Truck Cab Scoring Tool: An Ergonomic and Anthropometric Analysis Tool for Assisting Fleet-Purchasing Decisions

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ABSTRACT

This paper presents a tool developed as part of a capstone design class at Oregon State University. The Cab Analysis and Scoring Tool (CAST) system was developed to assist Oregon DOT fleet services assess and select truck candidates, from an ergonomic perspective. The motivator to focus on ergonomic standards is the number of ergonomically induced truck driver related injuries in the United States. As a result, musculoskeletal disorders are one of the leading causes for on the job injuries. ODOT’s maintenance fleet must perform a variety of maintenance functions such as snow plows, asphalt application, sanding and as roadside vegetation control. As a result, a specific set of controls must be implemented in the truck cabs, resulting in awkward positioning, which increases the risk of MSD related injuries. As a result, the capstone project involved a team of three industrial engineering students that followed the engineering design method to analyze the problem and design a tool to evaluate truck cabs based on ergonomic standards. The goal of the CAST is to benchmark candidate trucks, based on ergonomic and anthropometric standards to assist with the Fleet Management Department’s purchase decisions. The resulting Cab Analysis and Scoring Tool (CAST) has the potential to assist departments of transportation, private fleet managers or any transportation organization in the evaluation and selection of truck cabs based on ergonomic standards to minimize ergonomic related injuries.
INTRODUCTION

The Oregon Department of Transportation (ODOT) maintains a fleet of trucks for a variety of highway maintenance functions, including material transportation, snow removal, sanding, deicing, asphalt application and roadside vegetation control. The same trucks are used for different tasks depending on the time of year, so equipment on and in the truck change in accordance to the needs. ODOT truck drivers spend much of their working day operating the truck controls; and according to ODOT staff, the continuous operation of the truck cab controls often result in different levels of injuries, forcing drivers to take time off of work and claim workers’ compensation. This is due to differences in truck cab interior designs, which result in ODOT having to position the controls in often ergonomically awkward control positions. The ODOT Fleet Services Management unit approached the school of Mechanical, Industrial and Manufacturing Engineering (MIME) at Oregon State University (OSU) to request an analysis of their truck cabs to provide feedback on how to make their trucks ergonomically sounder for their drivers.

Given the scope and complexity of the problem, it was determined it would be addressed through the Capstone Design class. A group of three undergraduate industrial engineering students was assigned to the project. The Capstone Design student team designed a process for scoring truck cabs based on their ergonomic readiness to fit ODOT’s desired set of controls and cab features. The team used the engineering design method and human factors principles to develop a two-phase Cab Analysis and Scoring Tool (CAST) system. The system is composed of the Cab Analysis Tool (CAT) that guides its users through a process of taking truck cab measurements and the Cab Scoring Tool (CST) software tool that utilizes the measurements taken to generate a final truck cab score. The goal of the CAST is to assist the Fleet Services Management unit at ODOT benchmark all candidate trucks for purchase, based on ergonomic and anthropometric standards.

Capstone Design Class

In the school of Mechanical, Industrial and Manufacturing Engineering at Oregon State University (OSU), capstone design projects are defined as “[an] assessment system based on written reports and the quality of deliverables [of the prototypes designed by students]” (1). The capstone design class is split into two academic terms (usually Fall and Winter) to provide: near real world working experience for students, to comply with Accreditation Board for Engineering and Technology (ABET) requirements, and to bridge the gap between classroom outcomes and applications. Different versions of capstone design classes are implemented across engineering schools in the United States as part of their engineering degree program. They provide students with options to choose between external or internally sponsored projects. In the School of MIME, externally sponsored projects are defined as requests from companies who have a social commitment and need help solving a particular problem while internally sponsored projects are projects originating from within the department of MIME(1).

