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# Measurement and Analysis of Vehicle Vibration for Bottled Water Delivery Trucks

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**Abstract** A bottled water delivery truck was instrumented with a field data recorder to analyze the vibration inputs experienced by the freight holding area of the vehicle. Three delivery routes were chosen for this study–rural delivery, highway delivery, and inter-city delivery. Statistically there were no differences between the generated PSD profiles produced from the study, but it was determined the inter-city delivery had the highest overall Grms of the three delivery routes analyzed.
**Keywords** *Vehicle Vibration; Delivery Truck; Vibration Testing; PSD Profiles*

## 1. Introduction

Packaged products are transported via multiple distribution channels to reach their specified destinations. Throughout the various distribution channels, the packaged products are subjected to three major categories of dynamic hazards: shock, vibration, and compression [1]. While shock and compression hazards cannot be overlooked when designing packages or packaging materials, the basis of this research focuses on vibration, specifically beverage delivery truck vibration. The nature and intensity of vibration experienced by a packaged product depends on the type of transportation used. Different modes of transport produce different vibration inputs to the packaged product system.

This study evaluated three different types of delivery locations for bottled water. For the purpose of this paper they will be classified as rural delivery, highway delivery, and inter-city delivery locations. The rural locations utilized roads containing non-highway routes for delivery. Highway locations utilized a combination of major highways and interstates for delivery. Inter-city locations focused on metropolitan businesses utilizing city roadways. These varying routes were evaluated to determine if there were any significant differences of vibration input for the different delivery locations.

The purpose of the project is to measure and analyze vehicle vibration for 5 gallon bottled water (beverage) delivery vehicles. Previous vehicle vibration studies have focused on over-the-road trailers and local package delivery vehicles (UPS and FedEx), but currently there are no published vibration profiles for beverage delivery vehicles [2]. Figure 1 displays the commonly used vibration power spectral density (PSD) profiles used for analyzing truck vibration as reported by the International Safe Transit Association [3]. It should be noted these are the uncompressed PSD profiles.

ISTA produces test standards and PSD profiles in order to simulate truck vibration. These PSD profiles represent the intensity of vibration that occurs inside the cargo hold of the vehicle where packages are placed during transit [2]. Currently, PSD profiles are used to drive vibration tables in order to simulate a particular vehicle environment. Current data collection techniques for obtaining over-the-road vibration data for a truck require the attachment of a recorder to the floor of the vehicle [4]. Data collected from the recorder is then used to drive vibration tables in order to simulate the recorded environment. Through the use of field data recorders this study aims to characterize the vibration profile of a bottled water delivery vehicle. The benefit of more accurately characterizing a vehicle's vibration response is the improvement of testing standards and the tools for package design.

