

Analysis and Redesign of Battery Handling using JACK™ and HUMOSIM motions

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ABSTRACT

The evaluation of maintenance tasks is increasingly important in the design and redesign of many industrial operations including vehicles and airplanes. The weight of subsystems can be extreme and often tools are developed to abate the ergonomic risks commonly associated with such tasks, while others are unfortunately overlooked. We evaluated a member of the family of medium-sized tactical vehicles (FMTV) and chose the battery handling from a list of previously addressed concerns regarding the vehicle. Particularly in larger vehicles, similar to those analyzed in this paper, batteries may exceed 35 kg (77 lbs). The motions required to remove these batteries were simulated using motion prediction modules from the Human Motion Simulation (HUMOSIM) laboratory at the University of Michigan. These motions were visualized in UGS JACK™ and analyzed with the embedded Static Strength Prediction program. Critical design issues were immediately apparent, such as location, orientation, contact stress, and clearance; all directly related to the difficulty and increased risk of injury associated with replacing the batteries. Simple ergonomic interventions were evaluated for modification of existing vehicles.

INTRODUCTION

Since this is not a perfect world, nearly everything requires some form of maintenance. In many circumstances, manual handling is required that exceeds the physiological limits of our bodies. Numerous organizations, including the Occupational Safety and Health Administration (OSHA) and the National Institute for Occupational Safety and Health (NIOSH), have attempted to define regulations and ergonomic design limits for physical tasks to reduce preventable work-related injuries. In theory all injuries are preventable; a stark contrast with estimates of direct

costs for occupational injuries in 1999 exceeding \$45 billion, and indirect costs reaching over \$200 billion (Liberty Mutual Safety Index 2003). As in years past, overexertion injuries are by far the most costly (25.7% of direct total).

Overexertion is the principal concern of the maintenance task that we have analyzed and reported. The removal of a 35 kg battery from the FMTV (Figure 1) requires physical strength, balance, and experience to minimize the risk of an injury. Indeed this load exceeds NIOSH recommended weight limits for manual handling tasks by 50% (Waters et al. 1993).



Figure 1. Digital representation of medium-sized military vehicle used in analysis.

Additional concerns include the configuration of the batteries, clearance restrictions, and obstacles, which all compound the risk of injury. Through analysis of design modifications, made simple through digital human modeling (DHM), each issue is mitigated. The individual improvement or risk reduction resulting from each change is determined, providing a basis for cost-justified improvements.

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MATERIALS AND METHODS

Two software packages were used for the analysis of this maintenance task: UGS *Jack* for creating a digital environment and performing biomechanical analysis, and motion prediction software from the University of Michigan for creating accurate human motions.

The analysis steps listed below are a general methodology for using digital human modeling in the analysis, design, and redesign of manual material handling tasks. This study focuses mainly on steps two through five, as step one can be performed to the extent desired and generally varies without regard to the remaining steps.

1. Create virtual environment
2. Create valid human postures and/or motions
3. Analyze postures and motions for risk of injury
4. Determine component of task creating increased risk
5. Evaluate alternatives to reduce overall risk of injury.

A digital environment was created in *JACK* to assist in the visualization of the battery handling task. Initial accuracy of the digital environment was established by directly importing the FMTV (.jt format) and comparing dimensions of the digitally represented FMTV with the actual truck.

Creating accurate postures and motions, is an essential step in any DHM biomechanical analysis. Too often this is attempted through keyboard and mouse manipulation of the digital human, or avatar. Facial validity of postures may be possible, but construct validity is difficult to establish. A priori knowledge of the task requirements can sometimes help increase the fidelity of the postures. However biomechanical analyses of digital humans are dependent on accurate postures and movements (Chaffin 2002), second only perhaps to the validity of the analysis tools used.

An increasingly popular means by which to obtain accurate movements is through motion capture. However the cost of these systems is difficult for many companies to justify. Even for companies with motion capture systems, iterative analysis almost certainly requires additional capture sessions, thereby increasing the total cost to perform the analysis.

Another means to obtain human motions, which was used in this study, is to predict the movements that would be used to perform a given task, based on specific parameters. Functional regression analysis is used to predict the resulting movement from a database comprising over 73,000 motions that have been collected to date at the HUMOSIM Laboratory at the University of Michigan (Faraway 2003, 2001, 2000).

The avatar's motions were predicted based on the location of the battery: height from the floor and distance from the worker. These motions were analyzed using

the Static Strength Prediction (SSP) program incorporated in the *JACK* software. The percent of the population that is physically capable of performing the task is given throughout the motion, so that every part of the movement can be analyzed. Although the exact relationship is not clear, it is evident that the percent of the population capable of performing a task is inversely proportional to the amount of risk inherent in performing the task.

