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Research Article

Effect of Packaged Product Size, Weight and Shipping Location on Mean Drop Heights in the Small Parcel Shipping Environment

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Abstract This project evaluated the effects of package weight and size on the equivalent free fall drop height of instrumented packaged products traveling through the small parcel supply chain. To evaluate the relationship between package weight and drop height, the package size was kept constant and the weight of the overall system was varied. To evaluate the relationship between package size and drop height, the package weight remained constant and changes were made to the dimensional size of the container. A total of 13 round trip shipments were performed where the instrumented packages were shipped via small parcel Ground transport. Results from the study showed package dimensional size does have an affect the average drop height of a packaged product ($P < 0.05$), but neither package weight or geographical shipping location influenced mean drop height ($P > 0.05$). The results from this study indicate current package test standards should incorporate package dimensional size as a factor when determining the test drop height for a packaged product.

Keywords *Small parcel; e-commerce; Drop height; Package size; Package weight*

1. Introduction

The small parcel delivery system has experienced significant growth over the past several years due to the increase in E-commerce sales offerings (Grant, 2018). This is partly a result of consumers switching away from traditional brick and mortar store shopping and into online ordering, due to convenience and ease of ordering. With this change in shopping behavior, new product and package types are entering the small parcel supply chain frequently. The introduction of new packaged products into this distribution channel requires further research to gain an understanding of how packaged products move through the dynamic and ever-evolving small parcel supply chain.

Over the past twenty years, there has been a significant amount of research conducted evaluating different small parcel systems and delivery programs (Singh, 1992; 1996; 2010; 2004; 2006; 2009). The majority of the studies reviewed focused on the handling of the packages through different providers or delivery programs (Singh, 2009). The findings from these research projects have influenced and defined many of the current packaging transport test standards utilized today.

However, as the small parcel delivery network continues to evolve, continued research projects are needed to ensure laboratory test methods and standards are properly aligned with the fields they are evaluating.

As part of the development process, packages are often tested to make sure they can adequately protect the product through the distribution channel. One common engineering test package systems are subjected to be mechanical shock tests. These mechanical shock tests are typically completed in the form of free fall drops using a drop tester. Current standards made available from the International Safe Transit Association (ISTA) and the American Standards for Testing and Materials (ASTM) use only the packaged product weight as the determining factor for package drop height (ASTM D4169-16 and ISTA 2A, 2018). Previous studies have shown that while package weight does play a role in how likely a package will fall during transport; other factors could additionally influence how a package is handled (Kipp and Russell, 2006). One factor of note is package size, which could also influence how a package system is handled, especially during manual handling operations during the small parcel delivery system.

This project explored the relationship between packaged product size and weight and how those parameters affect the estimated average drop heights experience in the supply chain. Packaged product systems with varying weights and dimensions were instrumented with field data recorders to understand the influence of package size on average drop height in the small parcel delivery system. Understanding how the package size effects drop height will allow for packaging engineers to develop more predictive test sequences in order to develop the optimum package system for the small parcel delivery system.

Instrumentation

In order to complete the objectives of this study, field data recorders were utilized to record dynamic mechanical shock data related to the small parcel delivery channel. This study employed electronic field data recorders manufactured by Lansmont Corporation (Monterey, CA, USA) to capture mechanical shocks experienced by packages traveling through the supply chain. These data recorders have a tri-axial accelerometer capable of recording mechanical shock used to determine estimated package drop height. The data recorder used for this study was the SAVER 3X90 and 9X30. Figure 2 illustrate the field data recorders used for this study. The SAVER determines the drop height of a package by determining the 'zero-g drop height' by sensing a change from a motionless state (zero-g), to a free-fall state (1g) followed by a shock state (several g). By measuring the time that the SAVER is in the 1g state, the free-fall drop height can be calculated from the following relationship:

$$h = 0.5gt^2 \ldots \text{ Eq. 1}$$

Where g = acceleration due to gravity, 386.4 in/s^2; h = free-fall drop height; and t = free=fall time. The parameters used for recording were as follows:

- Drop/Vib Gateway (SaverXware)
- Drop height range: 72 in.
- Record Time: 1.4 seconds
- Trigger Level: 2 g
- Pre-filter: 93%
- Filter frequency: 500 Hz

Figure 1: *SAVER 3X90 and 9X30*

Test Package Shipments

The field data recorder was shipped inside a regular slotted container (RSC) constructed of C-flute corrugated fiberboard. To carry out this study, a variety of package sizes and weights were used to collect estimated drop height data for selected small parcel delivery destinations. A total of 13 round trip shipments were carried out to investigate the relationship between package size and weight on the drop height experienced during small parcel transport. Table 1 shows the package dimensions, weights, and destinations used for this study.

