for example, there is a chance that the operator of one or both pieces of the equipment will experience jolting and jarring. Additionally, a jolt can occur when an off highway equipment operator drives over a road defect or inadvertently strikes a berm. Aside from the operators, there is seldom anyone else that witnesses the interaction and can accurately describe the extent of the jolting. This makes it difficult for health and safety managers to address jolting and jarring. The devices and software described in this paper constitute a method for installing "black boxes" called Shox Boxes onboard equipment that already have a GPS system onboard. The resulting configuration provides an objective assessment of jolting and a chance to determine the root causes of it. The Shox Box system reviews data in real time, onboard the vehicles, 24 hrs a day, and sends pertinent information via radio to a central database. The data generated shows whether jolts are above or below a supervisor defined target value for the equipment and the tasks being performed. This allows health and safety personnel to demonstrate safe operation of heavy equipment and recommend proactive actions to maintain jolting within a reasonable range.

INTRODUCTION

Overall health and fitness plays a role in injury prevention for operators. Physically demanding professions (sports for example) require training to prevent injuries. Equipment operators should consult with their physician about exercises to strengthen vulnerable areas, such as the lower back. Through no fault of their own, however, the actions of others or conditions such as a defect in the haul road may contribute to an operator injury. Human perception can be erroneous and misunderstandings as to what was an acceptable work practice or condition may happen. Therefore, an objective assessment that enables health and safety personnel to make data driven analyses is needed.

The National Institute for Occupational Safety and Health (NIOSH) has researched jolting and jarring cooperatively with Phelps Dodge Morenci, Inc. via a Cooperative Research and Development Agreement (CRADA). Phelps Dodge proposed connecting accelerometers with the GPS dispatching systems. The concept was to infuse GPS data into the collecting of accelerometer data and to record the information 24 hours a day. Traditionally, jolting and jarring data has been collected for a few hours at a time and correlations with injury data proved inconclusive. Understanding how frequently jolting occurs and what can be done about jolting requires 24 hour data. The product of the research is called the Feedback to Operator System or Shox Box System. The research to date has led to the conclusion that the best approach towards reducing jolting and jarring in GPS equipped surface mines would be to utilize the Shox Box system for a Six Sigma approach to the truck loading process.

The following are some of the factors that determine whether or not jolting occurs and also can be affected:

1. Operator Awareness and Skills
2. Road Conditions
3. Equipment Design and Maintenance

OPERATOR AWARENESS AND SKILLS

A central feature of the Shox Box system is its ability to provide objective feedback to equipment operators regarding performance. Currently, the main application is feedback concerning shovel operations. The system objectively determines whether a haul truck was jolted during loading and quantifies the amplitudes of the jolts. A second application is the miles per jolt ratio, which measures the proficiency of truck operators. Although these applications are in surface mining, the system could be adapted to other work environments.

The main application is to determine loading jolts during shovel operations, but statistically speaking, jolts during loading are infrequent. Loading jolts were 15 and 14 percent of the trucks' totals, respectively, for calendar years 2001 and 2002. However, when they do occur it is helpful to have an objective measurement to refer to during a discussion. An aim of the cooperative research is to reduce jolting during loading by applying engineering controls to the loading process and via supervisor to operator feedback.

The second application that provides objective feedback about performance is the miles traveled per jolt ratio. Equipment operators do not determine the road conditions or the maintenance of their equipment. However, they do control the location of the equipment within the lane, speed, and braking. Jolts at shovels do not count towards the jolt total. The ratio of miles per jolt is a qualitative measure of driver proficiency. Numbers greater than 1900 miles per jolt have been observed. When this occurs, it is an accomplishment of the truck operator, truck design, and road/truck maintenance. The lowest numbers were less than 100 miles per jolt. Research is needed to determine how these numbers can be communicated to enhance truck operator awareness. Such work would focus on a better understanding of jolting factors; either related to truck operation (sharp application of brakes), drive-train induced jolts, or those purely related to the condition of the road (including readability from the operator's cab). This careful attention to the Human Element[1] has been shown to result in increased safety and availability of the equipment[2].

A futuristic Shox Box application could integrate road jolt data into a "heads up" proximity warning display. It has been demonstrated that road defects and prescribed road maintenance can be processed and displayed in real time[3]. Utilizing this approach, the truck operator would see road defects on their screen before the truck arrives at the location of the road anomaly[4]. This would improve readability of the road and allow the operator to anticipate when to slow down or drive around a road defect.