In fall term at the School of MIME, students are asked to communicate their progress in detail by providing structured documentation for their professors, advisors and sponsors (ODOT served as a project sponsor). The structure of the report abides by the Engineering Design Method (2) by clarifying project objectives, establishing expected functionality, setting customer requirements, determining engineering characteristics, generating alternatives, evaluating alternatives, improving details on the selected alternative, and developing the selected alternative (see Figure 1). Steps 1-3 focus on the definition of customer requirements; for instance, the student teams will have to specify what the Customer Requirements (CRs), Engineering Requirements (ERs), and budget and resources will be as a part of the determining characteristics of the Capstone projects (1). Steps 4 and 5 focus on addressing the customer requirements, where the students will select the best design alternative and will plan the construction of the design. Steps 6-8 deal with building and implementing the design. For the Capstone class, and due to time constraints, steps 1 and 8 are left to the customer. In Winter term, students build, test and implement their designs (1). Budget and resources must be closely followed during the implementation and testing phase. At the end of the term, students must complete a final report that documents the complete capstone design experience. It is worth noting that the students are not required to generate new knowledge, just to apply existing methods, tools and techniques to solve a particular design problem.

LITERATURE REVIEW

The theoretical foundations for the development of the CAST are based on three descriptors of Musculoskeletal Disorders (MSDs): 1. types of occupations and tasks that present the highest MSD incidence rate, 2. specific location of pain as an indicator of risk of developing an MSD, and 3. the age distribution of groups who develop MSDs.
Types of Occupations and Tasks that Present the Highest MSD Incidence Rate

Christensen et al. (3) suggested eleven occupation classifications related to MSDs and identified transportation to have the highest rate of occurrence of MSDs among all other occupations (see Table 1). Notice that transportation is the occupation with the highest occurrence rate.

TABLE 1 Varieties of Occupations that Proposed Risk to Easily Contract to MSDs in 2005 - 2007, Oregon; Adopted from Christensen et. al (3)

<table>
<thead>
<tr>
<th>Types of Occupations</th>
<th>Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>23%</td>
</tr>
<tr>
<td>Production</td>
<td>14%</td>
</tr>
<tr>
<td>Construction and extraction</td>
<td>9%</td>
</tr>
<tr>
<td>Health care support</td>
<td>7%</td>
</tr>
<tr>
<td>Sales and related</td>
<td>7%</td>
</tr>
<tr>
<td>Installation, maintenance and repair</td>
<td>6%</td>
</tr>
<tr>
<td>Office and admin support</td>
<td>6%</td>
</tr>
<tr>
<td>Grounds maintenance workers</td>
<td>6%</td>
</tr>
<tr>
<td>Other health care practitioners</td>
<td>5%</td>
</tr>
<tr>
<td>Food prep and serving</td>
<td>5%</td>
</tr>
<tr>
<td>All other</td>
<td>12%</td>
</tr>
</tbody>
</table>

Types of tasks are also important to explain causes of MSDs, due to their potential to aid researchers to pin point which part of the body may have a conceivable risk of suffering an injury. According to the Bureau of Labor Statistics (BLS) (4), overexertion in lifting or lowering activities is the highest contributor of MSDs in the U.S. In transportation, several examples of workers repeating the same motion (overexertion in lifting or lowering extremities) over long periods of time can be found in truck drivers’ tasks. Figure 2 shows varieties of tasks which...
are accorded to MSDs nationally in transportation. In ODOT for example, while driving a snow plowing truck, a worker may find him/herself lifting and/or lowering a lever behind his back repeatedly which may potentially cause tendonitis (3).

FIGURE 2 Types of tasks that Present the Highest MSD Incidence Rate (adapted from (4)).

Location of Pain as an Indicator of Risk of Developing an MSD
Back pain is considered to be the leading symptom to anticipate MSDs both nationally and in Oregon (3, 4). Moreover, it is usually related to unexpected injury from overexertion in lifting or lowering tasks (3, 4). In transportation, back pain is found to be generated by the overexertion in lifting or lowering tasks (4). According to Robb & Mansfield (5), another source of this back pain is caused by, “prolonged sitting which leads to the release of fluids from the inter-vertebral disc and [hence,] reduces their [the disks] ability to cushion the spine.” Additionally, it has been observed that whole-body vibration when drivers sit inside of the cab for a long time (5) can also cause back pain. Figure 3 shows the distribution of locations of pain by comparing national and the state of Oregon demographic statistics.