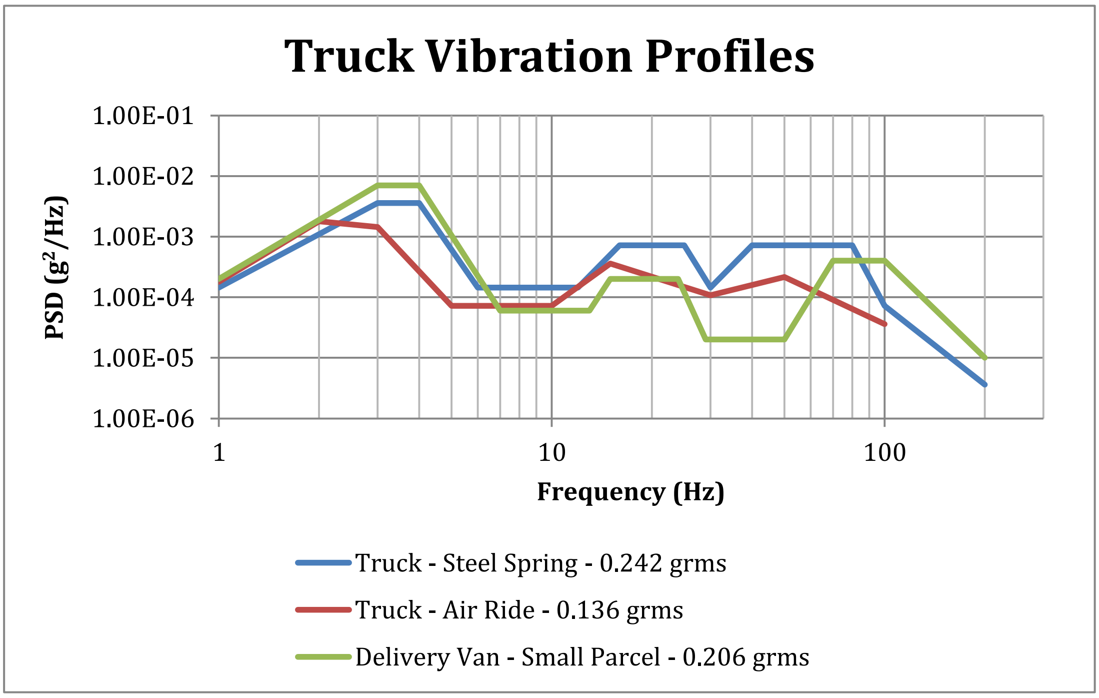


***Figure 1:*** *Commonly Used Vibration Power Spectral Density (PSD) Profiles*

## 2. Materials and Methods

Shock and Vibration Environment Recorder (SAVER™) (Lansmont Corp., Monterey, CA) model SAVER™ 9X30 with Saver Xware programming software was used in this study. This type of data recorder uses an internal triaxial accelerometer to measure vibration levels in the vertical, lateral, and longitudinal directions. The data recorder was rigidly mounted to the vehicle's chassis just above the rear wheel. Figure 2 illustrates the location of the data recorder.

***Figure 2:*** *Location of the Data Recorder*

The data recorder was programmed to record and analyze vibration using both signal and timer triggered data collecting methods. Signal triggered data refers to the data recorded during an event in which the intensity exceeds a preset threshold. Timer trigger data refers to the data recorder “waking up” at a preset frequency and recording for a preset duration. The following were the recording parameters used for this project:

- Signal Triggered Data
    - Event Trigger Threshold: 0.50 G
    - Sample Rate: 1000 Samples/Sec
    - Record Time: 2.048 sec.
    - Signal Pre-Trigger: 50%
- Timer Triggered Data
    - Wakeup Interval: every 7 min.
    - Sample Rate: 1000 Samples/Sec
    - Record Time: 2.048 sec.

The vehicle used for this study was a 2004 Navistar International 4300 model (Figure 3). Vibration levels were recorded both on signal trigger as well as a fixed interval. The data recorder was turned on prior to the delivery truck leaving the filling location and was turned off once the truck had returned.

For each location, measurements exceeded 20 hours of monitoring for each of the delivery locations. The locations of the study were as follows: Kingsport, TN, Winston-Salem, NC, and Atlanta, GA. The Kingsport, TN location captured the rural delivery routes, the Winston-Salem, NC captured highway delivery, and Atlanta, GA captured inter-city delivery of the bottled water.

***Figure 3:*** *International 4300*

## 3. Results and Discussion

For each of the three delivery locations, a separate PSD profile was created. Table 1 represents the overall Grms levels for each of the three delivery locations. Each of the PSD profiles (Figures 4-6) shows the results in power density levels versus frequency in the lateral, longitudinal, and vertical axes. The vertical axis produced highest overall Grms values of the three axes, and the inter-city delivery route had the highest overall vertical Grms value of 0.303.

The varying intensity of the Grms values reported in this study match closely with what other researchers have reported in previous studies of inter-city and highway delivery vehicles [5]. The higher Grms values of the inter-city location could be attributed to external sources such as road surface irregularities and repeated braking and forward acceleration [6]. These irregularities and repeated braking and accelerating happen much less frequently in the rural and highway delivery routes of this study resulting in lower overall Grms values.

***Table 1:*** *Overall Grms Values for the Delivery Locations*

| | Overall Grms Values | | |
|---|---|---|---|
| | **Rural** | **Highway** | **Inter-city** |
| **Longitudinal (x-axis)** | 0.152 | 0.144 | 0.165 |
| **Lateral (y-axis)** | 0.244 | 0.210 | 0.277 |
| **Vertical (z-axis)** | 0.280 | 0.253 | 0.303 |