ROAD CONDITIONS

Four haulage trucks at the Morenci mine were instrumented in 2000 with the Shox Box "black boxes". The boxes detect vertical jolts to the trucks' cabs anytime that the engines are on[5]. For calendar year 2001, 85 percent of the jolts to the trucks occurred on the haulage roads and the rest at loading points (shovels). For calendar year 2002, 86 percent were haulage road jolts. Since 2000, ten more trucks have been instrumented with various versions of Shox Boxes.

This data correlates with an injury report by Aldinger, Kenney, and Keran[6]. In their study of surface coal haulage mine injuries, 1989-1991, these researchers found that rough ground was the main category for jolting and jarring incidents.

Since the vast majority of jolts occur on haulage roads, a jolt mapping feature now shows jolts on a mine map. A Geographical Information System (GIS) map of the mine can be viewed with the locations of jolts reported by the trucks. However, a location that resulted in one jolt has the same priority as a location with many jolts. To prioritize road maintenance, an algorithm is needed that denotes clusters of jolts. This would likely be based on a combination of jolt severity experienced by the operator, expected traffic volume on the particular section of road, and an economic assessment of rolling resistance versus costs per ton hauled. Road maintenance models exist for haulage trucks. To apply them here would require a conversion between conventional measures of road roughness and Shox Box parameters. Irrespective of the Shox Box system, an academic understanding of the relationship between physical road profiles and the resultant jolting severity requires more experimentation.

EQUIPMENT DESIGN AND MAINTENANCE

The Shox Box system distinguishes between jolting on roads and jolts that occur during loading. Currently, it lacks a transducer to determine the root of the jolt. A jolt at a shovel could be due to dropping the load from too high, the shovel striking the side of the haulage bed, or a boulder. Instrumentation or cameras on shovels that determine the position of the shovel when a jolt occurs would be very beneficial. With this instrumentation and/or human observation, a Six Sigma DMAIC (define, measure, analyze, improve, and control) approach to the loading process would identify what conditions result in jolts. Insight into equipment interactions would lead eventually to process or equipment changes.

Overall, the quality of equipment maintenance must remain high, for some of the Shox Box features to be applied. A jolt occurring on the haulage road could partly be due to an improperly tuned truck suspension. Preventative maintenance is a key to success. To delineate whether a jolt is induced by the road or a truck malfunction, existing truck maintenance systems may need to be accessed and truck parameters verified[7].

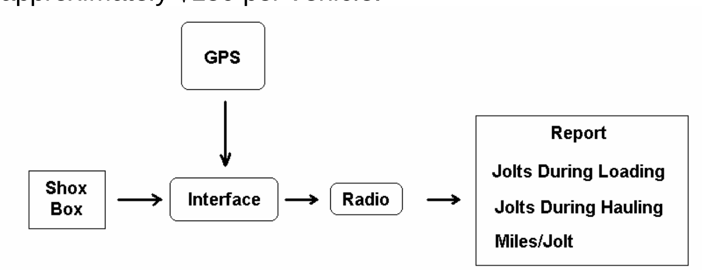
SHOX BOX TECHNOLOGY

For the purposes of this paper a jolt is defined as a peak in acceleration below 120 Hz and above 2 g (> 0.5 g rms). ISO 2631 style frequency weightings were not applied to the data stream, to reduce hardware complexity. Jarring for the purposes of this paper is defined as low amplitude, yet perceptible peaks in acceleration/vibration, which are less than or equal to 0.5 g rms.

Traditionally, measuring jolting and jarring has involved an accelerometer connected to a data logger. The data logger would operate for a few hours at a time. There are two downfalls of the traditional approach. First, jolts can occur at a rate as low as none, one, or two per day and second, incident locations are unknown. Typically, data showed mostly jarring, limited jolting, and no location information. Correlating the data with equipment activities at the time of a jolt was especially cumbersome. To remedy the downfalls of the traditional approach, personnel at Phelps Dodge recommended that NIOSH investigate connecting GPS data from haulage trucks and accelerometers[5].

A Shox Box runs off of the vehicle's power supply and is in operation whenever the vehicle is operating. It takes an analog signal from the accelerometer and determines whether the value is above or below a preset trigger value. If it is higher, then the Shox Box sends a signal to the GPS system to record the vehicle location and that a jolt has occurred. On the latest version of the Shox Box, the peak value of each jolt is also sent (via radio) to be logged.

Besides the GPS hardware, the Shox Box system needs several main components. They are the Shox Box itself, an analog to digital interface which is connected via a radio to the central GPS database, and lastly software on the central server which tabulates and formats the results. All of the pieces except for the Shox Box and the reporting software were already available at Phelps Dodge Morenci, Inc. The reporting software was written as part of the software maintenance contract for the mine's haul truck dispatch system[5]. The current cost for the Shox Box alone is approximately $150 per vehicle.



