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Aim and Scope

The *Journal of Applied Packaging Research* is an international forum for the dissemination of research papers, review articles, tutorials and news about innovative or emerging technologies for the packaging industry. The journal is targeted towards the broad packaging community including packaging scientists and engineers in industry or academic research and development, food scientists and technologists, materials scientists, mechanical engineers, industrial and systems engineers, toxicologists, analytical chemists, environmental scientists, regulatory officers, and other professionals who are concerned with advances in the development and applications of packaging.

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RESEARCH

Packaging Requirements for Less-Than-Truckload Shipments to Reduce Damage—Paint, Televisions, and Copiers

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ABSTRACT: This paper provides results from a comprehensive damage assessment study that analyzed the various challenges products endure during shipping and handling in the less-than-truckload logistics environment. The study shows the various package forms, handling and loading challenges that carriers experience when shipping a multitude of mixed products as part of daily shipments, and recommendations to reduce or avoid damage and avoid personal injury. Results of a comprehensive survey present the major findings from this unique distribution environment. This paper presents findings for paint drums, flat screen televisions, and copiers and is part of series of three papers. A second paper in this series will cover packaging challenges with furniture, doors and windows, machinery and appliances. A set of new recommendations on both packaging and loading methods is presented with each product type to safely load and transport less-than-truckload shipments, and to reduce damage claims without compromising safety.

1.0 INTRODUCTION

EVERY day thousands of tons of commodities are transported around the country via motor carriers. A large majority of this freight is moved through the less-than-truckload (LTL) distribution environment, which has very unique characteristics that are inherent to how the system functions. Freight moving via LTL motor carrier is handled frequently, with multiple loading and unloading points during transit. During distribution, freight may be mixed with a wide variety of commodities, which

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impacts how and where in the trailer it is loaded. Packaging plays a significant role, not only in protecting the freight, but also making it easier to handle and stow with other freight. Carriers are faced daily with the challenge of optimizing the available space in the trailer with the largest number of shipping units that can be shipped without causing damage and compromising safety. This is sometimes a difficult task if the carrier does not truly comprehend the protective capabilities and the integrity of the package that has been placed in shipment with other packages from other customers, all moving in the same truck. One leaking pail, or broken glass products, can compromise several other packages in their vicinity, and so damage is often progressive in LTL shipments.

Previous studies conducted with collaboration with Michigan State University School of Packaging have shown that LTL shipments will be susceptible to damage due to a lack of proper packaging and improper loading methods [1,2]. Vibration levels measured in LTL shipments have also shown that these levels are significantly higher than those in other types of truck shipments [3,4]. Results from recent studies have shown that vibration levels measured in LTL trailers and pup-trailers are higher than those recommended truck shipments [5,6] and in industry

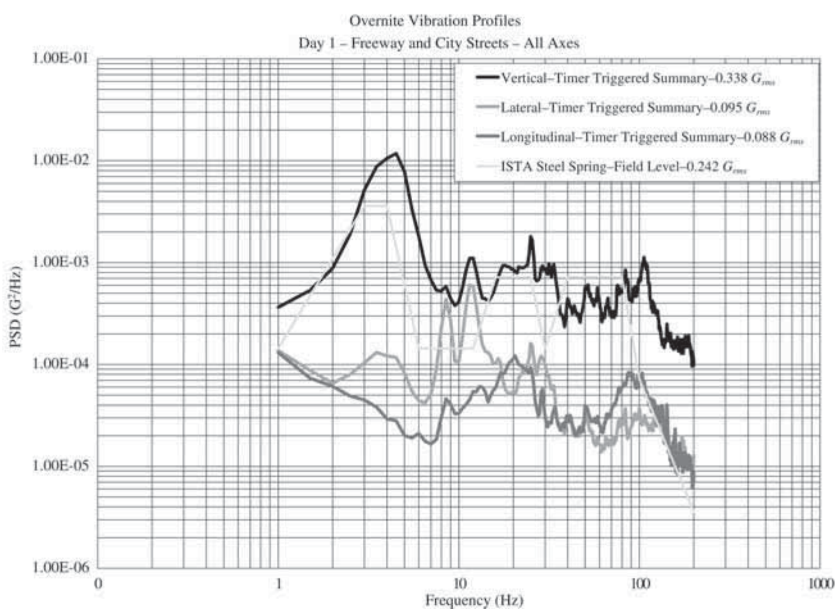

Figure 1. *Vibration levels in LTL shipments compared to truck load test methods [7].*

standards [7]. As a result the International Safe Transit Association (ISTA) developed a new test method that used the new vibration data to better represent this unique shipping and handling environment [8]. This test method "Project 3B: Packaged-Products for Less-Than-Truckload (LTL) Shipment" is a general simulation test for packaged-products shipped through a motor carrier (truck) delivery system, where different types of packaged-products, often from different shippers and intended for different ultimate destinations, are mixed in the same load. Project 3B is appropriate for four different types of packages commonly distributed in LTL shipments: Standard 200 lb (91 kg) or less, Standard over 200 lb (kg), Cylindrical, and Palletized or Skidded8. Requirements may include atmospheric conditioning, tip-over, shock and impact, random vibration with top load, concentrated impacts, and fork lift handling.

Packaging requirements, for freight transported via LTL, are defined in the *National Motor Freight Classification* (*NMFC*). Each commodity description in the *NMFC* specifies minimum packaging requirements to ensure the products can be handled and protected in the motor carrier environment. The descriptions may be as simple as "in boxes," "in drums," "in boxes, crates, or on a lift truck skid or pallet". The *NMFC* does not stipulate what interior packaging is required, since that is dependent on too many factors that are inherent with a particular product. It is the shipper's responsibility to develop interior packaging that will protect and contain the product during handling and distribution.

However, despite the *NMFC*'s minimum packaging requirements, there are a variety of commodities that are inherently difficult to handle or stow, susceptible to damage, highly fragile, or problematical to develop packaging that is appropriate to adequately protect it from the rigors of this distribution environment. The goal when setting the minimum packaging requirements for commodities is to provide proper containment. When freight is damaged, a damage claim is often filed against the carrier by the shipper or consignee of the freight. The shipper or consignee generally determines the value of the damaged freight and will request the carrier to reimburse all or a portion of the monetary value of the freight. Obviously, the payment of damage claims to shippers can become very expensive for many carriers.

In trying to understand how packaging and different loading methods can affect damage claims, six LTL motor carriers were surveyed and asked the questions mentioned in the next section regarding their company's history. Overall, the survey has proven that there are some commodities that are generally more susceptible to damage and have more liability factors than other commodities. Packaging can play a very important role in not only preventing damage to the products, but also facilitate in the safe handling and stowing of the products for carriers. This study contains pictures from "actual" LTL shipments that depict the type of freight and packaging that is commonly seen in the LTL environment for paint, copiers and televisions.

2.0 MOTOR CARRIER SURVEY AND RESULTS

Six LTL motor carriers were surveyed and asked the following questions regarding their company's history and practices. The responses received from these six carriers varied, mainly due to the size and coverage area of the company. For confidentiality purposes, the companies are only identified as A, B, C, D, E, or F.

1. What are the top three commodities or commodity groups (as described in the NMFC) with the most claims?
2. Approximately what percentage of all claims does each of the commodities or commodity groups named in number 1 represent?
3. Approximately how much money does your company spend each year in claims?
4. What is your company's claims ratio?
5. What percentage of claims does your company pay and deny?
6. How often does insufficient packaging account for the denial of a claim?
7. What is the most common reason for damage claims rejections?

The six carriers were very forthcoming with proprietary information regarding the information requested. These six carriers spend approximately \$50 million combined each year in claims that range from \$33,000 to \$31 million. Three companies' claims-ratio ranged from 0.76% to 1.30%, with an average of 1.02%. Claims-ratio is calculated by dividing the dollars paid in claims by total overall revenue generated for all shipments. On average, these six carriers pay 65% of the claims filed, while denying only 35%. For one company over 80% percent of all claims were related to furniture alone.

Based on this survey, furniture was found to be the most frequently damaged commodity group, as four out of the six carriers named this as their top issue and concern. Furniture, as a whole, can be very fragile, large, and can be awkward in size and shape. The *NMFC* provides for specification-based packages for most furniture types, as well as Item (Rule) 181, which is a test procedure that simulates the LTL environment and was designed specifically for furniture and furniture parts. However, shippers often do not utilize these standards and use a minimal amount of packaging which may not help protect the products from scratches, dents, and scuffs. Company C reported that furniture represents 81% of all their damage claims, while Companies D and F indicated that furniture was responsible for about 11 percent of their damage claims. Of Company C's 81% of all claims, 60% of the claims were denied due to insufficient packaging. Additionally, many types of furniture can be expensive and have a high value per pound.

Electronics, electrical equipment and supplies, and machinery were also identified by the carriers as commodities with the most claims. Not unlike furniture, some of the products can also be quite fragile. However, the fragility is often determined by a particular component within the product. These products may also be very large, which would hinder the manufacturer from developing packaging that can sufficiently protect the entire unit.

Companies C and F indicated that certain types of paper goods are also liable to damage due to a lack of packaging. Company C denies 100% of damage claims on these goods based on insufficient packaging. While paper goods are dense freight with few negative handling and stowing issues, when they are not packaged properly the product can be subjected to damage from handling and the external environment. Company A reported 20% and Company E reported 29% denial of claims due to insufficient packaging. In the case of Company A, this is the most common reason for claim denial. Of the 84% of Company E's claims are filed for damage, while 16% is for loss of product.

Overall, this survey has proven that there are some commodities that are generally more susceptible to damage and have more liability factors than other commodities. The packaging can play a very important role in not only preventing damage to the products, but also facilitate in the safe handling and stowing of the products for carriers. Unfortunately, as depicted by the pictures that follow, manufacturers are not always packaging their commodities in a way that is appropriate for the LTL environment. In many instances, the pictures prove why the numbers presented by the carriers in the survey are accurate and representative of the issues carriers face on a daily basis.

3.0 DAMAGE ISSUES AND PREVENTIVE METHODS WITH SHIPMENTS OF PAINT

Paint and paint products are some of the most hazardous products to package and distribute. Many of these products are regulated by government agencies, and the packaging is no exception. The United State Department of Transportation (DOT) has many specifications and regulations for the appropriate packaging, care, and handling of paint products—particularly those that are considered hazardous—within the United States. According to research, paint was reported to have over 62,000 claims filed against motor carriers, totaling $3.6 million, in a one year time period. The number of incidents with paint is significant not only due to the loss of product, but the potential damage caused by the paint to other freight and the carriers' equipment.

Most frequently, paint and chemicals are shipped in bulk in steel drums with or without removable heads or covers, or in pails. Smaller quantities of paint may be shipped in containers within fiberboard boxes. Figures 2(a)–(d) show how paint and chemicals are often tendered in drums on pallets. While pallets do help to facilitate handling with mechanical equipment, if the drums are not securely attached to the pallets, the drums may slide or fall off, resulting in spills, such as in Figure 2(c). Additionally, a single drum does not provide a sufficient load-bearing surface on which to load additional freight.

When tendered in pails and wrapped securely to pallets, like in Figures 2(e)–(g), not only is the load unitized to facilitate handling, but it also provides a flat load-bearing surface for other freight to be easily loaded adjacent to (assuming compatible freight is available based on DOT regulations). However, there are times when not all of the products are in bulk in drums or pails and the manufacturer will develop a mixed load, like those seen in Figures 2(h) and 2(i). While mixed shipments may be ideal for manufacturers to save on shipping costs, when boxes and pails are loaded on a pallet, if the freight is not stacked or secured to the pallet properly, the load may shift during transit resulting in damage or loss of product.

In order to improve upon the packaging of paint, a manufacturer could simply ensure that the freight is securely attached to an appropriate-sized pallet to prevent sliding and tipping during handling and transit. Additionally, segregating the boxed freight from the drums and pails may permit better stacking and provide for load-bearing surfaces for freight to be loaded on top.