FIGURE 3 Developed locations of musculoskeletal injuries for truck cab drivers in transportation arena of work; adopted from (3, 4).
Age Distribution of Groups Who Develop MSDs

Workers with ages that range between 35 to 44 years are the most common victims of MSDs (3). According to ODOT’s Fleet Services, the majority of the drivers fall within this age group. Figure 4 shows the age group breakdown comprised of accepted disabling MSD claims and non-MSD claims.

![Population of Age Groups who Constituted to Work Related MSDs](image)

**FIGURE 4** Age group breakdown, by percentage, in Oregon for accepted disabling MSD and non-MSD claims adopted from Christensen et al. (3).

According to BLS (4), injuries result in a median of 20 days away from work in transportation, with heavy and tractor-trailer truck driving as specific activities. With so many days away from work, it is possible to realize the financial and operational impact that non-ergonomically conforming truck cabs can have on a truck fleet operation. Thus, if certain tasks such as overextension of limbs can be reduced, it is possible to reduce musculoskeletal injuries, increase productivity and efficacy of truck drivers. Hence, a tool that can assist ODOT’s Fleet Services Management select truck cabs can reduce injuries, and the costs associated.

METHODOLOGY

The CAST was designed to assist fleet services users through the process of analyzing and scoring a candidate cab based upon ergonomics standards and cab features (6). ODOT fleet services manager, supervisors and drivers were all considered users and as such all participated with the CAST validation process.

The engineering design method was coupled with the House of Quality (HoQ). The HoQ was developed by Mitsubishi’s Kobe in 1972 and adopted by Toyota in 1978 (7). The HoQ tool is used to guide the customer requirements (CRs) and engineering requirements (ERs) generation (see Figure 6). In the HoQ the customer requirements are defined as the requirements provided by the project sponsor, while engineering requirements convert those CRs into measureable descriptions that can be tested. The CRs are weighted against what the customer deems more relevant, which results in a hierarchical list that states the most important requirements as described by the customer. Finally, engineering tests that can exhibit the fulfillment of each ER are designed.

Design Process

For the CAST design, the CRs were determined as a result of interpreting the needs from the ODOT Fleet services personnel (management, engineers and drivers). The CRs reflect the functions and capabilities that the sponsor desired and were assigned a specific weight that reflected its importance. 250 possible points (determined by class
point distribution) were distributed amongst all CRs, and a score of LTE (low technical effort - the LTE concept is used at the MIME capstone design class) was given to any customer requirement that required low technical effort. The CRs were then translated into specific technical objectives called engineering requirements (ERs). Each ER satisfies one or more CR. Testing procedures were created to provide a means to measure each engineering requirement. In this project, the testing procedures were evaluated as a pass/no pass test as they had no specific tolerances to meet. Thus, the evaluation and validation of each ER would require the involvement of expert panels, which were selected from faculty members, PhD students and fleet services personnel. It is important to note that all CRs (including LTEs) must be satisfied with a passing grade, otherwise the project would be considered a failure. The resulting CRs, ERs and Targets and Tolerances can be seen in Figure 6.