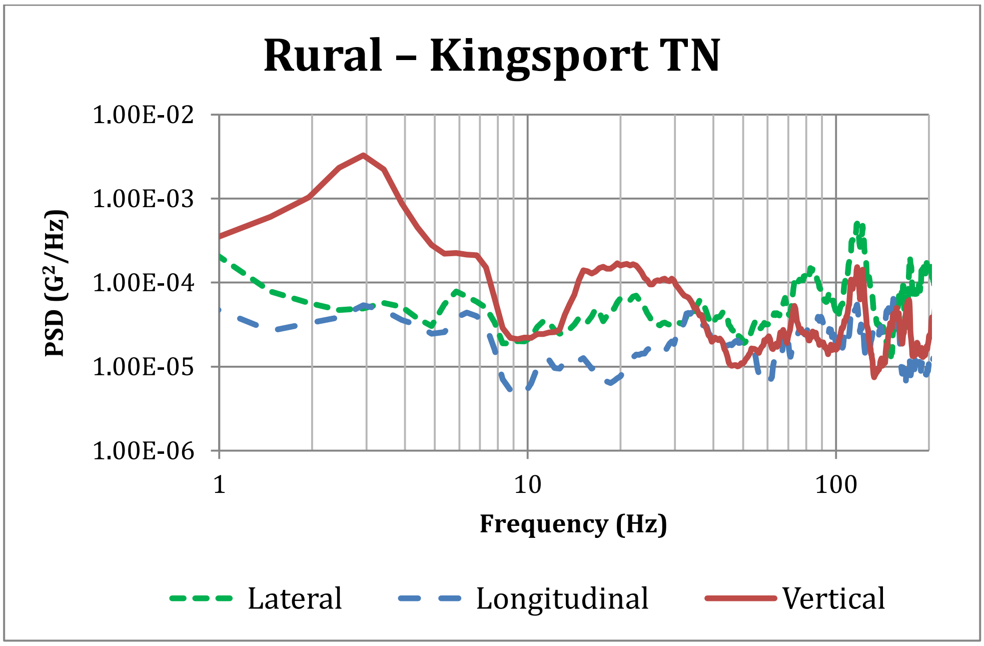


***Figure 4:*** *PSD Profile for Rural Delivery – Kingsport, TN*

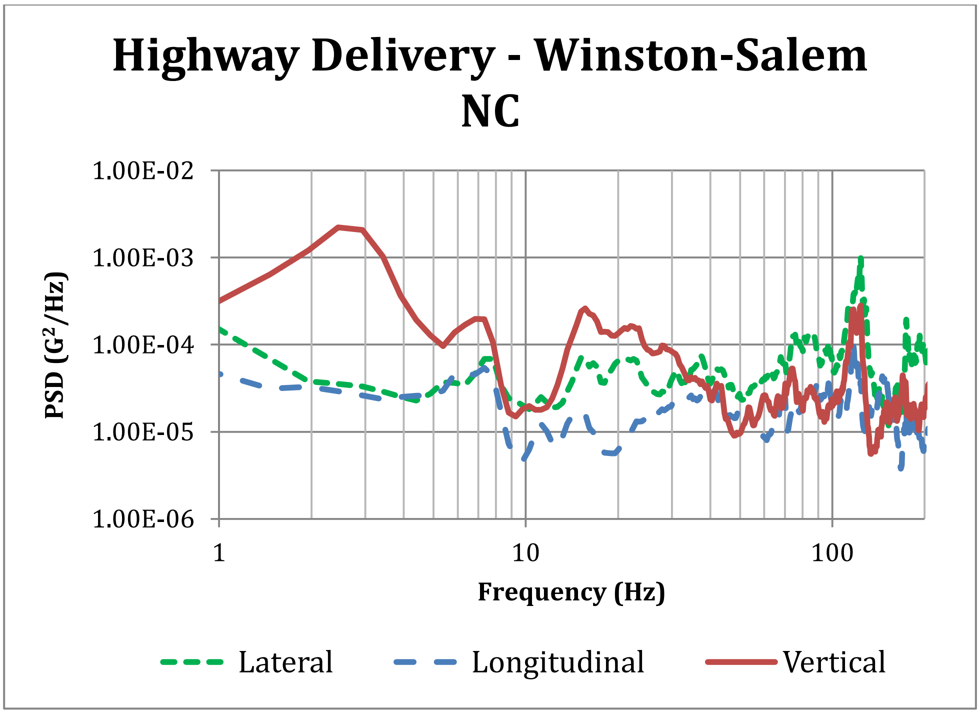


***Figure 5:*** *PSD Profile for Highway Delivery – Winston-Salem, NC*

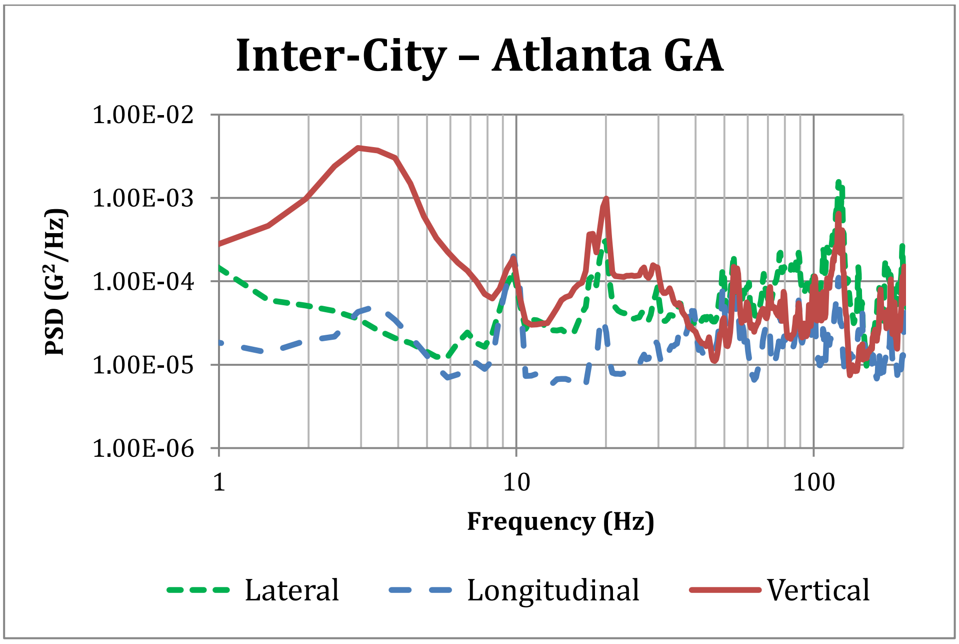


***Figure 6:*** *PSD Profile for Inter-City Delivery – Atlanta, GA*

The vehicle used during this study was a leaf spring style truck. Figure 7 illustrates the results from this study in comparison to the uncompressed ISTA Steel Spring Truck and Delivery Truck profiles. While it is important to consider the overall Grms level of the five PSD profiles, the general shape of the curve should also be evaluated as different peak intensities and frequencies will excite packages and products differently. The results from this study follow closely with the ISTA Steel Spring PSD profile at frequencies less than 10 Hz, but vary significantly between 30-100 Hz. When comparing this study with the ISTA Delivery Truck PSD profile, the shapes of each of the curves follows closely with that of the ISTA profile, except between 50-100 Hz. The energy reported by ISTA is much greater than that reported by this study.