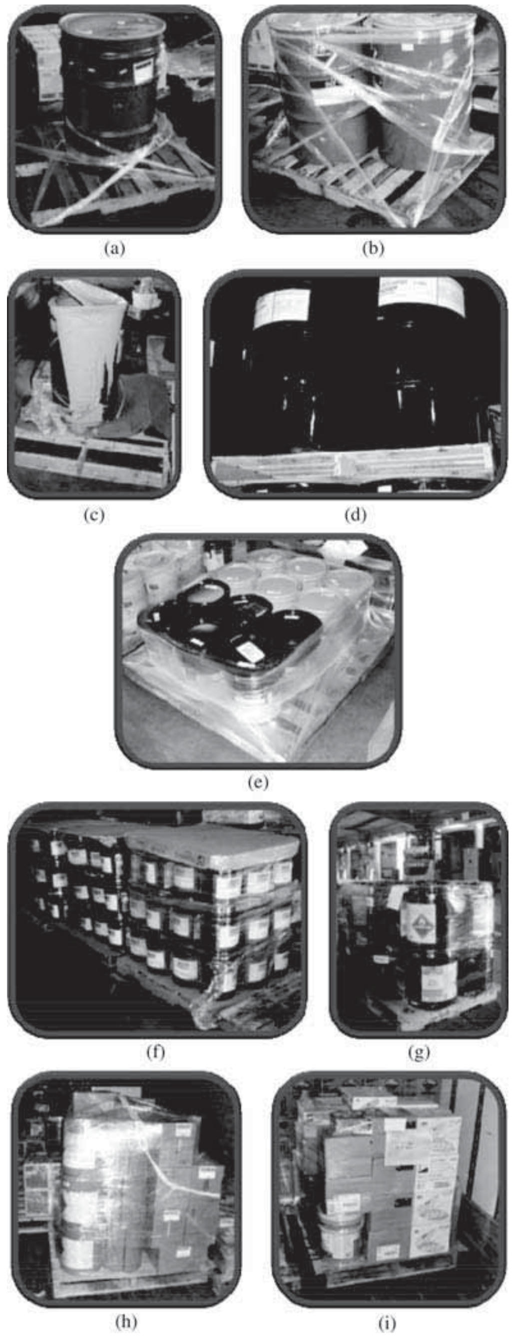

Figure 2. *Shipments of paint.*

4.0 DAMAGE ISSUES AND PREVENTIVE METHODS FOR SHIPMENTS OF COPIERS

Copiers have always been a commodity that is highly susceptible to damage due to its inherent fragility from the many components such as trays and feeders. Three carriers surveyed have indicated that copiers are a major claims issue, which relates to the packaging. The damage appears to be a result of stacking during transit and little or no packaging to support top loading, other than the box and product itself. In particular, when the machine has a document feeder incorporated into the design, no additional packaging to support this fragile component is provided. One carrier indicated that their claims ratio for these products was four times that of the company's overall claims ratio.

The packaging used by manufacturers varies and is most likely a result of how much money they are willing to invest in their packaging. Figures 3(a) and 3(b) show copiers that were tendered in fiberboard boxes; however, we do not know the level of interior packaging forms that was used by the manufacturer. Presumably, the copier is firmly packaged

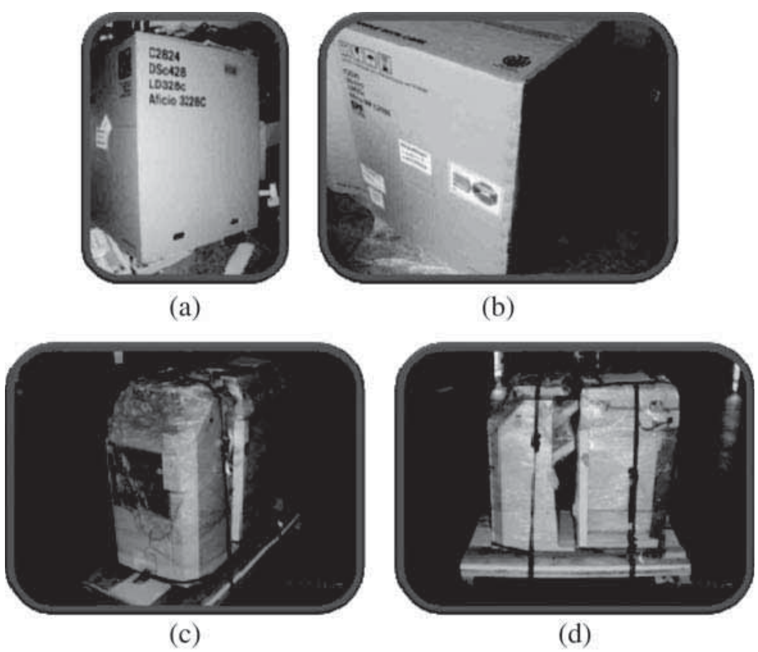

Figure 3. *Shipments of copiers.*

within the box using foam or corrugated forms that will absorb the vibrations and impacts the box will endure during transit. Regardless, the strength of the fiberboard boxes will be more likely to protect the copiers from damage than the plastic wrap, as seen in Figures 3(c) and 3(d). While the boxes will help protect the fragile components of the copiers, these copiers were not tendered on pallets, which can make it difficult for a carrier to safely handle with mechanical equipment.

The copier shown in Figures 3(c) and 3(d) was tendered strapped to a platform; however, it only contained minimal packaging. Foam and fiberboard forms protect the edges and then the entire unit is wrapped in plastic wrap. There is no firm packaging protecting the sides, top, or main components of the machine. It appears that the manufacturer may have put a thin foam pad under the copier, possibly to absorb some of the vibration, however, with the entire unit exposed any number of incidents could damage part of the machine.

5.0 DAMAGE ISSUES AND PREVENTIVE METHODS FOR SHIPMENTS OF TELEVISIONS

The technology and quality of televisions has greatly increased over the last ten years. TVs used to be very large and heavy, however, today's flat screen TVs are much thinner, lighter, and made of more fragile components. Three major manufacturers of plasma televisions reported their claims ratios exceeded 40 percent at one time when they were first produced and released to the public. However, their claims ratios today range between five and ten percent. These numbers, while improved, are still very high when compared to the overall claims ratios reported by carriers of approximately one percent or less.

Almost all televisions are shipped in fiberboard boxes with foam cushions on the edges, corners, and screens to protect against shifting, impacts, and vibration. Depending on the screen size, TVs are often shipped either secured to pallets, as in Figure 4(a), or only in the box, as in Figure 4(b). When tendered not on pallets, televisions may be more difficult for a carrier to handle with mechanical equipment since there is no space between the box and the floor for the forks to go. Therefore, utilizing a pallet makes it much easier for carriers to handle and stow the TVs safely.

Smaller TVs are also shipped in fiberboard boxes with interior packaging forms and tend to be easier to stack and unitize on pallets, as show

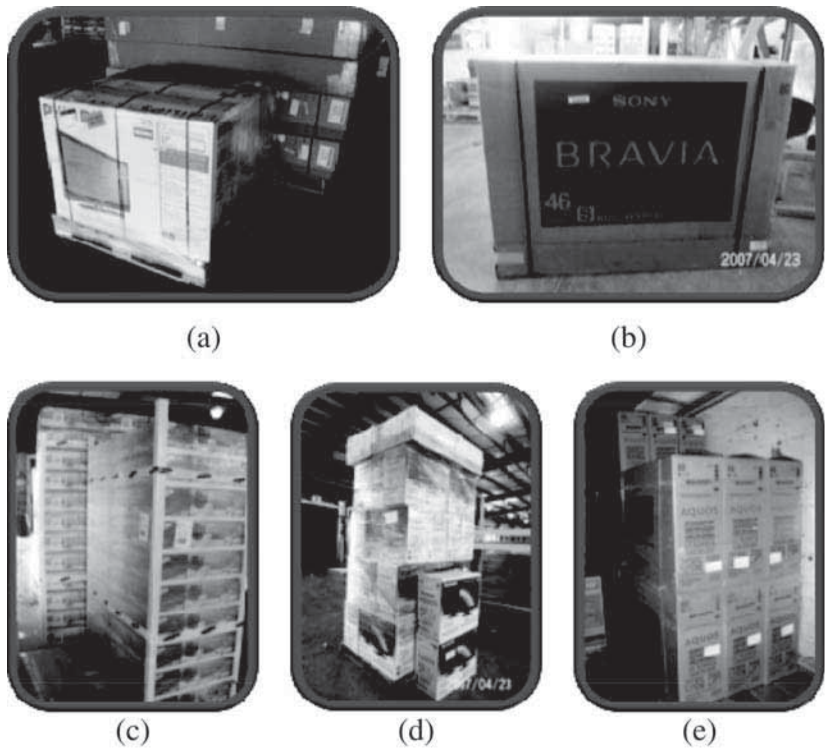

Figure 4. *Shipments of televisions.*

in Figures 4(c) and 4(d). However, as can be seen in Figure 4(d), one manufacturer attempted to unitize their boxes of TVs with some plastic wrap, but did not fully encase the boxes to prevent shifting and did not attach it to a pallet. This type of packaging configuration would make it very difficult for a carrier to handle safely, as the “unit” will most likely shift.

When the units are stacked very high, like in Figures 4(c) and 4(d), the manufacturer must ensure that they use plastic wrap and/or banding that is of sufficient strength to keep the entire load securely unitized throughout the distribution life. However, when looking closely at Figure 4(d), the blue plastic wrap only secures the boxes together, but there is nothing to attach them to the pallet and, therefore, the unit can shift or collapse under the right circumstances.

Since TVs are an expensive and desired commodity, some manufacturers wrap their units in black opaque plastic wrap in order to prevent people from knowing exactly what is in the shipment. However, using the black plastic wrap can sometimes draw more attention to the shipment than when shipped in boxes, such as those in Figures 4(a) through 4(e).

6.0 CONCLUSIONS

The study concludes the following:

- Packaging and loading methods are critical in reducing damage and injury during transportation and handling of LTL shipments.
- LTL shipments must be properly blocked and braced with other packages or using load securement methods such as straps, retaining bars, air-bags, or dunnage.
- Loads will shift in LTL shipments if void spaces exist in filled trailers.
- LTL shipments produce significantly high level of vibration during transport as compared to fully loaded trailers, and as such must be tested to higher levels of pre-shipment testing.

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Measurement and Analysis of Vehicle Vibration for Parcel Delivery Vehicles in Single Parcel Shipments

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ABSTRACT: The hub and spoke system is commonly used throughout the United States by major single parcel carriers. While in most cases the hub represents the centralized sorting facility where all parcels are brought in to be re-routed to their respective destinations, the spokes represent various equipment used to move parcels to and from hubs. A parcel or package therefore is subjected to a range of vibration levels that vary in frequency and acceleration while moving between these facilities. One important component of this shipping environment is the vibration that occurs to parcels when they are picked up in a van/small truck from a shipper to the local sorting facility and the vibration in the delivery vehicle used to deliver them to the ultimate consignee. This study measured and analyzed vibration levels incurred by FedEx during daily pickup and delivery routes in California. Using data recorders, vertical, lateral, and longitudinal vibrations were monitored over 50 hours of travel time in three different types of delivery vehicles. The study presents this data as Power Density Spectrums and compares it to previously measured vibration levels in commercial long-haul inter-state tractor-trailer truck shipments.

1.0 INTRODUCTION

ONE of the factors that determine product damage during shipping is the type and amount of vibration experienced. In order to efficiently protect a product, the levels of these vibrations must be known so that the product-package system can be accurately tested. The type of vibration varies depending on how the product is shipped because trucks, rail cars, and airplanes all produce different types of vibration. Additionally, the specifications of each vehicle will affect the vibrations. Past

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studies have shown that air- ride truck vibration levels are significantly lower than leaf spring truck vibration levels [1].

