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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.

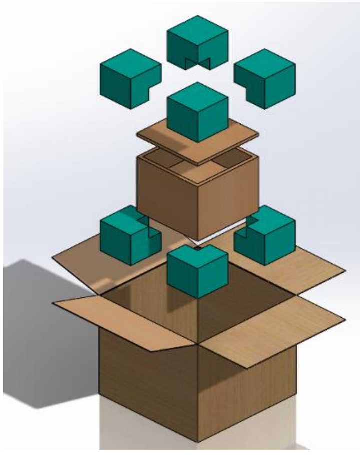

Figure 2: *Rendering of the instrumented test box*

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.

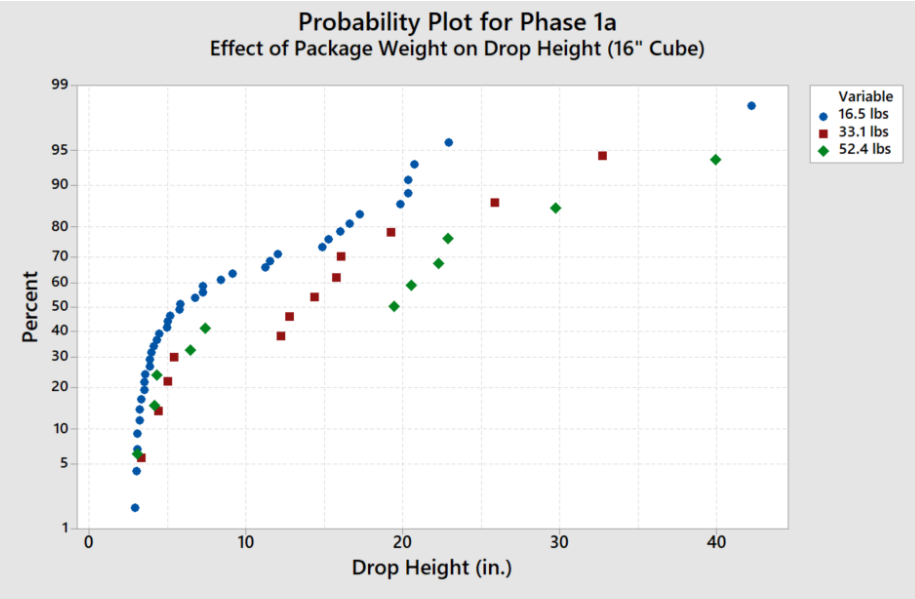

Figure 3: *Probability plot for Phase 1a*

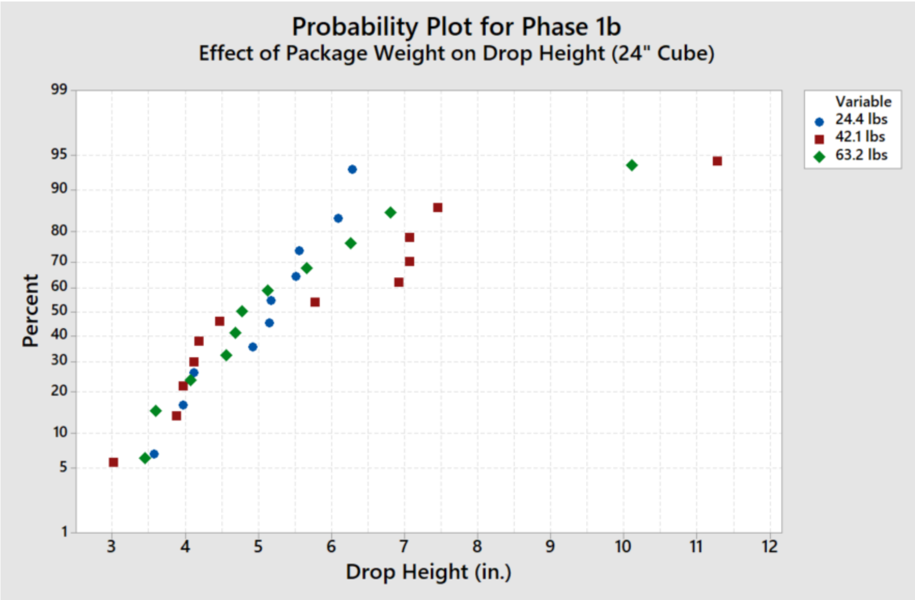

Figure 4: *Probability plot for Phase 1b*

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.