Table 1: *Instrumented package dimensions, weight, and shipping details*

Test Phase	Ship From	Ship To	Returned To	SAVER Model	Pack Dimension (in.)	Weight (lbs.)	Ship Via
1a	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 9x30	16 x 16 x 16	16.5	Ground
1a	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 3x90	16 x 16 x 16	33.1	Ground
1a	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 3x90	16 x 16 x 16	52.4	Ground
1b	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 9x30	24 x 24 x 24	24.4	Ground
1b	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 3x90	24 x 24 x 24	42.1	Ground
1b	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 3x90	24 x 24 x 24	63.2	Ground
2	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 9x30	6 x 6 x 6	12.3	Ground
2	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 3x90	16 x 16 x 16	12.4	Ground
2	Rochester, NY	Memphis, TN	Rochester, NY	SAVER 3x90	24 x 24 x 24	11.8	Ground
3	Rochester, NY	Orlando, FL	Rochester, NY	SAVER 9x30	12 x 12 x 12	10.3	Ground
3	Rochester, NY	Waukesha, WI	Rochester, NY	SAVER 9x30	12 x 12 x 12	10.3	Ground
3	Rochester, NY	White City, OR	Rochester, NY	SAVER 3x90	12 x 12 x 12	10.3	Ground
3	Rochester, NY	Fort Collins, CO	Rochester, NY	SAVER 3x90	12 x 12 x 12	10.3	Ground

The data collection was carried out using three phases to understand the relationship between package size, weight, and shipping location on the drop height experienced. Below is a description of the phases:

Phase I: Effect of Package Weight on Drop Height

For this phase, the package dimensions were held constant, and the total weight was changed for each package. To increase/decrease the package weight, steel plate weights were attached to the wood test box. The weights used were evenly distributed as to not influence orientation or handling. For each test phase (1a and 1b) all packages were shipped on the same day in an attempt to ensure the packages were handled by the same systems.

Phase II: Effect of Package Size on Drop Height

For this phase, the package weight was held constant, and the package size (dimensions) were changed. The three packages for this phase were all shipped on the same day to attempt in an attempt to ensure the packages were handled by the same systems.

Phase III: Effect of Shipping Location on Drop Height

For this phase, the package weight and dimensions were held constant, and the delivery location was changed. The four packages for this phase were all shipped on the same day.

To ensure the proper drop height was determined, the field data recorder was placed in the geometric center of each container. For most packages, the field data recorder was rigidly attached to a wood container placed into the corrugated container and fixed to the geometric center by encasing the wood test box with expanded polyethylene (EPE) foam. All test packages were sealed clear 2 in. packaging tape. Figure 2 displays a rendering of the package system employed for this study. Prior to shipping the containers, a preliminary testing was completed to ensure the data recorder was accurately calculating the EFFDH from each container.

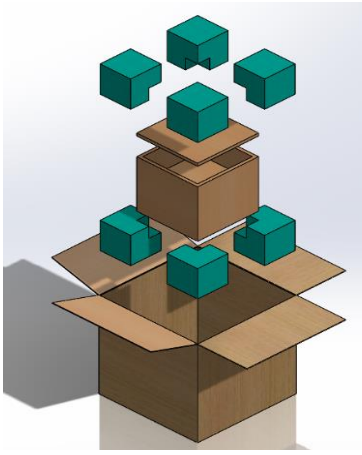

Figure 2: *Rendering of the instrumented test box*

2. Results and Discussion

For each of the test study phases, drop height and frequency of occurrence were tabulated. For this study, drop heights less than three inches were not considered as they produce very little damage to single parcel shipments (Saha et al., 2010). For each of the study phases, a one-way analysis of variance (ANOVA) was computed using Minitab 18 for each data set to determine if the mean drop heights were different from each other (Minitab, LLC, State College, PA). Additionally, probability plots were generated for each of the test study phases for analysis.

Phase I: Effect of Package Weight on Drop Height

Results from Phase 1a and 1b are shown in Figure 3 and 4. Table 2 displays the results from the Tukey Pairwise Comparison performed for Phase 1. Based on the results collected for Phase 1a, no statistical differences in mean drop height were observed for the different weight packages ($P>0.05$). The majority of all calculated EFFDH for Phase 1a occurred below 20 inches. Results computed for Phase 1b also showed no statistical differences in mean drop height for the different weight packages ($P>0.05$). The mean drop heights for all packages from Phase 1b were less than 6 inches as compared to Phase 1a, where the mean drop height was as high as 16.4 inches for the 54.4 lbs. instrumented packaged product. Based on these findings, increasing the package weight for each phase proved to have only a minor influence on the mean drop height calculated. Comparing Phase 1a and 1b, the package size appeared to have a large influence on drop height. This difference in cubic size of the package may have altered how individuals handled the packages during transport.