A large portion of retail and consumer goods are distributed in the United States through various methods of truck transportation [1]. Insufficient packaging protection will be evident in a product that receives damage during shipping [2]. Previous studies have been done to measure and quantify shipping conditions [3,4]. This has lead to an increased focus on designing cushioned packages that will enable products to overcome the severity of the shipping environment. The data acquired from these studies offer engineers the ability to create optimum product-package systems that reduce the amount of damage to products.

Previous studies have compared the shipping conditions for major carriers, such as DHL, FedEx, and United Parcel Service. These studies primarily monitored drops and impacts that packages are exposed to during handling, and have shown both similarities and differences based on the operating conditions of the carrier [5].

The purpose of this study is to expand on the available data from previous studies by comparing the vibration conditions found at local distribution channels using pickup and delivery vehicles. The study was conducted in a California distribution center operated by FedEx.

2.0 INSTRUMENTATION AND TEST VEHICLES

This study used SAVER 3X90 electronic data recorders manufactured by Lansmont Corporation (Monterey, CA, USA). These recorders use tri-axial accelerometers to measure the vibration levels for vertical, lateral and longitudinal movements. The data recorders were attached to rigid metal plates that were firmly attached to the vehicle, in the rear

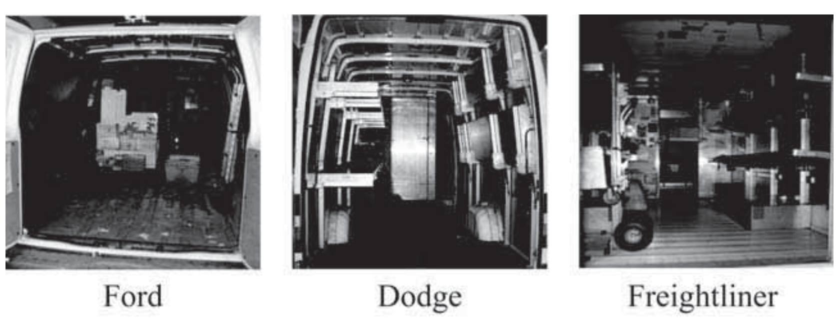

Figure 1. *Cargo holds of the pickup and delivery vehicles studied.*

Ford Dodge Freightliner

Figure 2. *Instrument mounting inside the pickup and delivery vehicles.*

cargo section. Figure 1 shows the cargo holds where packages are placed during shipping, and Figure 2 shows the data recorders mounted in the vehicles.

The specifications of the three vehicles monitored are shown in Table 1:

The recording parameters of the SAVER 3X90 :

- Timer-triggered interval: 5 minutes
- Timer event size: 2 sec
- Signal-triggered threshold level: 0.5 G
- Signal event size: 2 sec
- Pre trigger data: 50%
- Post trigger: 50%

Vibration levels were recorded both based on a fixed time interval and all those that exceeded the trigger threshold level. The measurements were done over a five day period, exceeding 50 hours of monitoring in three different vehicles described earlier.

The average distance driven per day for the Freightliner vehicle was 40 miles, mostly on well-maintained city roads with very limited highway travel. The Dodge van traveled an average distance of 124 miles and

Table 1. *Vehicle Specifications.*

Chassis Model Year	2007	2005	2006
Chassis Mfr.	Ford	Dodge	Freightliner
Vehicle Type	Van 1	Van 2	Light Truck
Chassis Model	E-250	VA2L16	MT-45 FD
Suspension Type	Leaf spring	Leaf spring	Leaf spring
Gross Vehicle Weight	8600	8550	16000
Equipment Type	Panel Van	Walk In	Walk In

followed a route that featured both highways and inner-city roads. Finally, the Ford van traveled an average distance of 130 miles on a route that included highways, inner city roads and unpaved roads. Each data recorder was turned on in the morning before each truck left for the day and was subsequently turned off once the trucks finished their daily routes.

3.0 RESULTS AND DISCUSSION

Both the American Society for Testing and Materials (ASTM), and the International Safe Transit Association (ISTA) have created standards for simulating ground transportation [6,7]. These standards use Power Density Spectrums that are developed as a composite profile based on summarizing various types of truck and rail shipping environments. The measured vibration results for this study were analyzed and reported in the form of power spectral density (PSD) spectra. The PSD plots represent the intensity of vibration that occurs inside the cargo hold of the vehicle where packages are placed for shipment.

Three Power Density Spectrums (Figures 3–5) were created to show the power density levels versus frequency for the three types of vehicles in the longitudinal, lateral and vertical axes. Table 2 represents the maximum G_{rms} for the various spectrums shown in these figures for each type

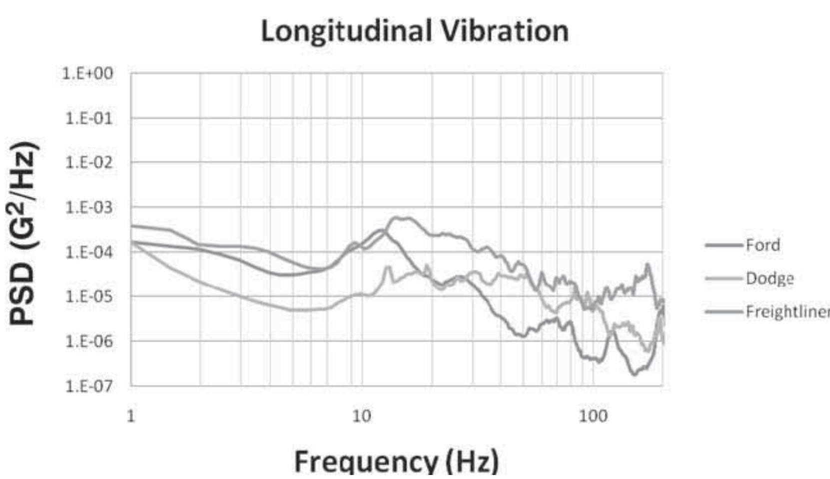

Figure 3. Power spectrum density plot for longitudinal vibration levels in San Luis Obispo County.

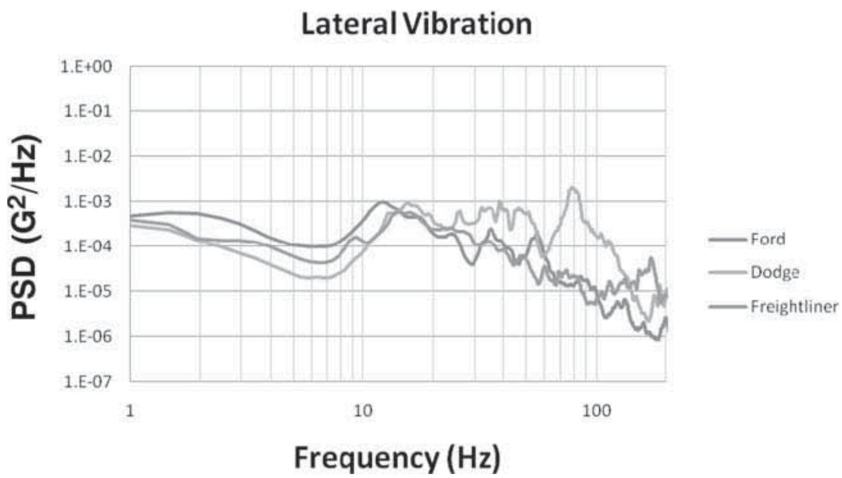

Figure 4. *Power spectrum density plot for latteral vibration levels in San Luis Obispo County.*

of trailer and orientation. It is important to consider both the G_{rms} level and "shape" of a given spectrum to estimate how a product/package with a known natural frequency will respond in a vibration test. Two different spectrums with the same G_{rms}, but different "shapes" and different peak intensities at different frequencies will excite products differently.

Based on the levels of these spectrums it is clear that the Freightliner

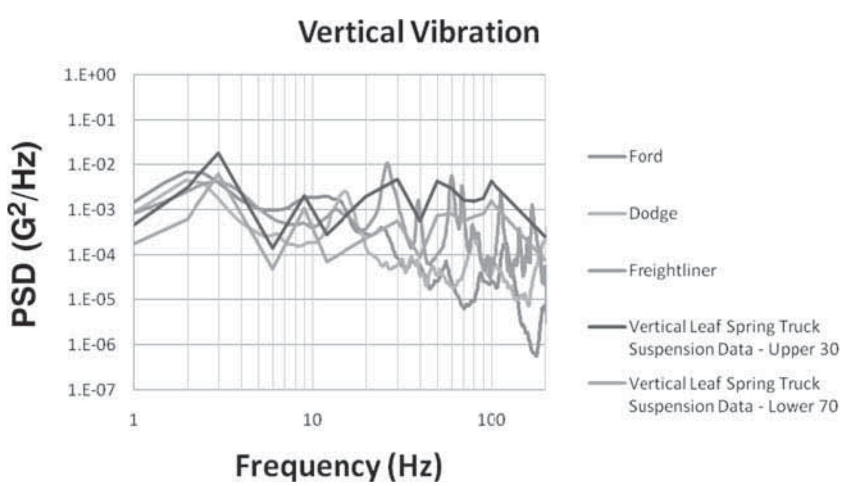

Figure 5. *Power spectrum density plot for vertical vibration levels in San Luis Obispo County.*

Table 2. *Overall* G_{rms} *Values for Parcel Delivery Vehicles in San Luis Obispo County.*

	Maximum Level (G_{rms}) for the Most Severe Event		
	Ford	**Dodge**	**Freightliner**
Longitudinal (x-axis)	0.402	0.52	0.553
Lateral (y-axis)	0.747	2.168	0.953
Vertical (z-axis)	2.514	1.838	3.403

vehicle, which is a small truck, produces significantly higher vertical vibration as compared to the two types of vans. The vertical vibration levels in the two vans are similar. The lateral and longitudinal levels in all types of delivery vehicles is much lower than the vertical, and because of the extreme low G_{rms} levels, they are not likely to produce damage.

Figures 6 and 7 were created to show the vertical vibration levels in a van or small truck, compared to previously measured vertical vibration levels in leaf spring suspension truck-trailers used for inter-state highway transportation. These inter-state trailers are usually 48 to 53 feet long and widely represent the majority of US trucking fleet [1]. The data in Figures 6 and 7 shows the average power density spectrums (representing the entire data), the spectrum representing the top 20% most severe events recorded, and the spectrum representing 80% of the remain-

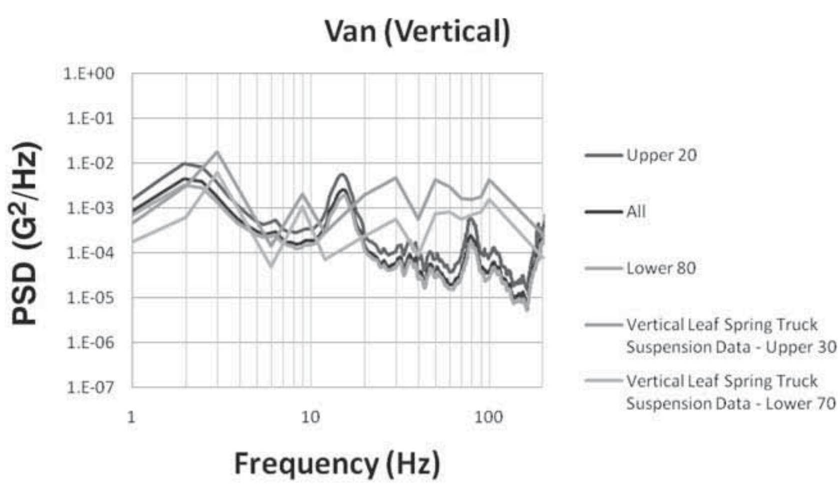

Figure 6. *Power spectrum density plot for vertical vibration in delivery van in San Luis Obispo County.*

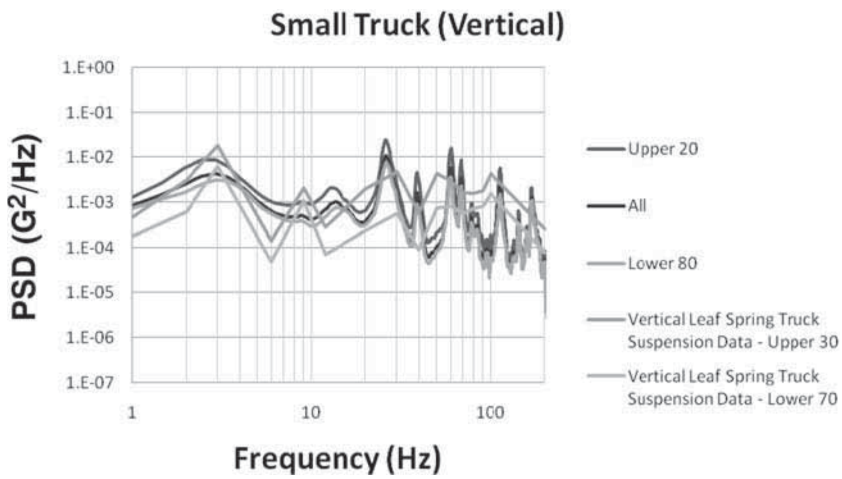

Figure 7. *Power spectrum density plot for vertical vibration in delivery small truck in San Luis Obispo County.*

ing data. In recent trends, the industry has started to use the 80% and 20% spectrums to conduct testing as opposed to the average spectrum [1].