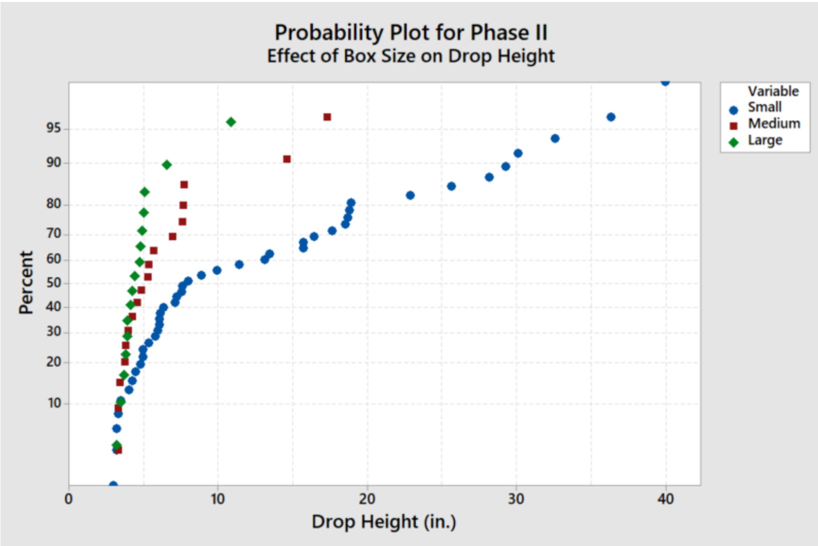

Figure 5: *Probability plot for Phase II*

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.

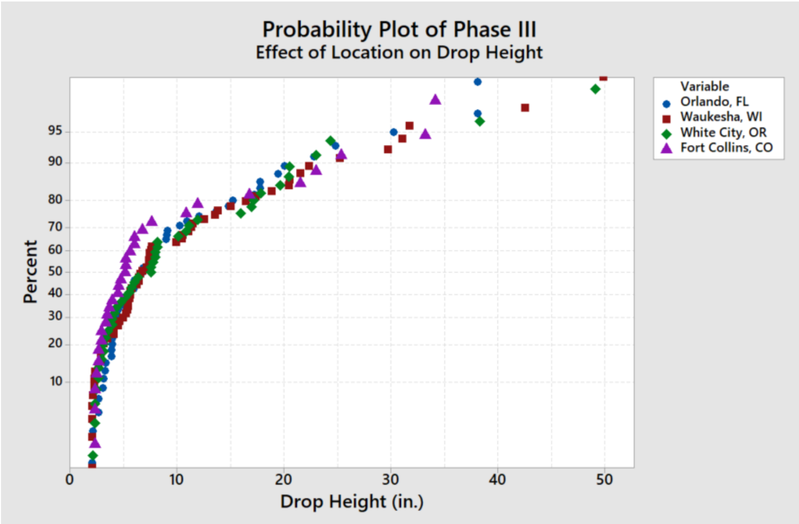

Figure 6: *Probability plot for Phase III*

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.

Acknowledgements

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Research Article

Corrugated Box Compression Strength Enhancement

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Abstract In this study, 5x5x12 single-wall RSC corrugated boxes were strengthened to increase their compression strength using four different methods; horizontal brace, diagonal brace, L-shape corner post, and triangular corner stiffener. All braces are of 2-inch width.

- **Horizontal Brace**: Compression strength increased by 9% when the unsupported box height was reduced from 12 inches to 3 inches.
- **Diagonal Brace**: Compression strength increased by 8% and 14% for single and double braces, respectively.
- **L-Shape Corner Post**: Compression strength increased by 29% and 38% for exterior and interior posts, respectively.
- **Triangular Corner Stiffener**: Compression strength increased by 36% when the stiffener depth increased from 0 inch to 9 inches.

The interior corner post method was the most effective and most practical.

Keywords *Compression Strength; Corrugated Box; Horizontal Brace; Diagonal Brace; Corner Post; Corner Stiffener*

1. Introduction

The compression strength of corrugated boxes can be increased by using different methods, including diagonal corner [1] and corner post/stiffener [2]. In this study, four additional methods to increase corrugate box compression strength were explored.

- Horizontal Brace: This method was inspired by the belt of power lifters. A previous study [3] also showed that increasing in lateral force to a pack of drinking-water bottles increased the vertical compression strength of the pack.
- Diagonal Brace: This method was modeled after diagonal single and double braces found in building structures [4].
- L-Shape Corner Post & Triangular Corner Stiffener: About 2/3 of box compression strength is attributed to the strength of its four corners. Thus, strengthening box corners increases overall box strength.

Figure 1: *Concepts Utilized in This Study to Increase Compression Strength of Corrugated Box*

2. Materials and Methods

C-flute single-wall 5x5x12 corrugated boxes were used in this study. All braces and stiffeners were of 2-inch width of the same corrugated fiberboard. All samples were conditioned at standard test environment of 73°F and 50% RH. Five samples were crushed to failure for each case and an average strength was used to represent the case. The four methods for enhancing compression strength of the 5x5x12 box are shown in Figure 2.