The SSP analysis tool evaluates each major body joint to determine the limitations at each joint, and calculates the "percent capable" for each joint. This provides the analyst with important insight into why a particular motion increases risk and also towards modifications that may reduce that risk. With this knowledge, effort can be focused on the critical areas of the task so that the redesign process is efficient and effective.

Developing alternatives without the use of digital human modeling often requires expensive prototypes to iteratively evaluate. Using DHM software, each new design can be simulated and analyzed on the computer without additional capital investment. Several aspects of the environment and original design must be considered when proposing alternatives.

As can be seen in Figure 2, four batteries are arranged in a 2x2 configuration, where there is only 15 cm clearance above the batteries in some trucks. The back batteries cannot be removed without first removing the front battery, essentially doubling the amount of effort required to complete the task.

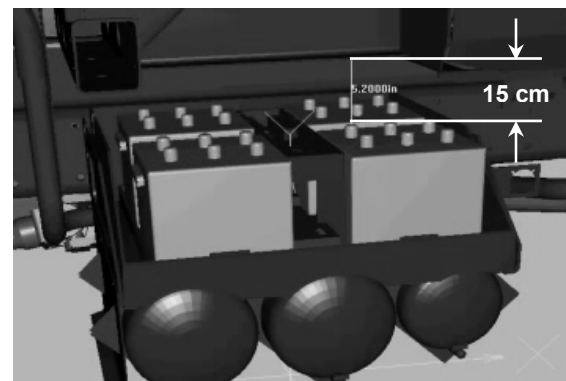


Figure 2. Depiction of limited clearance for maintenance of the batteries.

Figure 3 below shows the approximate posture used by the maintenance worker grasping the rear battery. Notice the limited clearance and extended reach that requires awkward posturing of the worker. There is also a retainer that holds the batteries in place from the bottom. This prevents the worker from sliding the battery forward.



Figure 3. Posture used to lift rear battery.

RESULTS

Figure 4 shows the percent capable of a 50th percentile worker removing the back battery and placing it on the ground. Two noticeable dips are evident; the first is due to excessive forces on the shoulder while lifting the battery and the second is due to limitations of the torso while bending to place the battery on the ground. The (1) and (2) designations indicate the limiting body joint with respect to the shoulder and torso respectively.

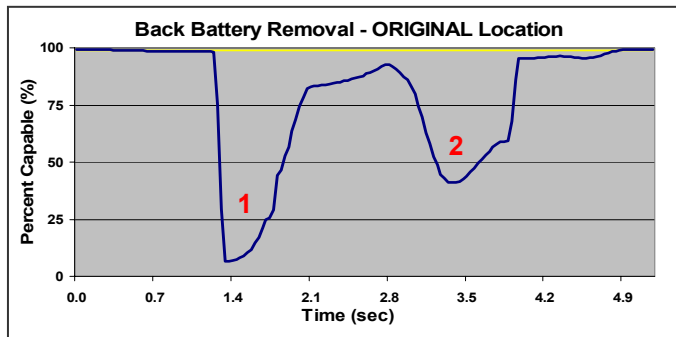


Figure 4. Percent of population capable of removing back battery from “original” location.

For comparison, removing the front battery also reveals increased risk of injury in the shoulder, although to a lesser extent, as shown in Figure 5. Note that the limitation with respect to the torso remains at approximately 40%.

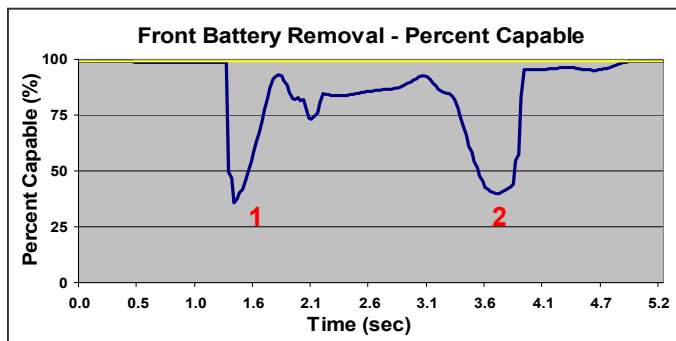


Figure 5. Percent of population capable of removing front battery from “original” location

One limitation of the original configuration is that the back battery is not easily accessible. A “slide-out” tray was proposed to allow the worker direct access to all batteries without having to remove another one first.

The other principal concern is the height at which the worker must perform this heavy manual task. In addition to the sliding tray, a lower height was also proposed. Figure 6 and Figure 7 show the lower tray height and the resulting impact on the percent capable at the shoulder.