![Figure 6 House of Quality](image)

<table>
<thead>
<tr>
<th>Customer Requirements</th>
<th>Engineering Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information on human factors and ergonomics provided</td>
<td>The system shall provide an evaluation of each ergonomic measurement.</td>
</tr>
<tr>
<td>Tool for analyzing stock cabs</td>
<td>The system shall provide a failure of each ergonomic measurement.</td>
</tr>
<tr>
<td>Tool for scoring stock cabs</td>
<td>The system shall provide a failure of each ergonomic measurement.</td>
</tr>
<tr>
<td>Tool for analyzing best location for cab controls</td>
<td>The system shall provide an evaluation of how each task is performed by each ergonomic measurement.</td>
</tr>
<tr>
<td>Maximum score is 100</td>
<td>LTE</td>
</tr>
</tbody>
</table>

**CAST Development**

The Cab Analysis Tool (CAT) was developed using a truck that at the time was considered to have the best ergonomically adept cab in the ODOT fleet. The truck was housed at the OSU motor pool for the tool development and validation. The explanations of each ergonomic measurement, for the CAST system, were created using the principles outlined by Tiersma.(8) Tiersma developed a nine-step process to create clear instructions that provide a useful framework that is transferable to many contexts. Since the tool was mainly going to be used by engineers, logical organization and clear concise instructions were paramount. In order to convey the most information with the least amount of effort, visual instructions were used as much as possible. The visual instructions include each measurement required to be taken.

The Cab Scoring Tool (CST) was created using Microsoft Excel. The user interface (UI) of the tool was developed from a list of approved measuring created and evaluated using guidelines from Shneiderman’s ‘Designing the User Interface’.(9) Shneiderman’s set forth a simple rule set for creating a user interface. His rules reduce user frustration by increasing interface clarity and simplicity. There is also a focus on aesthetics of interface design and
how the appearance of a system interface can affect the user experience. These tools were implemented into the CST system to create a user interface that was aesthetically pleasing as well as programmatically powerful. A point and click interface with visual feedback, in the form of color change, provides clear informative feedback and helps prevent errors. Data entry would be separated into blocks to allow for easy entry. The user’s skill level was assessed during the basic training provided to ODOT managers that would be using the program. It was determined based on this assessment that the best interaction style for this tool would be a ‘form fill-in’ structure. The form was then designed such that it provided consistent, informative feedback to prevent errors.

Each measurement of the CST received a score based on the range of the measurement and a weighting. Weights ranged from 1-3. Weightings were decided by using Guan et. al.’s (10) paper on anthropometric models for cab designs and Salvendy’s Handbook on Human Factors and Ergonomics(11). A weighting of 3 was given to any measurement that poses a risk for ergonomic injury. A weighting of 2 was given for any measurement that increases a driver’s comfort, but still has a low chance to cause musculoskeletal disorders. A weight of 1 was given to measurements that create an overall larger truck dimension and have no direct impact on the driver. All measurements received an initial score 0-5. These scores were generated based on the ability of a measurement to meet ergonomic standards. A score for minimum range and maximum range were combined, averaged and then multiplied by the weights to determine that particular measurements final score. Additional feature scores received an initial score of 1 if the cab contains the feature and 0 if it does not. These scores were multiplied by the same weighting system to determine the final score for these features. Once all of the measurement and additional feature scores were calculated, all scores were normalized. Normalization takes the total points earned by the current truck and divides it by the total possible points and multiplies it by one hundred. In this case the calculation looked like (∑(scores*weights)/156)*100.

Testing procedures
The CAST was validated with two tests: in-class testing procedures and ODOT fleet services engineers’ tests. Both tests were conducted by teams of two members, one to read the instructions and record results while the other performed the desired measurement. Each dimension was measured three times. If the average of these measurements had an error greater than 5% that was considered a failed measure. In order to pass the test, less than three of the twenty two measurements could fail. If more than one individual failed to pass the test then the CAT was redesigned and tested again.

The in-class testing procedures were divided into two evaluations. The first evaluation requires the students to make sure, by running through all the testing procedures – and refining if necessary- that their design is “testable” in accordance to the CRs and ERs reflected in the HoQ. The second evaluation required the participation of the panel of experts to evaluate the CAT and CST using an ODOT fleet vehicle. The panel of experts would test the CAT and CST in accordance to the testing procedures and evaluate the CAST overall.