Figure 2: *Four Methods of Enhancing Box Compression Strength*

3. Data & Results

Horizontal Brace

Corrugated strips with a two-inch width were used as horizontal braces as shown in Figure 3. Approximate unsupported lengths shown in the figure were used to represent the four cases. Five specimens of each case were crushed with results summarized in Table 1. The sample figures shown below in Figure 3 were computed based on compression strengths obtained from the trendline equation shown in Figure 4. More horizontal braces reduce the unsupported lengths, thus increase box compression strengths.

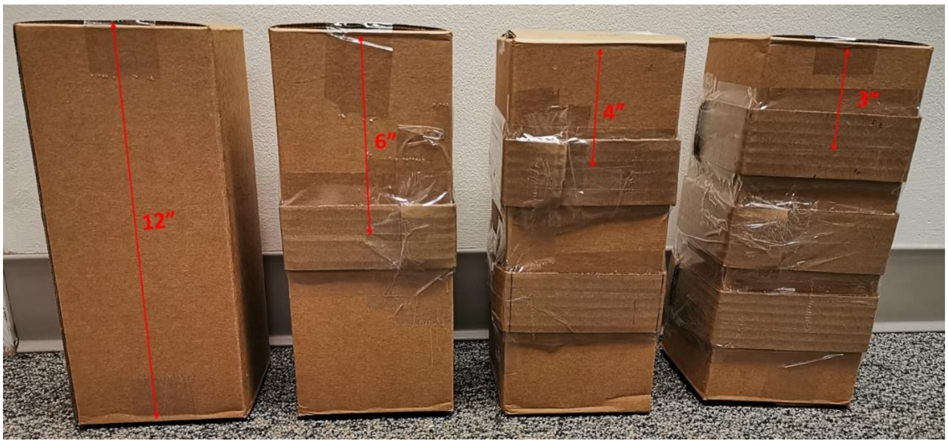

Figure 3: *Approximate Unsupported Length Due to Horizontal Braces*

Table 1: *Horizontal Brace Box Compression Strength*

Horizon Brace									
Box Size	Unsupported Length (in)	Maximum Load (lb)							% Increase
		1	2	3	4	5	Avg	Trendline Equation	
5x5x12	3	364	377	374	404	410	386	392	9
	4	382	394	385	386	421	394	388	8
	6	357	396	413	386	363	383	381	6
	12	322	406	362	362	335	357	359	0

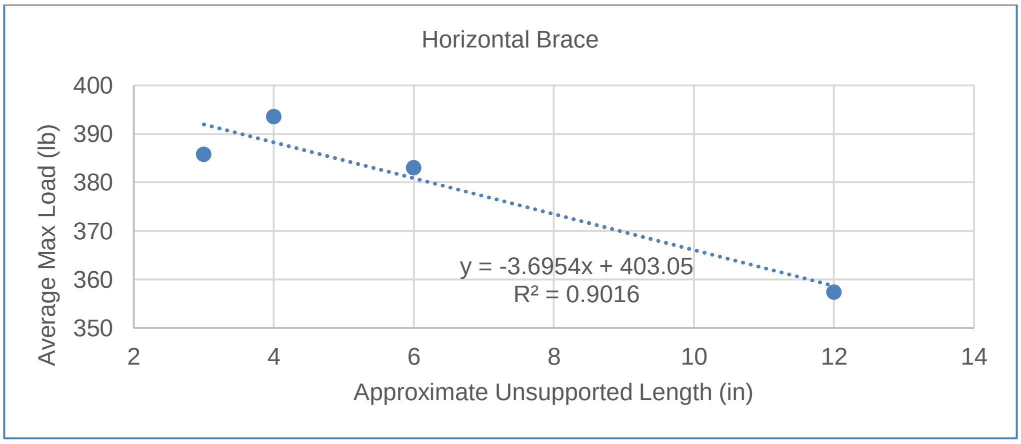

Figure 4: *Box Compression Strength vs Approximate Unsupported Length*

Diagonal Brace

Corrugated strips with a two-inch width were used as single-diagonal and cross-diagonal braces as shown in Figure 5. Five specimens of each case were crushed with results summarized in Table 2. As expected, the cross-brace case yielded higher compression strength. In both cases, braces had to be extended to fit the corners in order to transfer load from the top of the box and through the braces as shown in Figure 6.