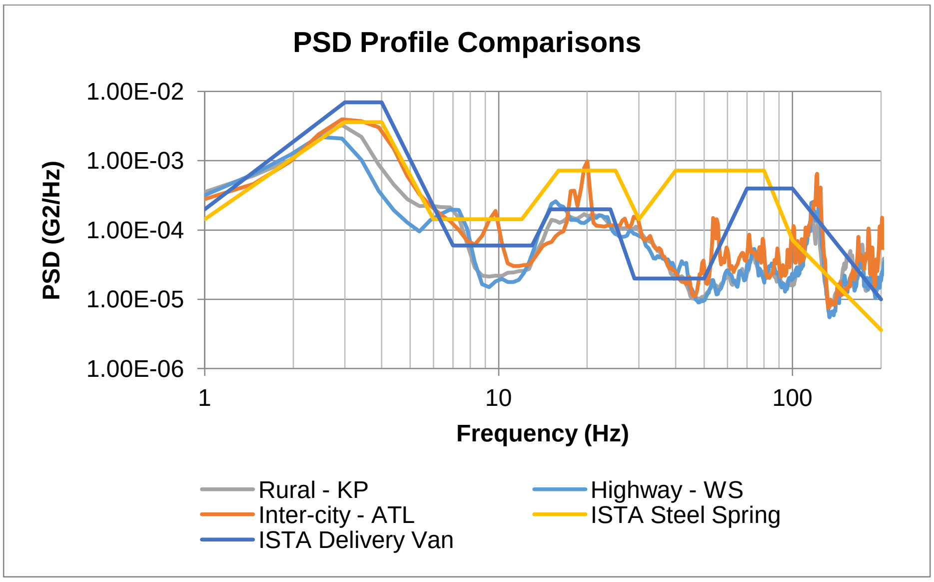


***Figure 7****: Comparison of Truck Vibration Profiles*

Table 2 displays the highest overall Grms value for each of the three delivery locations. Overall the highway delivery routes resulted in the lowest overall Grms levels, while the highest overall Grms levels occurred during the inter-city delivery of the bottled water. When the three delivery routes were compared however, there were no statistical differences between the mean overall Grms levels ($\alpha$=0.05).

***Table 2:*** *Maximum Grms Values for the Delivery Locations*

| Maximum Grms Values | | | |
|---|---|---|---|
| | **Rural** | **Highway** | **Inter-city** |
| **Longitudinal (x-axis)** | 0.543 | 0.498 | 0.587 |
| **Lateral (y-axis)** | 0.933 | 0.853 | 0.979 |
| **Vertical (z-axis)** | 3.234 | 3.198 | 4.012 |

Using the vertical axis results, the data for each delivery location was used to determine the cumulative distribution function (CDF) of the RMS (G) and fitted in a modified Weibull distribution model [7]. The PSD levels shown in Figures 4-6 represent 100% of the CDF. The RMS (G) values were then evaluated to observe the distribution for each delivery location. Histograms containing the frequency and cumulative percentage of the RMS (G) values are presented in Figures 8-10.