Table 3 displays the highest analyzed Power Density Spectrum G_{rms} values, for each vehicle based on the three axes. This data represents the single most sever event.

4.0 CONCLUSIONS

The study concludes the following:

- The vibration levels are significantly higher in the vertical axis as compared to lateral and longitudinal for both small trucks and vans.

Table 3. *Upper* G_{rms} *Values for Parcel Delivery Vehicles in San Luis Obispo County.*

	Overall G_{rms} Values		
Carriers	**Ford**	**Dodge**	**Freightliner**
Longitudinal (x-axis)	0.054	0.053	0.066
Lateral (y-axis)	0.121	0.252	0.120
Vertical (z-axis)	0.207	0.231	0.377

- The vertical vibration levels in small trucks are significantly higher than vans used for package delivery.
- The suspension frequency and highest low frequency Power Density level in a van occurs at 2 Hz. and for both the small truck and large tractor trailers with leaf spring suspensions is at 3 Hz.
- For suspension response, the vertical vibration response (1–10 Hz) is higher in inter-state tractor-trailer truck shipments. However for structural and higher frequency responses (10–20 Hz) the levels in both the van and small truck are more severe.

5.0 ACKNOWLEDGEMENTS

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Measurement, Analysis and Comparison of Drops Experienced by Packages in Inter-State and Intra-State Next Day Shipments in United States

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ABSTRACT: Several past studies have been conducted for the purpose of measuring and analyzing the dynamics of single package shipping environment for the next day delivery services provided by companies including DHL, FedEx, UPS and USPS. Over the past few decades increased shipping hazard evaluations using data recorders has influenced protective package designs to offer optimized product protection due to a better understanding of the distribution environment. This study analyzes the drops sustained by packages during next day shipments within California (intra-state) using two different carriers—FedEx and OnTrac and within United States for shipments to two different regions in east and west (inter-state). This study established that the intra-state drop heights experienced by the packages exceeded the current levels recommended for inter-state distribution by international standards like ISO, ISTA and ASTM.

1.0 INTRODUCTION

THE US small parcel delivery industry typically transports packages small enough to be handled by one individual without the need for special equipment The landscape for this industry has changed significantly over the past decade. With parcel delivery companies branching out from their niche business models into adjacent services, such as UPS into the express air shipment and FedEx into ground deliveries, the competition between such companies has escalated over the past decade. In May of 2008 DHL Express announced the restructuring plans for its US network, which also included terminating its business relationship with

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ABX Air and entering into a contract with competitor UPS for air freight operations. [1].

FedEx and UPS are the leading small parcel corporations in the US with annual revenues in 2008 of $37.95 and $51.48 billion respectively [2]. The four largest networked couriers with national and international delivery capabilities include United Parcel Service (UPS), Federal Express (FedEx), Dynamex and the US Postal Service. These four organizations which provide air, surface or combined delivery services of parcels, accounted for approximately 90% of the segment's revenues last year [3].

Small parcels within the US are shipped between different states (inter-state) or within the same state (intra-state) using various means of transportation. Typical collection, pick up and delivery operations that packages experience during the express shipments expose them to physical and climatic hazards such as shocks, vibration, compression, humidity, etc. Over the past two decades there has been a continuous increase in measurement studies related to the dynamic events that occur to packages in different transportation methods. This data offers very useful information to design and test packages to potential hazards like drops and impacts.

There has been a common belief that the number of drops per package and their severity is a function of distance between origin and destination. This study compared next day shipments between three different regions in the United States (Michigan, California and New York) and two different destinations within California (Redding and Carlsbad). This study compared drops experienced by packages during overnight shipments for the next day delivery service offered by FedEx for inter-state (Michigan, California and New York) and by FedEx and OnTrac for intra-state (California) shipping environments. FedEx provides next day services which include First Overnight, Priority Overnight and Standard Overnight with associated delivery times of 8:30 A.M., 10:30 A.M. and 4:30 P.M. respectively. OnTrac, a subdivision of Arizona's Express Messenger Service, Inc. (EMS) also offers several levels of next day services including Super Sunrise Gold, Sunrise Gold and Sunrise service that promise delivery at 7:00 A.M., 8:30 A.M. and 10:30 A.M. respectively.

During inter-state next day shipments, packages are commonly moved using trucks and aircraft, while they are more commonly moved in an intra-state environment by trucks and occasionally by aircrafts. In order to move products successfully it is necessary to identify the causes for damaged products. There have been several past studies conducted to quantify the impact and drop levels that packages experience in single parcel shipments of different carriers [4–14]. These studies have measured the drops observed by various categories of packages such as small, mid-sized and large during small parcel distribution. Drops are a major cause of damaged products, and they typically occur when the package is manually handled during loading and unloading.

Due to the unpredictability in distribution center environments and delivery locations, packages must be designed to withstand the force experienced during drops from a range of heights. Prototyped product-package systems can be exposed to a replication of the real environment in a lab setting for the purpose of validating its resistance to expected hazards. Designing optimum packaging to meet the severity of the environment yields cost-effective and efficient protective packaging for the product. These tests are created from laboratory experiments as well as studies such as this one that conduct field measurement using data recorders.

There have been no studies conducted to compare the drops experienced by packages in the next day small parcel shipping environment for the inter-state and intra-state distribution. Due to a lack of data from past studies, this research focused on measuring and analyzing these environments with the following objectives:

1. To characterize the dynamics of the inter-state next day shipping drop environment for small and light weight packages shipped by FedEx within the United States
2. To characterize the dynamics of the intra-state next day shipping drop environment for small and light weight packages shipped by FedEx and OnTrac within California
3. To compare inter-state versus intra-state next day shipping drop environments
4. To provide recommended test levels for drop testing packages for express inter-state and intra-state single parcel shipping environment for small and light weight packages.

2.0 TEST PACKAGES AND INSTRUMENTATION

This study used electronic data recorders manufactured by Lansmont

Corporation (Monterey, CA, USA) to capture the shocks experienced by packages during drops. These data recorders have built in tri-axial accelerometers to measure the vibration levels for vertical, lateral, and longitudinal shocks. The data recorder used was model SAVER 3X90 as shown in Figure 1. The parameters for recording were as follows:

- Drop height range: < 122.8 cm
- Record time: 1.4 seconds
- Trigger level: 2 g
- Pre filter: 93%
- Filter frequency: 500 Hz

The data recorder was shipped in a regular slotted container (RSC) made from C-flute corrugated fiberboard. The test package measured 20.32 cm × 17.78 cm × 15.24 cm, and is shown in figure 2. Each of the data recorders were encased with 5.08 cm thick high-density polyethylene foam on all six sides, which secured the recorders in the geometric center of the test packages. The test packages were sealed with 5 cm wide pressure sensitive tape. The test packages, including the data recorders, weighed approximately 0.8 kg.

For the inter-state shipments four instrumented packages were shipped between East Lansing, MI to San Luis Obispo, CA and Rochester, NY each. These round trip shipments resulted in 16 one-way trips for next day shipments. Similarly, for intra-state shipments, test packages were shipped round trip from San Luis Obispo, CA to Redding, CA and from San Luis Obispo CA to Carlsbad, CA. The distance between East Lansing, MI and San Luis Obispo, CA is 3,868 km and distance between East Lansing, MI and Rochester, NY is 626 km. Similarly, the distance

Figure 1. *SAVER 3X90.*

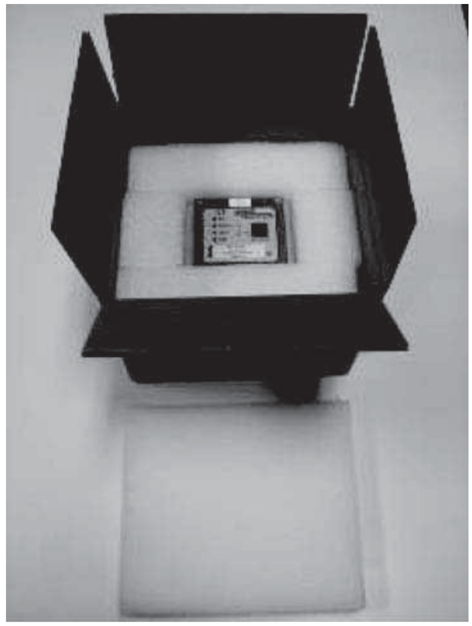

Figure 2. *Instrumented test package.*

between San Luis Obispo, CA to Redding, CA is approximately 692 km and the distance between San Luis Obispo CA to Carlsbad, CA is approximately 443 km.

The actual shipping distances varied from these point-to-point distances due to the hub-and-spoke models employed by both couriers. The carriers use the hub-and-spoke system to route packages to one major hub every night that is located geographically in the center, where packages are sorted and then shipped on to the final destinations. Ideally packages shipped to major cities like Los Angeles, Chicago, Atlanta, New York, etc., may go through a sort at the major hub at night and delivered the next morning. However for destinations such as San Luis Obispo, CA, the packages may get additional handling after reaching Los Angeles, and either sent on to San Luis Obispo in a smaller aircraft also known as the "feeder" or trucked. This results in additional handling of the packages due to a secondary sort and delivery.

Figure 3 presents the inter-state FedEx Priority Overnight shipments with routing through the local and major hubs, Indianapolis and Memphis respectively and Figures 4 and 5 represent the round trip OnTrac Sunrise shipping routes to each destination for the intra-state shipments.