Figure 5: *Single and Cross Diagonal Braces.*

Table 2: *Diagonal Brace Box Compression Strength*

Diagonal Brace								
Box Size	Brace	Maximum Load (lb)						% Increase
		1	2	3	4	5	Avg	
5x5x12	None	322	406	362	362	335	357	0
	Single	426	367	374	390	367	385	8
	Double	403	424	394	389	436	409	14

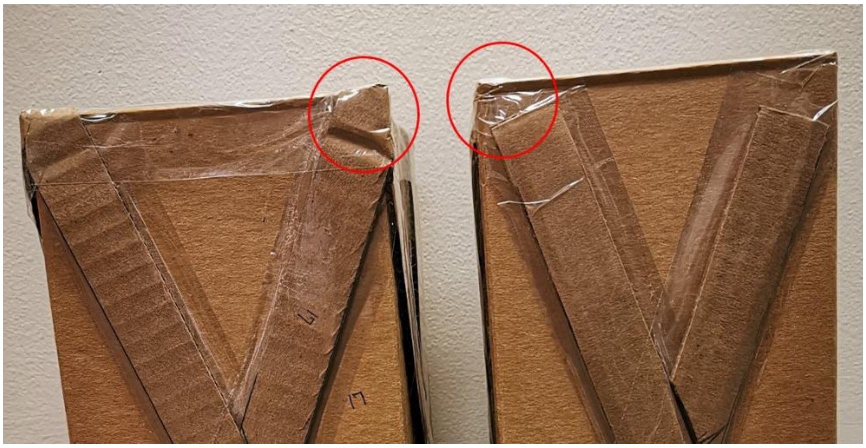

Figure 6: *Corner-Fitting Brace (Left) vs Corner-Unfitting Brace (Right)*

L-Shape Corner Post

Corrugated strips with a two-inch width were used as an L-shape post as shown in Figure 7. Five specimens of each case were crushed with results summarized in Table 3. The interior-post case yielded greater strength.

Figure 7: *L-Shape Corner Post: Exterior (Left) and Interior (Right)*

Table 3: *L-Shape Corner Post Box Compression Strength*

L-Shape Corner Post								
Box Size	Stiffener	Maximum Load (lb)						% Increase
		1	2	3	4	5	Avg	
5x5x12	None	322	406	362	362	335	357	0
	Exterior	433	460	455	497	452	459	29
	Interior	440	463	482	544	532	492	38

Triangular Corner Stiffener

Two-inch wide corrugated strips were used to create 1”x1” triangular corner stiffeners with various depths as shown in Figure 8. Five specimens of each case were crushed with results summarized in Table 4. The deeper the stiffener, the higher the box compression strength as shown in Figure 9.

Figure 8: *Triangular Corner Stiffeners with Various Depths*

Table 4: *Triangular Corner Stiffener Box Compression Strength*

Triangular Corner Stiffener										
Box	Corner Stiffener	Depth (in)	Maximum Load (lb)							% Increase
			1	2	3	4	5	Avg	Trendline Equation	
5x5x12	None	0	322	406	362	362	335	357	368	0
	1x1x1	1	455	367	379	405	411	403	390	6
	1x1x2	2	426	400	391	409	416	408	409	11
	1x1x3	3	470	448	451	344	447	432	428	16
	1x1x5	5	419	482	443	470	442	451	458	25
	1x1x7	7	451	474	460	537	478	480	482	31
	1x1x9	9	471	522	539	529	450	502	499	36

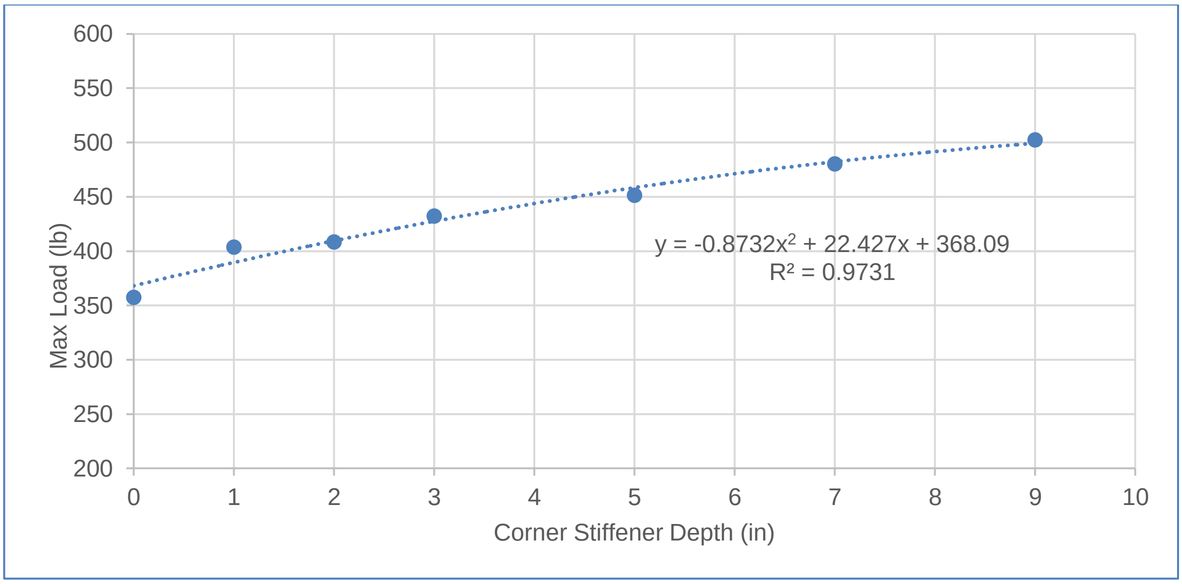

Figure 9: *Effect of Triangular Corner Stiffener Depth to the Box Compression Strength*