For the ODOT tests, the fleet services engineers created five teams composed with ODOT engineers and drivers. The groups were tasked with gathering data with the CAST system from different trucks from the OSOT fleet.

CAST SYSTEM
As stated above, the finalized system is composed of the Cab Analysis Tool (CAT) that guides its users through a process of taking truck cab measurements and the Cab Scoring Tool (CST) software tool that utilizes the measurements taken to generate a final truck cab score.

Figure 7 is a representation of the main sections contained in the CAT. The image at the top of the figure shows the labeling of each part of the cab. These labels provide the end user with a standard language that will be used throughout the rest of the document.

Reference points increase the precision of the measurements(12), and are marked with colored stickers such as the one seen in the middle image of Figure 7. Tools required for each reference placement, as well as instructions, are provided alongside each of the pictures in the analysis tool. An example of these instructions can be viewed under the ‘Reference Placement Technique’ section of the figure. The reference points were determined considering best practices (12), truck driver specific anthropometric studies (10), and ODOT’s specific needs and preferences.

The measurement technique image in the bottom left of the figure is a representation of the type of picture used in the measurement section of the CAT. This particular measurement requires an angle finder to measure. Each of the images is accompanied with list of tools needed in order to measure each dimension as well as a list of instructions. Instructions on how to take this particular measurement are under the ‘Measurement Technique’ section of the figure above.
Tools Required: Tape Measure, Angle Finder

Reference Placement Technique:

1. Use the tape measure to find the center of steering wheel.
2. Place sticker 4 as close as possible to the center of the steering wheel.
   - This point will be used to measure angles. Avoid crevices, emblems, and anything that will distort consistent angle measurements.

Measurement Technique:

1. Adjust steering wheel tilt and telescope so steering wheel is as close to 0 degrees as possible.
2. Place angle finder on Reference Point 4.
3. Perform measurement three times, calculate average, and record all results in Table 4 below in “Minimum” column.
4. Adjust steering wheel tilt and telescope so steering wheel is as close to 90 degrees as possible.
5. Repeat steps 2 and 3, recording all results in “Maximum” column.

Figure 8 presents a snapshot of the CSTs features. Each measurement from the analysis tool is placed into the CST by clicking on the cell corresponding to the range where the measurement is. When a cell is clicked it becomes highlighted. A perfect score for the tool is when all cells underneath the highest value column are highlighted. For instance, in order to have a perfect static scores section, all of the highlighted measurements would have to be under the leftmost column of the chart with the title 5. This yields the maximum potential of 100 points after the normalization.
Each of the measurements or features has a weight attached that can be edited to reflect the user’s preferences. All default weights are set by the criteria from anthropometric studies and ergonomics mentioned above. The final score for each measurement is computed by taking the number of the corresponding column and multiplying it times the weight. These scores are then summed together in order to get the final score in the summary section. For instance, Figure 8 presents an example of what ODOT Fleet Management considers one of their best cabs after being evaluated using the CAT and CST. The cab received a score of 60.90 meaning some of the dimensions of the truck allowed for safe comfortable fit for less than 35% of the population indicating that there are still serious areas of opportunity for manufacturers.

The truck model in the summary section is for record keeping and is able to be changed by the end user. In this instance the truck being evaluated has been given a coded name, but the score is based on a real state of the art truck from ODOT.

**FIGURE 8 Pertinent Areas of the Cab Scoring Tool.**

**CONCLUSION**

The CAST is the product of a capstone design class at Oregon State University. The class follows the engineering design method and has for goal that the students apply existing engineering concepts in a creative and successful way into specific contexts. As a result, the CAST tool provides a simple framework to evaluate truck cab designs based on ergonomic standards applied to the specific DOT context. It provides a set of clear instructions to obtain all measurements (CAT) and an interface that is simple to use (CST). ODOT fleet services management has
incorporated the CAST system into their operations and will use it to evaluate current and candidate truck cabs to continue moving towards a multi-purpose fleet.

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