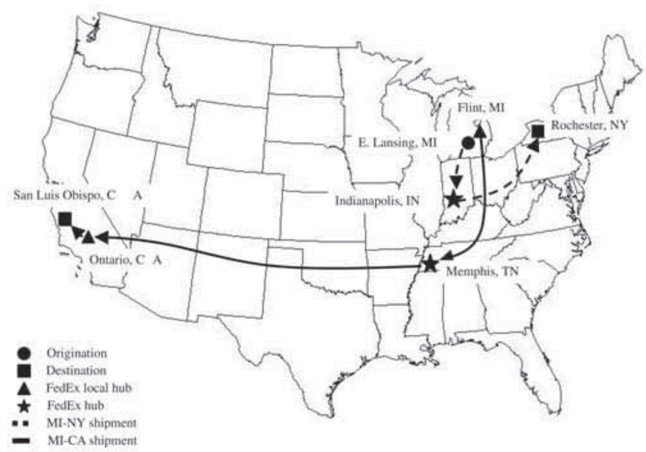

Figure 3. *FedEx Priority Overnight Inter-State Shipment Routes from Michigan to California and New York.*

Figure 4. *FedEx Priority Overnight Intra-State Routes from San Luis Obispo to Redding and Carlsbad.*

Figure 5. *OnTrac Sunrise Routes Intra-State Routes from San Luis Obispo to Redding and Carlsbad.*

3.0 RESULTS AND DISCUSSION

Based on the data collected, drop height and frequency of occurrence were tabulated for the two types of shipments (inter-state and intra-state). Tables 1 and 2 show the top ten severe drops in the order of severity, for the inter-state and intra-state shipments. Figures 6 and 7 show the cumulative percent of occurrence versus drop height for inter-state and intra-state shipments. During the data analysis, drop heights below 76 mm (3 inches) were not considered in the final analysis, since they typically produce very little damage on single parcels, as observed in previous studies [5, 6, and 7].

Tables 1 and 2 summarize the ten highest drop heights observed for both distribution environments. The highest drop height measured in this study was 2.58 m. This happened within the intra-state shipments (OnTrac Sunrise) between San Luis Obispo and Redding. This drop was approximately 30% higher than other drops measured in this study.

Table 1. *Drop Height Levels for Shipments: Inter-State.*

	FedEx Standard Overnight	
Drop Height (m)	**East Lansing/San Luis Obispo**	**East Lansing/Rochester**
Highest	1.63	2.11
2nd Highest	1.45	1.70
3rd Highest	1.43	1.50
4th Highest	1.36	1.22
5th Highest	1.33	1.15
6th Highest	1.32	1.06
7th Highest	1.09	1.01
8th Highest	1.06	0.86
9th Highest	1.05	0.85
10th Highest	0.99	0.77
Average	1.30	0.127

It was also observed that shipping distance can not be directly correlated to the severity of the handling i.e. number of drops and drop heights. When comparing the drops observed during the inter-state shipments, the highest drop height of 2.11 m was observed for the shorter shipments between Michigan and New York as compared to 1.63 m for the shipments between Michigan and California. The overall average of the ten highest drop heights observed for the shipments to the two destinations were similar. While the highest drop observed for the OnTrac shipments from San Luis Obispo to Redding was approximately 37% higher as compared to the FedEx shipments, the same for shipments to

Table 2. *Drop Height Levels for Shipments: Intra-State.*

	FedEx		OnTrac	
Drop Height (m)	**Redding**	**Carlsbad**	**Redding**	**Carlsbad**
Highest	1.61	1.75	2.58	0.94
2nd Highest	1.45	0.92	1.74	0.82
3rd Highest	0.97	0.62	1.46	0.60
4th Highest	0.93	0.51	1.23	0.38
5th Highest	0.79	0.49	1.12	0.33
6th Highest	0.76	0.40	1.06	0.23
7th Highest	0.75	0.37	0.51	0.17
8th Highest	0.63	0.34	0.51	0.14
9th Highest	0.63	0.32	0.38	0.13
10th Highest	0.58	0.26	0.23	0.13
Average	0.91	0.59	1.08	1.30

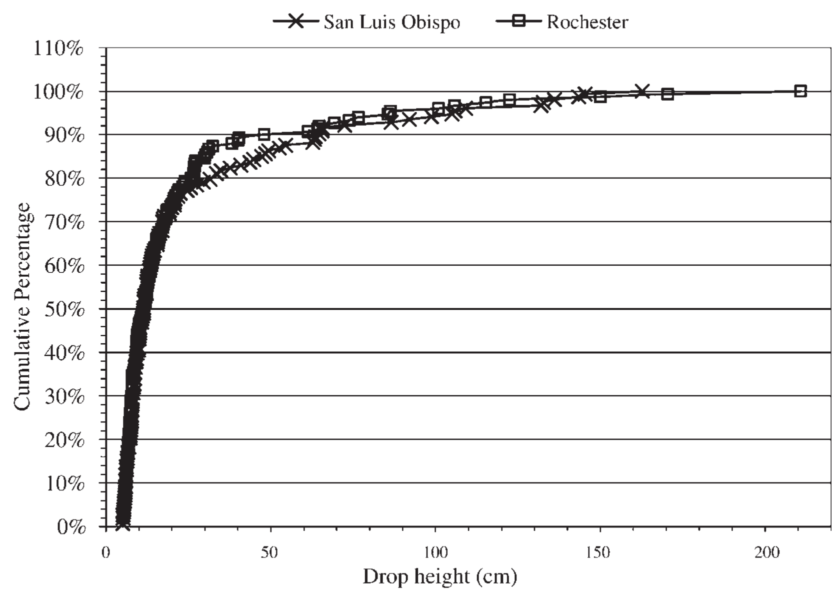

Figure 6. *Cumulative Percentage versus Drop Height: Inter-State Shipments.*

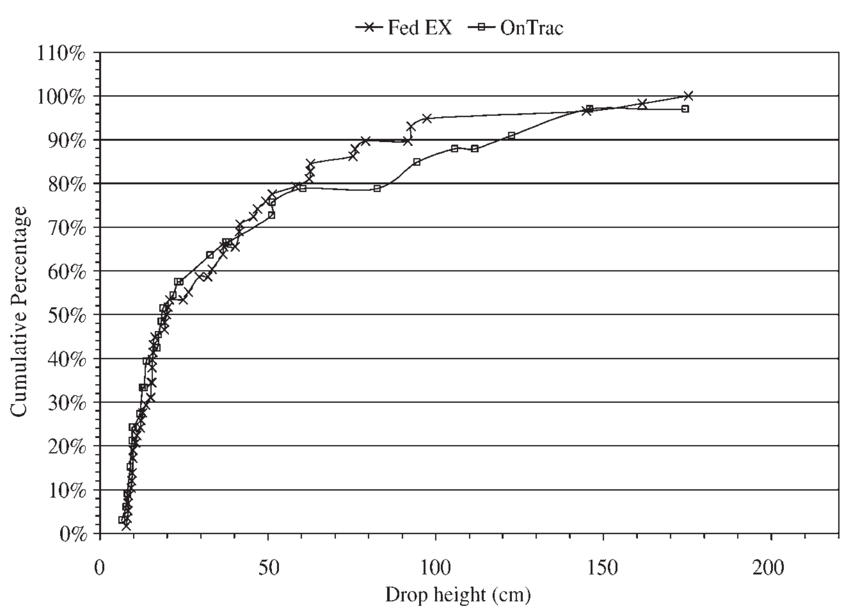

Figure 7. *Cumulative Percentage versus Drop Height: Intra-State Shipments.*

Table 3. *Summary of Drop Height Data Measured above 76 mm: Inter-State.*

Drop Data	MI-NY	MI-CA	Overall
Number of Drops	110	118	2.28
Maximum Drop Height (m)	2.11	1.63	2.11
Drop Height at 99% Occurrence (m)	1.70	1.45	1.63
Drop Height at 95% Occurrence (m)	1.05	1.32	1.15
Drop Height at 90% Occurrence (m)	0.69	0.86	0.77

Carlsbad was approximately 46% lower. The overall averages of the ten highest drop heights were higher for the OnTrac shipments to Redding and Carlsbad, 16% and 54% respectively, as compared to the FedEx intra-state shipments.

Tables 3 and 4 show the number of drops measured above 76 mm (3 inches) in inter-state and intra-state shipments, the highest drop height recorded during any one-way trip, and the 90th, 95th, and 99th percentile drop heights. The term "90% occurrence" means that 90% of all recorded drop heights were below this level.

Based on the data collected and analyzed as shown in Figures 6 and 7 and listed in Tables 1–4, it is clear that the drop height in next-day single parcel shipments is not a function of shipping distance. Drop heights are often a function of the number of times a package is subjected to loading and unloading as part of load sortation. In the next-day air shipments, regardless of the shipping distance, often only one hub is used to conduct the sortation. The more automated a hub, the less is the interaction of manual handling resulting in lesser drops and lower drop heights. As presented in the data, the intra-state shipments actually saw higher drop heights due to the carrier's practices as opposed to the distance between origin and destination.

Tables 5 and 6 show the orientation of all drops measured for the two types of shipments above 76 mm (6 inches). The most common

Table 4. *Summary of Drop Height Data Measured above 76 mm: Intra-state.*

Drop Data	FedEx	Ontrac	Overall
Number of Drops	58	31	89
Maximum Drop Height (m)	1.75	2.57	2.57
Drop Height at 99% Occurrence (m)	1.61	2.47	1.75
Drop Height at 95% Occurrence (m)	0.97	1.74	1.45
Drop Height at 90% Occurrence (m)	0.79	1.23	0.97

Table 5. *Percent Orientation of Impacts for Packages: Inter-state.*

	Orientation of Drops (%)		
	Face	**Edge**	**Corner**
Michigan to California	17%	42%	41%
Michigan to New York	21%	41%	38%

orientations for drops are edges and corners, followed by face (flat drops).

4.0 CONCLUSIONS

The study concludes the following:

- The highest drop height experienced for all roundtrip shipments happened within the intra-state shipments on OnTrac Sunrise service between San Luis Obispo and Redding. This drop was approximately 30% higher than the other measured drops in this study.
- Both types of shipments (inter-state and intra-state) exhibited multiple drops from heights significantly higher than the ASTM 4169 and ISTA 3A for packages in the 0 to 9.1 kg (0–20 lb) weight range [15,16].
- The shipping distance does not impact the severity of drop height for next day single parcel shipments.

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Table 6. *Percent Orientation of Impacts for Packages: Intra-state.*

	Orientation of Drops (%)		
Carriers	**Face**	**Edge**	**Corner**
FedEx	22%	45%	33%
Ontrac	18%	42%	39%

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Adding Barrier-shrink-film to a PET Bottle to Improve Barrier Properties

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ABSTRACT: The purpose of this research was to investigate the effect of adding high-barrier shrink films to polyethylene terephthalate (PET) bottles on oxygen permeation at ambient temperature and humidity. Polyvinylidene Chloride (PVDC) and Ethylene Vinyl Alcohol (EVOH) incorporating barrier shrink film were chosen to wrap a plain PET bottle. When comparing a high-barrier shrink-film-wrapped bottle to a plain biaxially orientated PET bottle, the PVDC-based barrier film sleeved bottle showed a 5.5% reduction in permeation. The EVOH-based barrier shrink film had a 9.9% reduction in permeation.

Oxygen transmission rates for the shrink films before and after heat shrink were also measured in an enclosed chamber using ambient air. The shrink-film barrier property was different before and after the heat treatment (heat shrink) process. Research and thermal analysis were carried out to explain the findings.

INTRODUCTION

BARRIER shrink films are commonly used in food packaging for their low cost, relative ease of use, and effectiveness at protecting the product. They protect the packaged food from various external influences such as oxygen and water vapor. One frequent use for this product is for packing meat to extend its shelf life. There are other applications for barrier shrink films as well. Metal fabricators occasionally use shrink films with good UV and moisture barriers to protect equipment that will be stored outside for an extended time.

Currently, there are many multi-layered PET bottle structures that work well in the industry, particularly for beer applications. These structures normally consist of the following multilayer design: PET/EVOH/PET [1]. RIT initiated the concept of adding a high-barrier

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shrink film to a PET bottle [2]. A shrink-wrapped barrier was added around the PET bottle to enhance the barrier properties in the center part of the bottle. This is effective because most often the bottle wall in the center is the weakest part for O_2 ingress and CO_2 loss. Preliminary results showed a difference between a plain PET bottle and EVOH and PVDC barrier-film-wrapped bottles [2]. Due to sample limitations, the oxygen transmission rate (OTR) between EVOH and PVDC that incorporated a wrapped bottle showed a conflicting result. The PVDC barrier- film-wrapped PET bottle had a relatively lower permeation than the EVOH barrier-film- wrapped bottle.