4. Discussion & Conclusion

Four different methods to increase corrugated box compression strength were explored. The following conclusions can be made:

- More horizontal braces reduce unsupported length (height) of the box, thus gaining more compression strength. However, these braces increased the compression strength only by 9% when the box's unsupported height was reduced from 12 inches to 3 inches as shown in this study. It becomes impractical when more braces are used. It would be more practical to use double-wall or triple-wall corrugated boxes than adding more horizontal braces.
- Cross braces result in higher compression strength than single diagonal braces. However, compression strength in this study only increased by 14% with double braces. Braces also alter the exterior appearance of the box, which may or may not be desirable.
- Placing L-shape corner posts inside the box yields higher compression strength than placing them on the exterior. These posts increased the box strength by 38%. Since they are placed in the interior side of corners, they do not change the exterior look of the box. Although, interior space would be reduced somewhat. However, the space taken would typically be used by cushioning materials anyway.
- The deeper the triangular corner stiffeners, the better the box compression strengths. To gain a 36% increase in compression strength, the stiffener depth had to go down ¾ of the box height. When the depth is more than ½ of the box height, the stiffeners from the top and bottom cross over. In addition, placing triangular corner stiffeners would be more difficult than placing L-shape corner posts.

The most practical and most effective method is to place four L-shape corner stiffeners inside the four corners. This is similar to corner posts used to carry heavy loads discussed in a previous study [2].

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Case Study

Product Protection and Packaging Operations Improvement

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Abstract Thistle & Bee is a non-profit organization. Its mission is to help women who have survived prostitution and trafficking thrive. The goal of this project is three-fold: (1) Product protection, (2) Environmental friendliness, and (3) Process improvement. This was a service-learning project that aligns with CBU's mission. CBU prepares its students with a slogan "Enter to Learn. Leave to Serve."

Product protection was done at both product and packaging levels. Environmental-friendly materials were chosen, and shipping box sizes were optimized. Process improvement included efficiency for manual operations and cost reduction. Various studies were performed, including an impact study of honey jars and a granola tray, as well as shock absorption of different cushioning materials.

The following recommendations were made:

- Using single-faced corrugated wrap around honey jars to separate glass jars.
- Using biodegradable peanuts to tighten up gift packs in shipping corrugated boxes.
- Using an optimum shipping corrugated box.
- Using crinkle paper as cushion in gift pack.
- Using paper labels to secure the lid of granola plastic tray.

Keywords *Packaging Improvement; Sustainability; Protection; Service Learning*

1. Introduction

Thistle & Bee [1] is a non-profit organization with a mission to help women who have survived prostitution and trafficking thrive. It offers a two-year residential program for these women by providing a home environment setting and daily opportunities to practice community living as they heal from histories of physical, emotional, and sexual trauma. Participants help the organization grow its honey and granola business. Thistle & Bee has several beehives and a great recipe for honey-sweetened granola. The women in the program help care for 80 beehives by assisting with harvesting and bottling honey, as well as baking granola. This social enterprise generates revenue to support programs designed to help women on a journey of healing and hope. The organization is not a business with a mission but rather a mission with a business.

The AutoZone Center for Community Engagement [2] at Christian Brothers University collaborates with communities on and off campus to enhance learning, enrich student life, and promote positive social change in Memphis and beyond. The Center supports programs that respond to defined community goals and social challenges, connecting the knowledge and enthusiasm of both CBU and community partners.

The work presented in this article is a collaboration of Thistle & Bee, the AutoZone Center for Community Engagement, and the Gadomski School of Engineering. Packaging students worked on this project as one of their four projects in PKG 490 Packaging Projects course during the Fall of 2019. The goal is to improve the packaging of Thistle & Bee's products using environmental-friendly solutions.

2. Materials and Methods

The products used in this study, shown in Figure 1, were honey (in 3-oz and 12-oz glass jars), gift box (containing an 3-oz honey jar, a candle bar, a bag of green tea, and a bag of granola), and a tray of granola. Multiple honey jars, gift boxes, and granola trays may be shipped per customer orders in shipping corrugated boxes.

Figure 1: *Thistle & Bee's Products Used in This Study*

Cushioning materials used in the study, shown in Figure 2, include single-face corrugated fiberboard, single-wall C-flute corrugated fiberboard, crinkle paper, biodegradable peanut, and 3/16" and 1/2" bubble wraps.