Figure 6. Depiction of battery tray at carrying height.

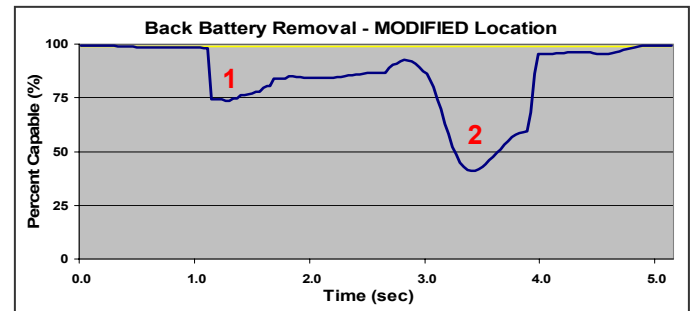


Figure 7. Percent of population capable of removing back battery from “modified” location.

This modification increases the percent of the population physically capable of lifting the battery from this modified height from approximately 10% to 75%. Obviously this does not have an effect on the second part of the task, as the worker is still required to place the battery on the ground.

CONCLUSION

As evident in the percent capable graph of the worker removing the battery from the original location, there are two significant parts of the task that create increased levels of risk. The shoulder is the limiting joint (only 10% capable) when attempting to lift the back battery from battery tray. Recall that the battery tray serves as a retainer to prevent the batteries from sliding during vehicle operation (Figure 8).

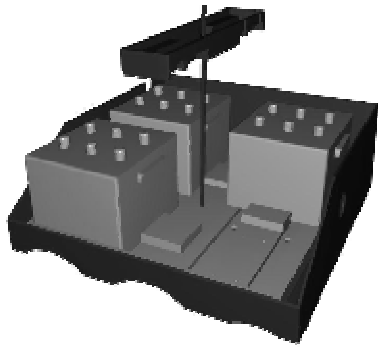


Figure 8. Depiction of retaining floor of battery tray.

An inverse mold could be made and inserted into the battery tray allowing the batteries to slide forward, and thus reducing the torque on the shoulder. This solution creates an additional problem in that the batteries are no longer held firmly in position.

An additional proposal would remedy this as well as another issue. A rotating shelf could be installed that would serve as a retaining wall in the up position. The shelf could then be rotated down to the modified height previously determined and serve as a staging area to enable the worker to reposition the battery if desired. The battery could virtually be dropped onto this shelf from the battery tray several inches higher. The depictions in Figure 9 show the rotated up and rotated down positions respectively.

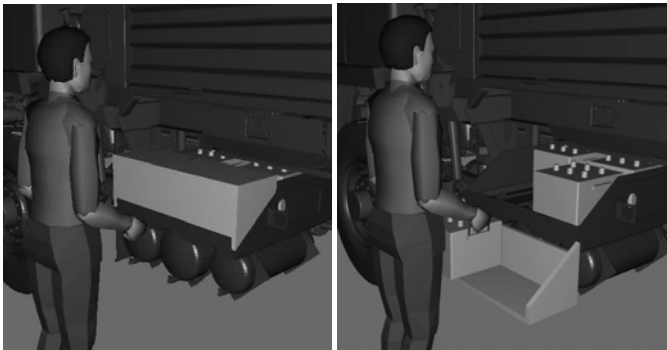


Figure 9. Intermediate shelf for repositioning battery.

Another possibility is attempting to remove the manual lifting entirely. If the maintenance work were performed in a shop, a lift cart might be available that could hold the entire battery tray, as shown in Figure 10. The tray could be slid on and off the cart through any number of manual, semi-automatic mechanisms, and enable the worker to perform desired maintenance on any or all of the batteries without handling each of them individually.

The combination of the DHM software with the motion prediction capability was an efficient and effective way to iteratively analyze the risk associated with the removal of a 35 kg battery, without additional capital investment.

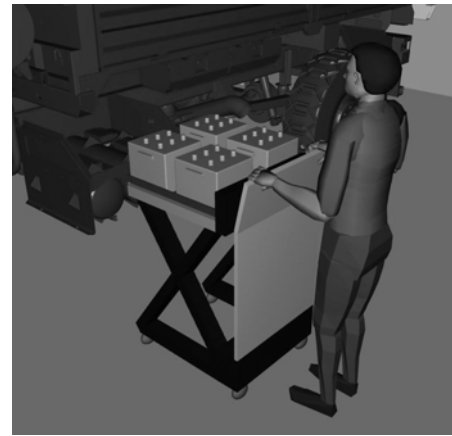


Figure 10. Proposed maintenance cart.

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