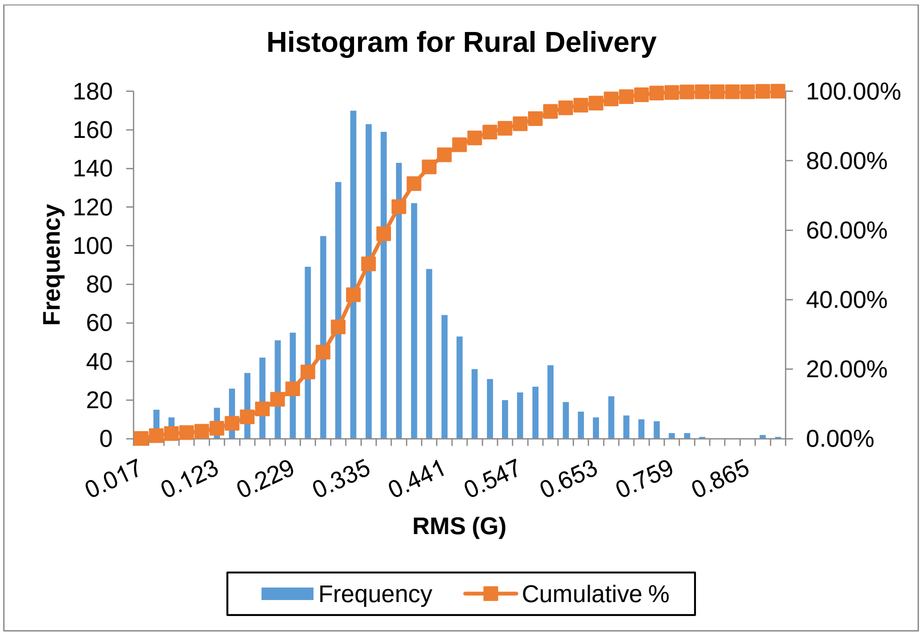


***Figure 8:*** *Histogram for Rural Delivery – Kingsport, TN*

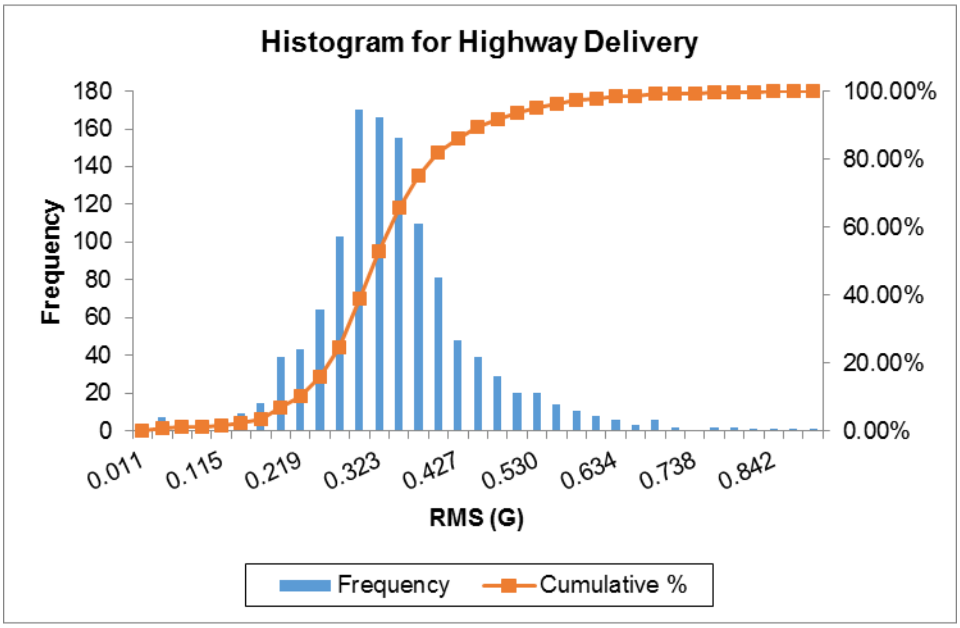


*Figure 9:* *Histogram for Highway Delivery – Winston-Salem, NC*

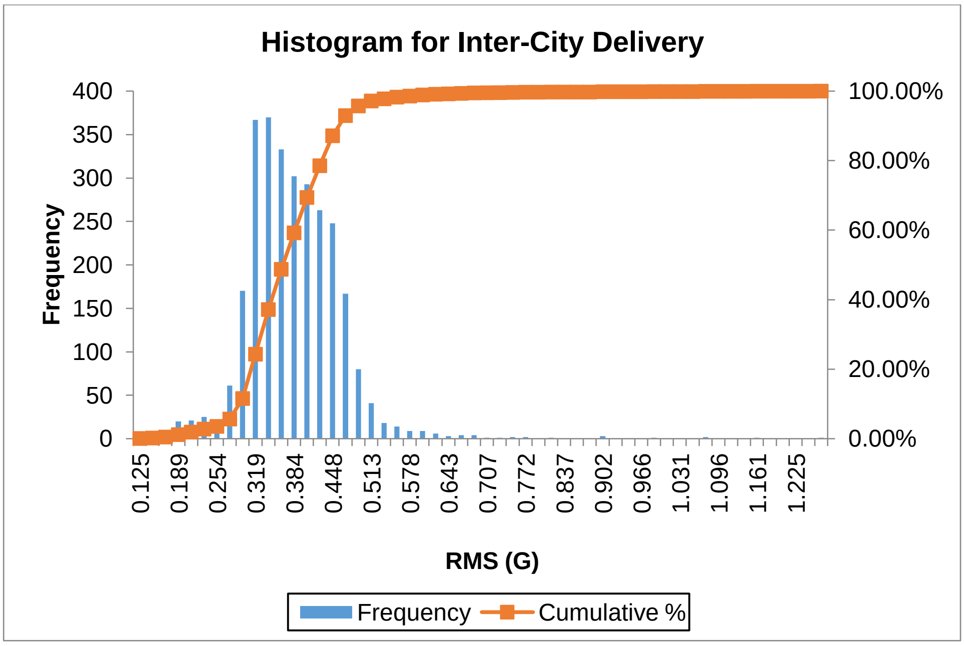


*Figure 10:* *Histogram for Inter-City Delivery – Atlanta, GA*

## 4. Conclusion

- The overall vibration intensity levels are higher in the vertical axis as compared with the lateral and longitudinal axes for all three delivery route PSD profiles.
- The inter-city delivery route produced the highest overall Grms levels, but there was not a statistical difference between the mean Grms values of the three delivery routes.
- PSD profiles produced from this study had similar ‘shaped’ curves.

- PSD profiles and Grms values can be utilized by the water bottle industry to produce a vibration test standard. In addition, the test standards can be time compressed to directly correlate to actual shipments.
- The PSD profiles which were analyzed from this research could be utilized to simulate bottled water delivery vehicles in a laboratory environment. This will enable further research in bottle and rack design, and aid in the optimization of package design and testing.

## Acknowledgement

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