Figure 2: *Cushioning Materials Used in This Study*

Drop test was performed on individual honey jar, granola plastic tray, and gift box. Based on ISTA test protocols [3] for small items, a 30-inch drop height was used. A 48-inch drop height was also sometimes used to simulate a situation whereby a customer accidentally drops a product after it is removed from a gift box. A 10-drop sequence based on ISTA 1A [4] was performed on the gift box. All single jar drops were done on the side of the jar, while surface/edge/corner drops were performed on the single granola tray. In the shock absorption study, a tri-axial accelerometer was used to measure peak impact acceleration, as shown in Figure 3.

Figure 3: *Tri-Axial Accelerometer*

3. Data & Results

Glass Jar Partition

When multiple glass jars are shipped in a box, they are separated by partitions, typically made from cardboard as shown in Figure 4. Empty glass jars often come with these cardboard partitions. However, honey-filled jars may be shipped in different quantity and the cardboard partitions that come with the empty jars may not fit. Cardboard partitions are not practical to make when packing is done manually as in the Thistle & Bee case. It is more practical to use single-face corrugated fiberboard to wrap around individual jars, as shown in Figure 5. The two ends of the fiberboard are connected by a paper label, in which a company logo can print on. This serves not only as partitions to protect a jar from its neighboring jars, but also protect the jar when it is accidentally dropped after taken out from a box.

Figure 4: *Cardboard Partition*

Figure 5: *Single-Face Corrugated Partition*

Gift Box Cushioning

Crinkle paper and biodegradable peanuts were used to secure the gift box products in place. Crinkle paper was recommended over the peanut due to its easy arrangement and classy appearance as shown in Figure 6. It should be noted that the biodegradable peanut is a plant-based product that can dissolve in water, as shown in Figure 7. Biodegradable peanuts are made from crop-based sources rather than petroleum-based materials [5]. Thus, it is non-toxic and more environmental-friendly.

Figure 6: *Crinkle Paper (left) versus Biodegradable Peanuts (right)*

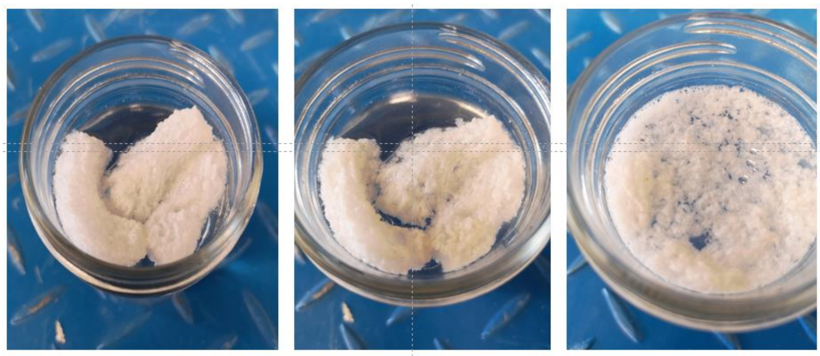

Figure 7: *Biodegradable Peanuts in Water*

Shock Absorption of Cushioning Materials

Corrugated fiberboard and biodegradable peanuts were used in this study. Their shock absorption abilities were compared with bubble wraps, 3/16” and 1/2”. A tri-axle accelerometer, Figure 3, was placed at the bottom of a 5”x5”x5” corrugated box without added cushioning material. The box was then dropped 35 times and its average peak impact acceleration was used as a baseline. The process was repeated for each cushioning material mentioned above with 1 ¾” thickness. Impact acceleration data was summarized in Table 1 and Figure 8.