The objective of this study was to quantitatively investigate the significance of reducing the permeation by adding a high-barrier shrink film to a PET bottle. In this research, more samples were measured to increase the reliability. Also, the OTR of the barrier shrink film uses ambient air as an oxygen source and correlates the measurement of the shrink-film-wrapped bottle. The experiment also studied the thermal properties before and after shrinking to investigate the effect of shrinking on the barrier property.

METHODOLOGY

The OTR is the steady rate (equilibrium) at which oxygen permeates through a package or container at specified conditions of temperature and relative humidity. OTR is expressed in cc/100 in^2-24 hour or cc/m^2-24 hour. In this study, the OTR measurement took place in an ambient environment where the bottle was exposed to room ambient air for measurement. In addition, OTR measurements for film before and after shrink were carried out in a closed chamber where ambient air was used as an oxygen source.

The barrier film added to the plain PET bottle reduced the oxygen permeation. Several oxygen permeation tests using the Mocon Oxtran equipment were run on the bottle variables to prove the hypothesis. OTR for bottles and film were compared to each other in terms of barrier properties.

Scanning Electron Microscopy (SEM) analysis was performed to study the morphology properties of the shrink film before and after the heat treatment. The Differential Scanning Calorimeter (DSC) thermal analysis technique was used to investigate the polymer structure of the barrier shrink film.

Samples Description

The clear polyethylene terephthalate (PET) bottle was:

- 13 mil thick
- 12 oz. volume
- 9 inch long × 2.5inch diameter
- manufactured by Constar Company, USA.

The shrink films used in this research were EVOH- and PVDC-based films produced by the Curwood Company, a subdivision of Bemis, USA. The basic film specifications are listed in Table 1.

Experiment Procedures

First, the plain PET bottle was filled to the shoulder with water to prevent the tunnel heat from deforming the bottle and shrink film. The cap was then screwed onto the bottle. The pre-cut shrink film was wrapped around the bottle, joining the two ends together and forming a 1/4″ center sealing line in height as well as the bottom of the bottle. The wrapped bottles were then placed in the shrink machine Damark conveyor shrink tunnel for heat treatment. The bottle wrapped with PVDC shrink film Protite Premier was run at 162°C on speed 5. The bottle with EVOH shrink film Ecotite was run at 145°C on speed 5.

The bottle sample was bonded to a brass testing fixture using epoxy to seal the bottle (Figure 1), and the bottle is connected to the test apparatus and flushed continuously with an oxygen-free carrier gas. It was exposed to the room's ambient air, which contained approximately 21.8% oxygen. As the oxygen diffused through the bottle wall, it was carried to an oxygen- specific coulometric sensor. The oxygen transmission rate was recorded after an equilibrium rate *was* established. The film samples were placed in the fully enclosed chamber in the Mocon Oxtran, and the ambient room air was used as a permeation medium instead of pure oxygen.

Table 1. *Structure and Properties of PVDC- and EVOH-based Shrink Film [Specification provided by Bemis].*

Trade Name	Structure	Thickness (mils)	OTR (cc/100 in^2-24hour)
Protite Premier	PE/EMA/PVDC/EMA/PE/PE	2.25	< 1.2
Ecotite	PA/PE/PA/EVOH/PA/PE/PE	1.50	< 1.02

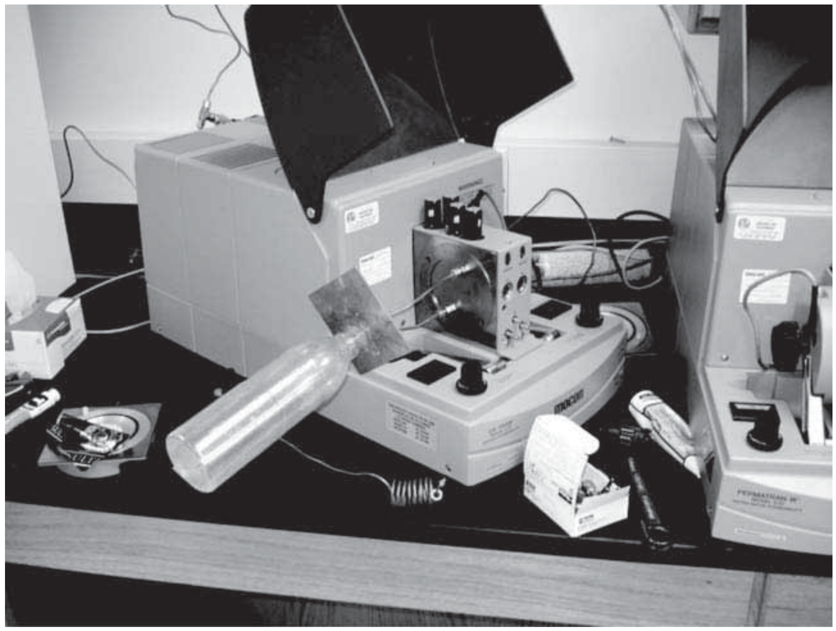

Figure 1. *Experiment set up.*

A total of five (5) plain bottles were chosen as control samples. The OTR was measured first, then wrapped with barrier shrink film for subsequent measurements. The ambient temperature ranged from 19.9°C to 20.8°C, and humidity ranged from 29.9% RH to 60.4% RH for both bottle and film.

OTR of the Plain PET Bottle and Barrier Shrink Film Wrapped PET Bottle

Table 2 compares the plain PET bottle Oxygen Transmission Rate (OTR) in cc/bottle-day to PVDC-based shrink film Protite Premier and EVOH-based shrink film Ecotite wrapped bottles.

As shown in Table 2, the bottle did a much better job as an oxygen barrier than the wrap alone, because the thickness of the bottle is significantly greater than the shrink wrap. While the barrier properties of PET, given the same thickness, are not as good as either of the barrier films used, the additional material makes up for this by having an overall lower permeability rate.

The bottles are approximately 13 mil or 0.3 mm thick. The shrink film

Table 2. *Unwrapped Bottle OTR Value Versus Protite Premier and Ecotite Wrapped Bottles [cc/bottle-day].*

		Wrapped with	
PET Bottle	**Unwrapped**	**Protite Premier**	**Ecotite**
1	6.07×10^{-2}	5.30×10^{-2}	4.69×10^{-2}
2	5.23×10^{-2}	5.30×10^{-2}	5.00×10^{-2}
3	5.10×10^{-2}	5.30×10^{-2}	5.00×10^{-2}
4	5.06×10^{-2}	5.30×10^{-2}	4.87×10^{-2}
5	5.03×10^{-2}	5.30×10^{-2}	4.54×10^{-2}
Average	5.30×10^{-2}	5.30×10^{-2}	4.82×10^{-2}
Change		–5.48%	–9.88%

only acts as an outer layer of protection with a thickness ranging 1.8 to 2.2 mil. The outside barrier had the initial protection that slowed the ingression of the oxygen at the initial stage, and then oxygen passed through the remaining plain PET structure.

The EVOH-based and PVDC-based sleeves had an added barrier property, but it was not significant in this study. The permeation rate overall was reduced 5.48% and 9.88%, respectively, for PVDC-based film and EVOH-based film.

Comparison of OTR between the Film Before and After Shrinking Process

In order to study the effect of the shrinking process to barrier properties, the OTR value of the Protite Premier (PVDC based) and Ecotite (EVOH based) before and after the treatment (Unit: cc/100 in^2-day) were measured. The sample for after-heat treatment used for the OTR measurement was taken from the film wrapping on the center part of the bottle.

Table 3. *Film OTR and Thickness Comparison Before and After the Shrinking Process.*

Materials	**Ecotite**	**Ecotite After Shrink**	**Protite Premier**	**Protite Premier After Shrink**
OTR(cc/100 in^2-24 hour)	0.59	1.09	0.76	0.92
Thickness at bottle neck (mil)	1.80	2.5	2.20	3.00
Thickness around the center part (mil)	1.80	1.50	2.20	2.10

As shown in Table 3, the actual measurement of the OTR before shrink is well within the range of the material specification provided by the supplier (Table 1). The barrier properties of the film after shrink were decreased significantly, especially for EVOH-based Ecotite. It is observed that the film thickness varied depending on the location of the film, even though the film was only observed thickening visually after the heat treatment. The thickness at the center part of the bottle of Protite Premier film was reduced from 2.2 to 2.1 mil and the Ecotite was reduced in thickness from 1.8 to 1.5 mil after the heat treatment. Therefore, the OTR values of both EVOH- and PVDC-based films could be changed due to the film thickness. The high permeation at the thinner part of the film led to a reduction of overall barrier properties.

Scanning Electron Microscopy (SEM) Analysis

Figure 2 shows the SEM image of the film before and after the heat treatment with two different magnification factors of 1000 and 4000. The film before heat treatment showed a rough and uniform surface. The surface after heat treatment was much smoother but had a significant image of pull-stressed tension.

The surface tension was largely created by the physical heat treatment process. The shrink film has different shrink rates in the machine direction and the transverse direction. The small diameter at the bottle neck resulted in a thicker film when the film shrunk toward the wall of the bottle. At the same time, the film shrunk in a transverse direction that led to a shrinking from the center part to the neck of the bottle. Table 3 shows that the thickness of the film at the bottle neck was 0.7 mil and 0.8 mil thicker for Ecotite and Protite premier, respectively, after the heat treatment, whereas the film thickness around the center part of the bottles was thinner after the heat treatment.

The Differential Scanning Calorimeter (DSC) Results

In order to determine if morphology also contributed to the permeation change before and after shrinking, the differential scanning calorimeter (DSC) analysis was conducted for both Protite Premier and Ecotite before and after the shrink to observe if there was a change in the polymer structure. All four DSC curves derived are almost identical in terms of melting temperature, heat of fusion, and crystallization temper-

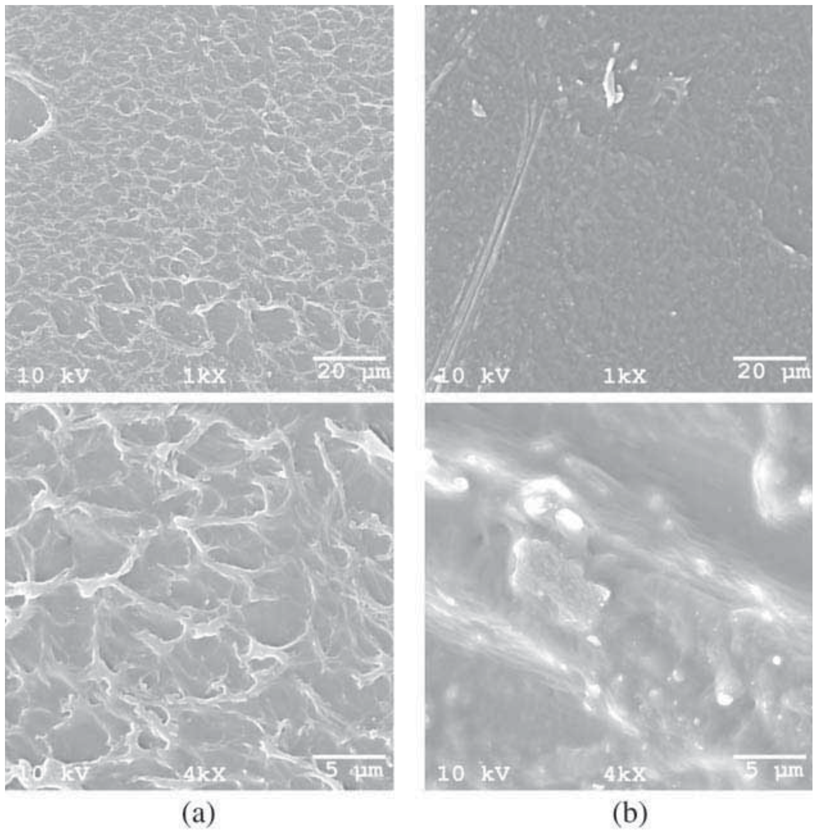

Figure 2. *(a) SEM for Ecotite before shrink; (b) SEM for Ecotite after heat treatment.*

ature. Therefore, there is no significant change in regular repeating arrangements of polymer structure. Table 4 summarizes the crystallization temperature of the films.