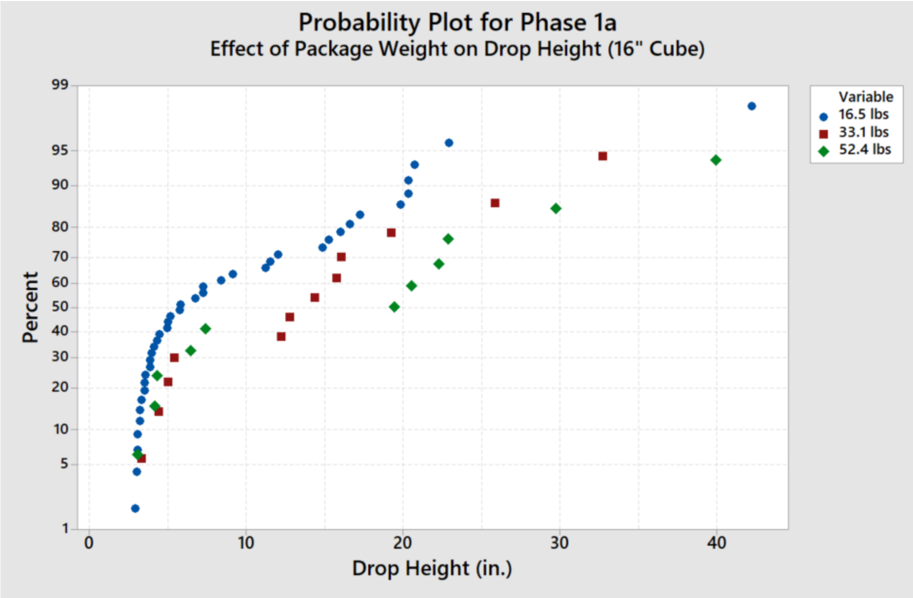

Figure 3: *Probability plot for Phase 1a*

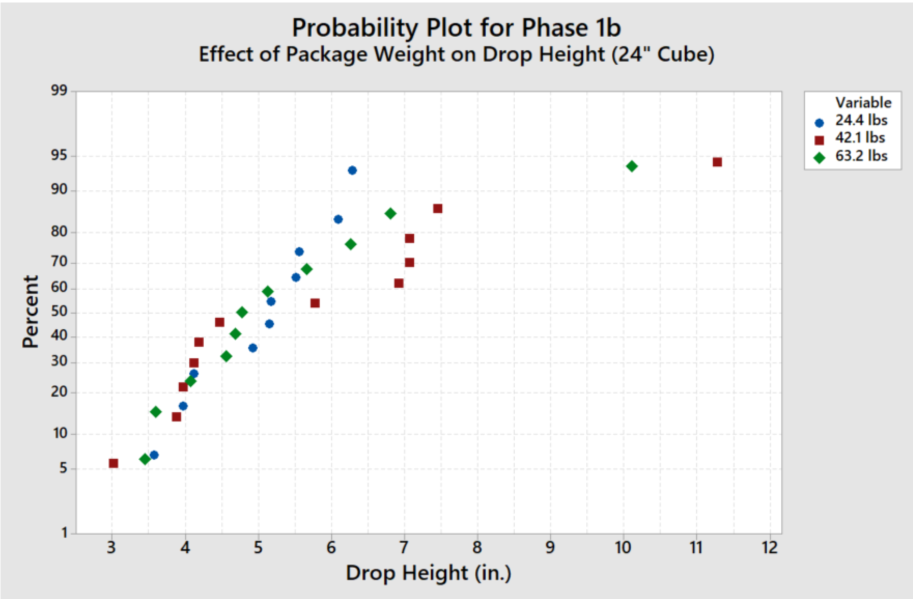

Figure 4: *Probability plot for Phase 1b*

Table 2: *Tukey Pairwise Comparison for Phase I*

Factor	Dimensions (in.)	N	Mean Dh (in.)	Grouping	
52.4 lbs	16 x 16 x 16	11	16.4	A	
33.1 lbs	16 x 16 x 16	12	13.9	A	B
16.5 lbs	16 x 16 x 16	40	9.6	A	B
42.1 lbs	24 x 24 x 24	12	5.8		B
63.2 lbs	24 x 24 x 24	11	5.4		B
24.4 lbs	24 x 24 x 24	10	5.0		B

Means that do not share a letter are significantly different.

Phase II: Effect of Package Size on Drop Height

Results from Phase II are shown in Figure 5 and Table 3. Based on the analysis completed using the data set for Phase II, the mean drop heights for the small volume packaged product were significantly different than the medium and large volume packages (P<0.05). Results from this phase indicate the dimensional size of the package can affect the anticipated drop height, and the total number of drops experienced during small parcel delivery. The small package experienced over two times the number of shock events as compared to the larger dimensional packages.