Table 1: *Peak Impact Acceleration Summary*

Drop (30")	Peak Impact Acceleration (G)				
	No Cushion	Corrugated	Peanut	Bubble - S	Bubble - L
1	78.32	44.73	32.64	11.19	15.26
2	66.89	44.72	40.81	10.71	17.75
3	79.51	63.06	37.02	11.96	11.63
4	59.12	47.84	40.34	17.90	12.80
5	56.96	49.14	31.78	19.01	14.80
6	54.33	60.13	32.75	13.24	17.17
7	55.51	47.29	31.23	10.99	16.42
8	67.16	63.27	35.09	14.99	14.07
9	57.27	56.17	32.63	11.00	17.32
10	71.80	41.23	29.36	15.51	16.61
11	58.51	49.56	30.01	17.96	10.84
12	71.45	53.17	30.70	10.27	13.40
13	65.05	49.37	30.37	26.21	11.58
14	54.51	51.43	37.81	21.95	12.23
15	73.34	50.17	32.96	11.43	13.16
16	78.06	47.78	36.43	17.86	17.03
17	67.95	50.36	33.60	10.15	14.80
18	78.48	52.73	29.37	26.94	12.92
19	58.94	40.76	30.21	19.75	12.63
20	72.03	45.58	33.98	19.24	13.17
21	80.07	50.80	33.26	24.94	14.62
22	69.39	56.23	33.97	16.73	15.42
23	75.66	43.65	41.98	22.41	16.22
24	65.32	41.75	36.78	32.87	14.47
25	77.07	44.56	31.55	28.09	12.66
26	68.09	51.81	28.89	18.26	15.49
27	70.14	60.34	34.73	16.38	11.64
28	71.36	58.38	35.74	30.43	16.68
29	65.02	40.81	29.68	26.44	14.51
30	76.79	49.92	38.67	24.23	14.00
31	65.87	41.63	31.90	17.84	18.96
32	70.91	38.63	33.52	31.30	14.36
33	54.26	39.79	31.62	31.96	15.24
34	60.35	56.51	32.06	18.61	11.98
35	70.12	53.05	30.21	17.93	18.54
Avg =	*67.59*	*49.61*	*33.53*	*19.33*	*14.58*
Min =	*54.26*	*38.63*	*28.89*	*10.15*	*10.84*
Max =	*80.07*	*63.27*	*41.98*	*32.87*	*18.96*
% of Base	***0.00***	***-26.60***	***-50.39***	***-71.40***	***-78.43***

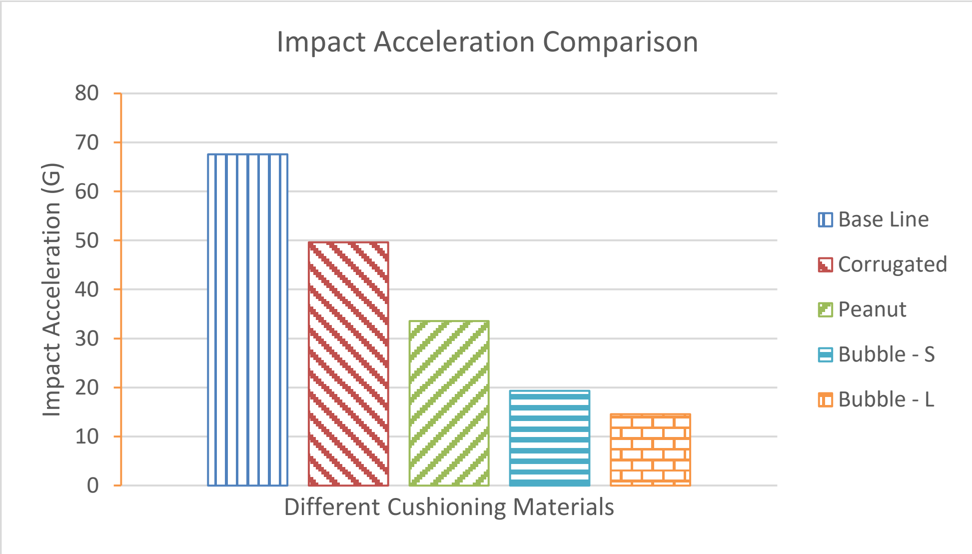

Figure 8: *Comparison of Different Cushioning Materials*

Optimum Shipping Box Size

Shipping cost typically depends on package product weight and volume. Using an oversize shipping box does not only cost more but uses more shipping materials, from boxes to cushioning materials and fillers. Table 2 below provides recommended box sizes to minimize the box volume and arrangements of multiple gift boxes. Biodegradable peanuts were used to fill the space around the products and for the interior surface of the shipping box as shown in Figure 9.

Table 2: *Optimum Shipping Box Sizes*

Number of Gift Box	Recommended Shipping Box	Packing Arrangement
1	9x7x4	
2	9x8x8	
3	11x9x9	
4	16x8x8	
5	10x10x14	

Figure 9: *Biodegradable Peanuts as Filler and Cushioning Material*

Drop Test

Similar glass jars were dropped at a 48-inch height with and without single-face corrugated wrap. As shown in Figure 10, the unprotected bottle (left) broke while the protected bottle survived with a little dent on its lid. Drop tests were performed on 3-oz honey jars with corrugated wrap at 48-inch and 30-inch drop heights. Cracks were observed as shown in Figure 11. However, no shattering of jars occurred. The same 30-inch drop was performed on a 12-oz honey jar with corrugated wrap. Unfortunately, it shattered. The 12-oz jar was heavier, thus had more mass. From Newton's second law of motion, F=ma, the impact force on 12-oz jar was greater than the 3-oz jar.