Shox Box System Components

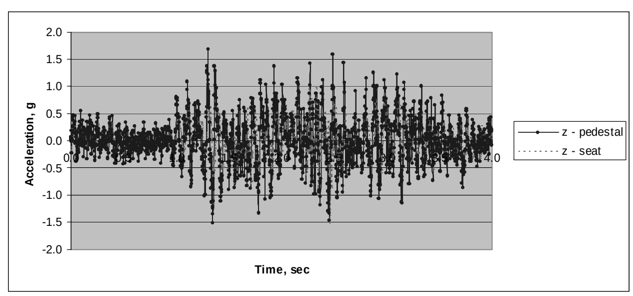
Two of the more recent advancements to the Shox Box system have been in the software that produces the data report and the third was with the electronics attached to the accelerometer.

The first advancement was a subroutine for determining when a jolt occurs during loading. This is a fairly complex function that was made efficient because of the design of the dispatch software.

Secondly, a subroutine was written to calculate the miles per jolt ratio. It divides the total distance traveled by a vehicle over a given time period by the number of jolts logged. The resulting ratio is a measure of an equipment operator's efficiency in terms of smooth operating. This application can be implemented for heavy equipment without a central database. However, downloading data by hand from each piece of equipment can prove to be cumbersome.

The most recent advancement is that the electronics now trigger off of the root mean square (rms) value of the acceleration signal and also output an analog value corresponding to the peak rms value of each jolt. This change is based on an experiment conducted at the Caterpillar Tucson Proving Ground in the Fall of 2000[3]. Caterpillar provided an obstacle course and a haulage truck for Spokane Research Laboratory to compare various types of haul road defects with the acceleration waveforms that they produce. To fully characterize and capture information about the test road, the instrumentation was set to trigger at a very low level (0.6 g) and with a low pass filter of 200 Hz. Severe road defects were intentionally built into the test track and the test truck was run over the test track while loaded and unloaded at different speeds. The road defects were surveyed with a GPS backpack system so that jolts and the haul road section (road defects) could be readily matched. The experiment lasted approximately two and a half hours of operating time. There were 189 events recorded with a four second event window. The experiment showed that many road defects can be identified by the waveform signature which they produce[7]. For example, a washboard area in the haul road can be clearly distinguished from a dip in the haul road.

While washboard road defects can be significant, they tend to produce insignificant, high frequency peaks of short duration. Depending on the selection of the frequency value, a low pass filter may be adequate to solve the problem. However, a rms filter is an improvement over traditional methods because it will more often trigger the logger on jolts related to significant road defects.



Waveform for Washboard Jolting

As can be seen from the table below, a washboard road defect is more likely to trigger a traditional data logger (19), than one triggered by rms acceleration (15). The values 1.1 g and 0.3 g rms were chosen to illustrate the differences.

	Number of events above 1.1 g in amplitude	Number of events above 0.3 g rms in amplitude
Washboard Areas	19	15
Dips in Haul Road	9	15
Humps	1	4
Fixed Stones	13	14

Table Showing Improvement by Applying R.M.S.

For the sake of brevity and intellectual property considerations, specifications of the Shox Box hardware and accompanying software are not given here. The circuit diagrams for the Shox Box may eventually be available to companies interested in building their own. The authors can provide information on how to acquire components to implement the system.

DISCUSSION

A significant advantage of the Shox Box system is that it is setup to measure jolting and jarring 24 hours a day. Traditional methods of measuring jolting and jarring are apt to miss jolts because they can occur as infrequently as none, one, or two per day.

The system currently provides objective feedback to equipment operators regarding their performance. Because of the capability to link GPS and accelerometer data, the system is utilized to settle disagreements as to whether or not a haul truck was jolted during loading and the jolt amplitude. When the Shox Box system is enhanced further to include instrumentation or cameras on shovels, an engineering control can be pursued.

Whilst currently unavailable, a “Real-Time Mine Road Maintenance Management System” appears feasible according to work done with GIS maps of Shox Box data. Feasibility of road defect identification by qualitative vibration signature was confirmed, although development of an operational road maintenance system will require enhanced software[3]. Once developed, a road maintenance system could be incorporated into a “heads up” proximity warning display. Proximity warning systems based on GPS are already on the way towards commercialization[4].

CONCLUSION

The Shox Box system was prototyped in a surface mining environment and shown to be durable and reliable. The equipment interaction and miles per jolt applications are two of the system’s features, which can be readily duplicated in any heavy equipment environment. Situations where heavy equipment and onboard GPS are being utilized together lend themselves to Shox Boxes. The next step in GPS equipped, surface mines is to utilize Shox Boxes and apply Six Sigma process control techniques.

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