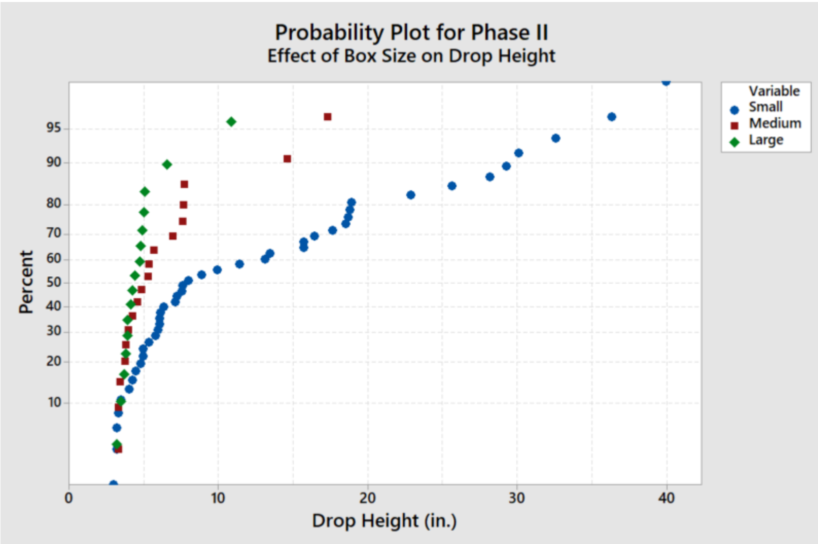

Figure 5: *Probability plot for Phase II*

Table 3: *Tukey Pairwise Comparison for Phase II*

Factor	Dimensions (in.)	N	Mean Dh (in.)	Grouping	
Small	6 x 6 x 6	44	12.8	A	
Medium	16 x 16 x 16	18	6.3		B
Large	24 x 24 x 24	16	4.8		B

Means that do not share a letter are significantly different.

Phase III: Effect of Shipping Location on Drop Height

Results from Phase III are shown in Figure 6 and Table 4. Based on the analysis completed using the data set for this, the mean drop heights for each shipping location were not significantly different from each other (P>0.05). Results from this phase indicated the instrumented packaged products traveling to these selected locations experienced similar shock measurements. While these locations do not represent all of the sorting hub types or delivery destinations in the small parcel supply chain, the results showed that for this study, shipping location didn't affect mean drop height of the packaged product.

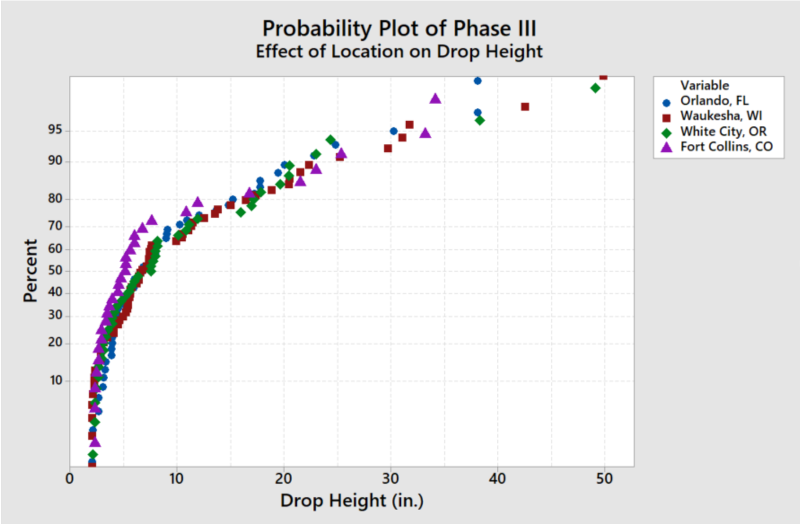

Figure 6: *Probability plot for Phase III*

Table 4: *Tukey Pairwise Comparison for Phase III*

Factor	N	Mean Dh (in.)	Grouping
Waukesha, WI	50	12.5	A
White City, OR	36	11.9	A
Fort Collins, CO	23	10.9	A
Orlando, FL	49	10.1	A

Means that do not share a letter are significantly different.

3. Conclusion

Examined during this project were the effects of weight and size on drop height of a packaged product system. These packaged product systems were instrumented with field data recorders to calculate the equivalent free fall drop height experienced by the package traveling through the small parcel shipping environment. Results from this study showed the dimensional size effected the average drop height of a package traveling via Ground through the small parcel shipping environment. Changes to the package weight and shipping location, did not significantly influence the calculated mean drop height of the instrumented package product. Based on the findings from this study, the dimensional size of the packaged product should also be considered when determining the test drop height for laboratory simulations.

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