Figure 10: *Preliminary Drop Test of Similar Glass Jars*

Figure 11: *3-oz Honey Jar with Single-Face Corrugated Wrap: 48-Inch Drop (Left) & 30-Inch Drop (Right)*

A few solutions were attempted to protect 12-oz honey jars from individual jar drop, including protecting the jar bottom with corrugated fiberboard and bubble pouches, as shown in Figure 12. Damages are shown in Figure 13. While bubble wraps have shown greater impact absorption in Figure 8, the honey jar in the small-bubble pouch broke from a 30-inch drop. In the pouch case, only one layer of bubble wrap was under impact as opposed to several layers used in the impact absorption study. The weight from the 12-oz honey jar crushed and broke bubbles in the only layer of bubble pouch. When bubbles broke, they no longer absorbed impact which resulted in broken jar.

Even though other solutions protected or partially protected the 12-oz honey jar, none of them have deemed practical. Dropping a honey jar without a shipping box is too extreme. The main purpose of packaging is to protect products from damages during distribution. These honey jars would be in a gift box and another layer of shipping box during the distribution. Crinkle paper and biodegradable peanuts provided additional protection on the top of the single-face corrugated wrap on the jar.

Figure 12: *Various Solutions to Protect 12-oz Honey Jar from Breakage of 30-Inch Drop*

Figure 13: *Damages of 12-oz Honey Jar from 30-Inch Drop*

Granola Plastic Tray

Granola was packed in a plastic tray as shown in Figure 1. The tray lid appeared to be tight under normal circumstances. However, a drop test, such as the side drop shown in Figure 12, at a 48-inch height caused lid popping. Four paper labels were used to secure the lid to the tray. Side and corner drops were made at 48-inch height. The labels were able to prevent the lid from popping off. However, the sides of the tray were pried open slightly, especially with the corner drop test. Regardless, the granola was still well secured within the tray as shown in Figure 13. This could be a problem with insects and/or moisture getting into these small openings. However, these small openings would not occur during shipment since these trays would be packed in a shipping box with biodegradable peanuts similar to the gift box packing method mentioned earlier.

Figure 12: *48-inch Side Drop of Granola Tray Caused Lid Popping*

Figure 13: *48-inch Corner Drop of Granola Tray with Lid Secured by Four Paper Labels*

Gift Box Drop Test

A gift box went through the 30-inch 10-drop sequence as specified in ISTA 1A as shown in Figure 14. A small scratch was found on the candle as shown in Figure 15. The 3-oz honey jar was not protected with single-face corrugated wrap and it was placed next to the candle. If the jar was protected with a wrap or placed away from the candle with crinkle paper in between, the scratch would not have occurred.

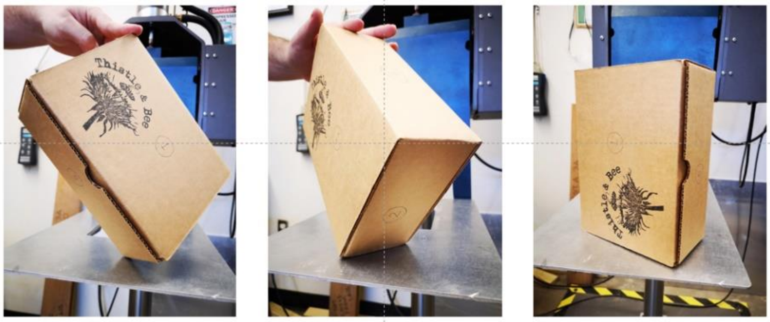

Figure 14: *30-inch 10-Drop Sequence of Gift Box*

Figure 15: *A Small Scratch on Candle in the Test Gift Box*

4. Discussion & Conclusion

Various aspects of packaging were investigated in this case study. Single-faced corrugated wrap is recommended for multi-pack honey jar packaging to provide cushion from jar-to-jar impacts during shipping. However, the corrugated wrap is not necessary in a gift pack since the honey jar is already protected by crinkle paper (which is recommended over biodegradable peanuts) and the gift box. A honey jar in a gift box looks better without a corrugated wrap. Also, packers need to place the jar away from the candle. An optimum size of shipping box should be used to minimize the packaging material utilization, which would benefit the environment. This includes less paper for the corrugated shipping box and less biodegradable peanuts in the shipping box. Paper labels are recommended for securing the lid to the granola plastic tray to prevent lid popping possibilities during drops. Bubble wraps are not recommended due to the impact plastic has on the environment. Wraps with big bubbles provide good protection from impact, but they are bulky. Small bubbles can be broken easily due to impact from the weight of the honey jar. Once broken, the bubble wrap can no longer provide protection.

This project gave packaging students at Christian Brothers University an opportunity to explore various aspects of packaging. Several recommendations as discussed in this article were given to Thistle & Bee. These solutions are practical and friendly to the environment. This is an excellent service-learning project that also helps a non-profit organization. The partnership with Thistle & Bee is on-going. As their social enterprise grows, more packaging needs will pose new challenges.

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