In Table 4, the crystallization temperatures for Ecotite before and after shrinking were 101.92°C and 102.25°C, respectively. The crystalliza-

Table 4. *Thermal Properties of the Film Before and After the Shrinking Process.*

Materials	Crystallization Temperature
Protite Premier-before shrink	98.67°C
Protite Premier-after shrink	97.63°C
Ecotite-before shrink	101.92°C
Ecotite-after shrink	102.25°C

tion temperature for Protite Premier before and after shrinking was 98.67°C and 97.63°C, respectively. The difference in film morphology before and after the heat treatment was negligible.

CONCLUSION

Wrapping barrier shrink film on the bottle can enhance the barrier property overall. The significance of the barrier property was related to the thickness ratio of the bottle and the wrapping film. Further testing would need to be performed with various combinations of bottle and wrap thicknesses to determine the most appropriate thickness ratios of both the bottle and shrink material. Potentially, a ratio allowing the actual bottle material to be a lighter weight by the inclusion of this shrink film could be found, increasing the sustainability of the product.

The heat treatment did not change the morphology of the shrink film but had a significant impact on the physical properties of the film. SEM imaging showed a clear surface tension on the heat treated film. The surface tension resulted in a non-uniform thickness between different parts of the shrink film such as the bottle neck and the center part of the bottle. Thus, the overall barrier property of a barrier-shrink-film-wrapped bottle was affected by a non-uniform shrink film around the bottle, because the oxygen still diffused into the bottle through the thinner part of the shrink-wrapped film.

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Design—An Opportunity in Reducing Corrugated Fiberboard Carbon Footprint—II

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ABSTRACT: This paper reports the findings of a second study based on evaluating the design based opportunities in reducing the carbon footprint of corrugated fiberboard containers for distributing fresh produce. Corrugated shippers have adapted well as distribution vehicles for fresh produce by providing the desired key functions such as containment, protection and communication and as such are the most popular choice. This study evaluated six variations of the traditional Bliss box as well as the regular slotted container (RSC) style containers. These variations have been identified and detailed in this paper as Split Minor Box Corner, Split Minor, Bliss End, Box Corner Bliss, Bliss End Internal and Slip Corner Bliss. All of these styles of containers can be assembled and glued using two categories of machines, the bliss formers and the rolled side (laminated) tray formers. This paper presents the findings in terms of the compression strengths for standard, refrigerated and tropical storage conditions as well as compares the material savings and the lifecycle environmental impacts for all eight designs. The best designs in terms of strength and environmental factors were Slip Corner Bliss, Box Corner Bliss, Bliss End Internal and Bliss End in a decreasing order. All of the Bliss style designs used approximately 60% of the material as compared to the RSC style and had the overall compression strengths in the range of 1.02–1.25% in comparison under the three storage conditions. The environmental benefits for alternate designs were realized with decreases in the range of 36–64% for energy usage for production, greenhouse gas emissions, wastewater and solid waste as benchmarked against the RSC style. This study shows that innovative designs for fresh produce corrugated fiberboard containers can provide adequate if not better stacking strength while using considerably lesser material in their construction.

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1.0 INTRODUCTION

FRESH vegetables and fruits are typically packed in various forms of containers to hold about 5 to 20 kg of net produce to facilitate their journey from farm to fork [1]. While the per capita fresh fruit availability at retail in the U.S. has increased only slightly (2.37%) between 1989 and 2007 to 54.31 kg, the corresponding number for fresh vegetables has increased significantly (10.14%) to 84.77 kg [2, 3]. Figure 1 shows this trend.

Worldwide demand for corrugated board has been increasing rapidly. Worldwide corrugated production increased 3.8% between the first quarters of 2007 and 2008 with a production of 44,271 million square meters in 2008 [4]. During the same period U.S. experienced a decline of 2.3% in the corrugated production, with a production of 8,736 million square meters in 2008 [4]. Figure 2 provides the historical data of corrugated fiberboard production in Asia, Europe and North America from 2000 to 2007.

The transportation and warehousing hazards faced commonly by corrugated shippers include compression, shock, vibration, temperature, creep and humidity among others. Due to its high-strength-to-low-weight ratio corrugated packaging is poised as the leading choice for transport packaging in the United States. The popularity of corrugated packaging also stems from the fact that it is practical, useful, eco-

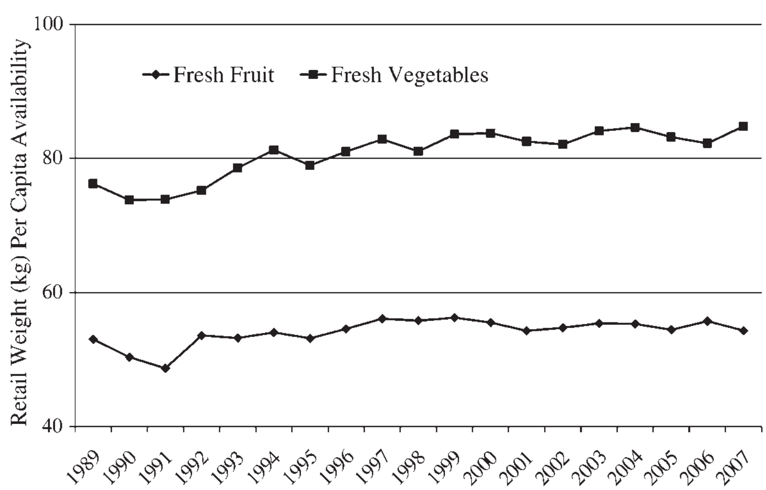

Figure 1. *Per Capita Fresh Fruit Availability at Retail (U.S.A): 1989–2007.*

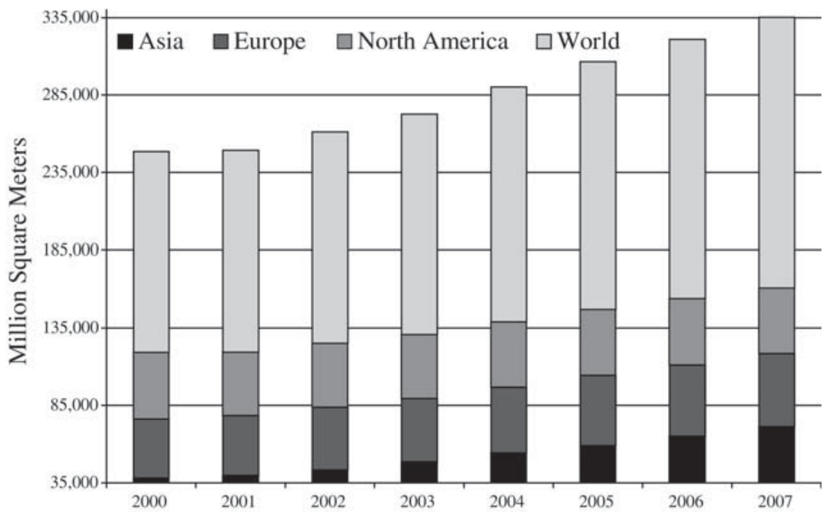

Figure 2. *Corrugated Production in Asia, Europe and North America—2000–2007 [4].*

nomical, renewable and recyclable [5]. It is also a substrate that can be custom designed and provides excellent merchandising appeal through printing on box panels.

The three most commonly used styles of corrugated boxes for fresh-produce application are [6]:

- *Slotted boxes:* generally made from one piece of corrugated or solid fiberboard. e.g. Regular Slotted Containers (RSC, FEFCO 0201)
- *Telescoping boxes:* usually consist of separate top or top and bottom that fit over each other or a separate body. e.g. Full Telescope Half Slotted Container (FEFCO 0320)
- *Rigid/Bliss boxes:* the three pieces of this style of box includes two identical end panels and a body that folds to form the two side panels, an unbroken bottom and the top. e.g. Bliss Style Container (FEFCO 0606)

FEFCO (European Federation of Corrugated Board Manufacturers) codes are an official system to substitute long and complicated verbal descriptions of fiberboard case and packaging constructions with simple symbols internationally understood by all, regardless of language and other differences [7].

This research involved redesigns of the Bliss style and RSC style containers and evaluated their compression strengths under three common environmental conditions. Evaluation was conducted in terms of life cycle inventory (LCI) calculations to quantify the material use, energy use, environmental discharges, and wastes associated with each stage of the eight box designs over their life cycle. New unique replacement designs – Bliss End Internal, Box Corner Bliss and Slip Corner Bliss for the Bliss style and Split Minor and Split Minor Box Corner for the RSC style were studied. Smurfit Stone's proprietary META box style container was also included as an existing option for the RSC style containers.

The scope of the research was:

1. To compare the compression strengths of seven replacement designs for RSC style boxes when stored under standard, refrigerated and tropical conditions.
2. To compare the material savings and quantify the lifecycle environmental impacts of these replacement designs as compared to the RSC style boxes.

2.0 MATERIALS AND METHOD

2.1 Corrugated Board

Single wall C-flute corrugated board was used in the construction of all eight existing or new container designs. For the RSC style and its replacements, the basis weights were (25/18C/25 kg)/92.9 sq. m. For the Bliss style boxes, the lids were made with lower grade corrugated fiberboard with a basis weight of (17/15C/17 kg)/92.9 sq. m. as compared to the bases with (25/18C/25 kg)/92.9 sq. m. as the basis weight, as is common industry practice.

2.2 Container Designs

The eight designs for the corrugated produce containers were constructed using ArtiosCAD software and the Premium Line 1930 model of the Kongsberg table (Esko Graphics, Ludlow, Massachusetts, USA). The designs included RSC, META Box, Split Minor, Split Minor Box Corner, Bliss End, Bliss End Internal, Box Corner Bliss and Slip Corner Bliss and are shown in Figure 3. All boxes were constructed to have the same internal volume of approximately 0.03 cu. m.

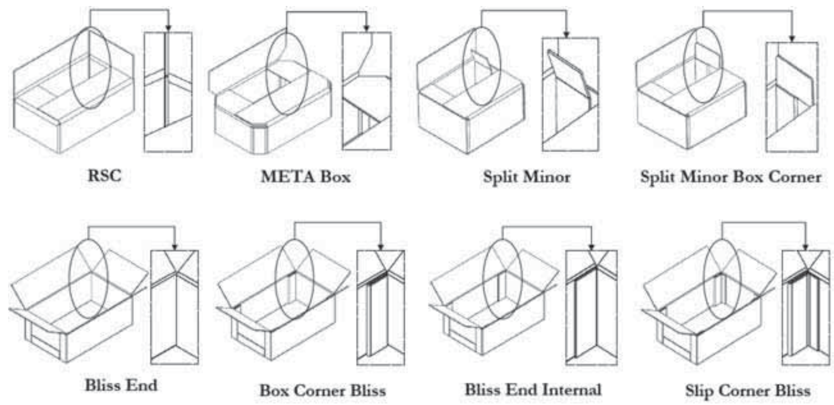

Figure 3. *Box Designs Evaluated in the Study.*

Table 1 reports the total area of the corrugated fiberboard used to construct the eight designs used in this study. It also reports the material savings for the replacement designs as compared to the RSC containers.

2.3 Box Conditioning

Corrugated boxes are considerably prone to fluctuations in moisture content and compression strength values are typically based on the ambient relative humidity exposure [8]. Prior to all testing the boxes were conditioned at three environmental conditions in accordance to ASTM D4332 for 72 hours [9]. The three conditions selected were standard (23 ± 1°C and 50 ± 2% relative humidity), refrigerated storage (5 ± 2°C and 85 ± 5% relative humidity) and tropical (40 ± 2°C and 90 ± 5% relative humidity). Five replicate tests were performed for all environmental conditions and the styles of boxes.

Table 1. *Total Area and Material Savings per Box Compared to RSC Design.*

Box Style	Area (sq.dm.)	Savings (%)
RSC	53.26	—
META Box	48.52	8.90
Split Minor	54.02	–1.43
Split Minor Box Corner	54.02	–1.43
Bliss End	31.04	41.72
Bliss End Internal	32.93	38.17
Box Corner Bliss	33.89	36.36
Slip Corner Bliss	33.89	36.36

2.4 Box Compression Strength Testing

ASTM D 642 (Standard Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads) was used to test the compression strength [10]. This procedure is commonly used for measuring the ability of the container to resist external compressive loads applied to its faces, to diagonally opposite edges, or to corners. This test method is also used to compare the characteristics of a given design of container with a standard, or to compare the characteristics of containers differing in construction. This test method is related to TAPPI T 804 om-02 [11]. The tests were conducted using a fixed platen arrangement on a Lansmont compression tester Model 152-30K (Lansmont Corporation, Monterey, CA, USA), with a platen speed of 1.3 cm/minute and a pre-load of 22.68 kgf for zero-deflection in accordance with the standard.

2.5 Lifecycle Environmental Impact Calculations

All environmental impact estimates were made using the Environmental Defense Fund Paper Calculator [12]. The information provided by this website is based on publicly available national averages and the research conducted by the Paper Task Force, a peer reviewed study of the lifecycle environmental impacts of paper production and disposal [13]. All calculations were based on the material usage for the four designs and a recycled content percentage of 43% [5]. Unbleached corrugated, as used to create all boxes for this research, was used as the identified paper type in the calculator.

3.0 RESULTS AND DISCUSSION

3.1 Box Compression Strength Testing

The compression test results are reported in Table 2. The values reported are averages for five replicate tests performed for each box style and conditioning environment. Figure 4 reflects the data in terms of percentage difference in force and deflection values for the six replacement designs and the META Box as benchmarked against the RSC design.

A shipper such as any of those tested, is likely to undergo compressive forces while exposed to the three climatic environments used for condi-

Table 2. *Compression Test Results.*

Box Style	Force (kgf)			Deflection (cm)		
	Tropical	Refrigerated	Standard	Tropical	Refrigerated	Standard
RSC	261.82	446.78	456.67	1.45	1.68	0.97
META Box	236.99	382.79	491.36	1.17	1.18	0.94
Split Minor	243.70	397.26	449.18	0.88	0.60	0.97
Split Minor Box Corner	268.68	453.39	480.03	1.21	1.15	1.24
Bliss End	266.82	428.91	499.15	1.15	0.82	0.95
Bliss End Internal	273.67	513.39	654.06	1.13	1.07	1.47
Box Corner Bliss	267.39	595.18	610.49	1.24	1.23	0.98
Slip Corner Bliss	313.54	628.75	651.48	1.17	1.27	1.28

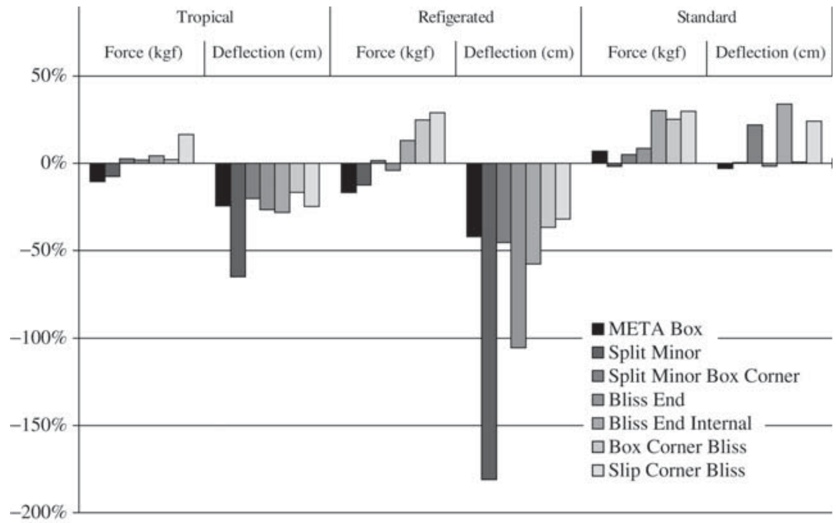

Figure 4. *Percentage Difference in Compression Test Values as Compared to RSC.*

tioning in this study. Comparing the average overall peak forces across all three environmental conditions of the RSC style box to that of the replacement designs, it was observed that:

- The META box was approximately 7% weaker, while providing material savings of approximately 9%
- The Split Minor box was approximately 7% weaker, while using approximately 1% more material
- The Split Minor Box Corner box was approximately 3% stronger, while using approximately 1% more material
- The Bliss End box was approximately 2% stronger, while providing material savings of approximately 42%
- The Bliss End Internal box was approximately 16% stronger, while providing material savings of approximately 38%
- The Box Corner Bliss box was approximately 17% stronger, while providing material savings of approximately 36%
- The Slip Corner Bliss box was approximately 25% stronger, while providing material savings of approximately 36%

It may be noted that the deflection, which is indicative of the side and bottom bulging of the boxes under compression, was considerably lower for the replacement designs as compared to that for the RSC boxes under the tropical and refrigerated conditions (Figure 4). The lower peak deflection values are to be expected due to the vertical edge reinforcements for the alternative designs.

3.2 Lifecycle Environmental Impact Calculations

Table 3 reports the results of the lifecycle environmental impact calculations for all eight styles of boxes and Figure 5 reports these results as benchmarked against the RSC style containers. All RSC style replacement designs provide distinct advantage in terms of all quantified LCI values due to material savings in the designs.

With the exception of the Split Minor and Split Minor Box Corner styles, savings in material ranging from 9 to 42% for the alternative designs, translates into significant energy savings, relative optimization of natural resources, reductions in green house gas emissions and relative minimization of waste water and solid waste generated during production in comparison to the RSC style boxes.

As reflected in Figure 6, a considerable amount of environmental benefits can be realized by improving currently used styles of containers employed for the distribution of fresh fruits and vegetables. The Bliss style boxes and improvements to them provide a considerable overall improvement in terms of compression strength and environmental im-

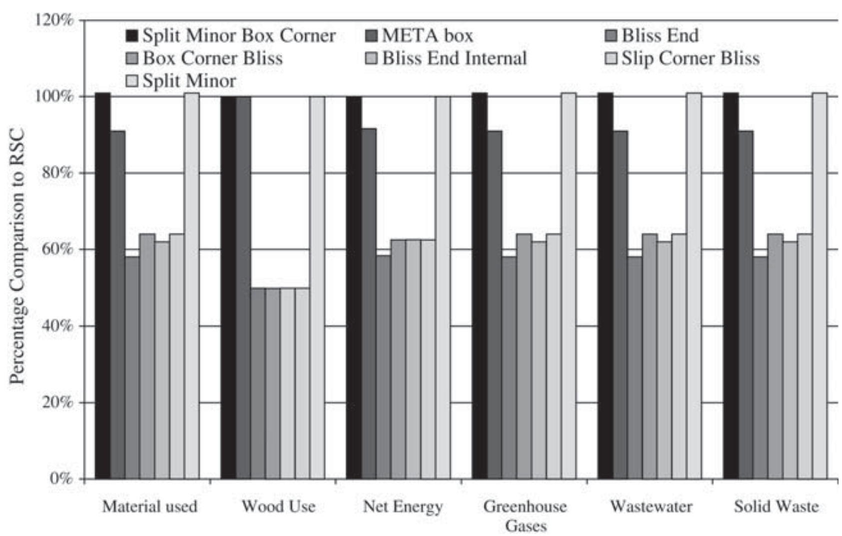

Figure 5. *Environmental Impacts of the Replacement Designs as Compared to the RSC Style.*

Table 2. *Environmental Impact Comparison.*

Box Style	Material Used (tons)	Wood Use (tons)	Net Energy (million BTU's)	Greenhouse Gases (kg CO_2 eq.)	Wastewater (cubic meter)	Solid Waste (kg)
RSC	1	2	24	1990.36	26.79	413.68
META Box	0.91	2	22	1811.19	24.38	376.48
Split Minor	1.01	2	24	2009.87	27.06	417.76
Split Minor Box Corner	1.01	2	24	2009.87	27.06	417.76
Bliss End	0.58	1	14	1154.39	15.54	239.95
Bliss End Internal	0.62	1	15	1233.77	16.61	256.28
Box Corner Bliss	0.64	1	15	1273.69	17.15	264.90
Slip Corner Bliss	0.64	1	15	1273.69	17.15	264.90

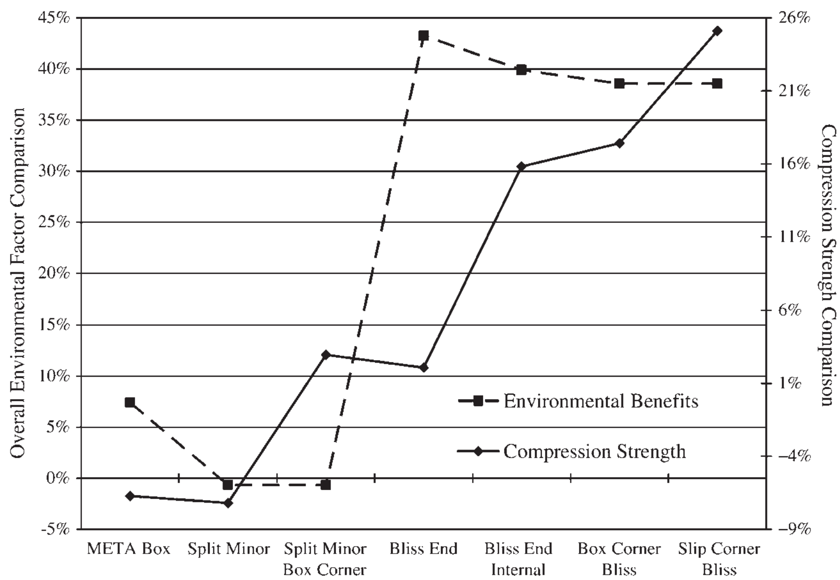

Figure 6. *Compression Strength and Overall Environmental Impact Comparisons to RSC.*

pacts when benchmarked against the very popular and widely accepted RSC style of containers.

4.0 CONCLUSIONS

This study shows that the alternate designs in comparison to the RSC style of containers, especially the Bliss style as well as modifications to it, can provide adequate if not better stacking strength while using considerably lesser material in their construction.

- *Strength, resilience and sturdiness:* While the META Boxes and the Split Minor boxes provided somewhat lower resistance to compression forces as compared to the RSC boxes, the Split Minor Box Corner, Bliss End, Bliss End Internal, Corner Bliss and Split Corner Bliss boxes proved to be superior in comparison with the improvement ranging from 2% to 25%. Considerable decrease in peak deflection values for the replacement designs was observed in comparison to the RSC style boxes.
- *Saving in material—commercial and environmental benefits:* The es-

timated production of corrugated fiberboard boxes used for distributing fresh vegetables and fruits is in the hundreds of millions in the US [13]. This presents a new opportunity to create considerable savings by converting to any of the replacement style boxes studied in this research. Saving in material translates into significant energy savings, relative optimization of natural resources, reductions in green house gas emissions and relative minimization of waste water and solid waste generated during production.

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Table 5. Comparison of state-of-the-art matrix resins with VPSP/BMI copolymers.

Resin System	Core Temp. (DSC peak)	Char Yield, %
Epoxy (MY720)	235	30
C379: H795 = 1.4	285	53

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