COLLEGE OF NATURAL RESOURCES AND ENVIRONMENT
SUSTAINABLE BIOMATERIALS
VIRGINIA TECH

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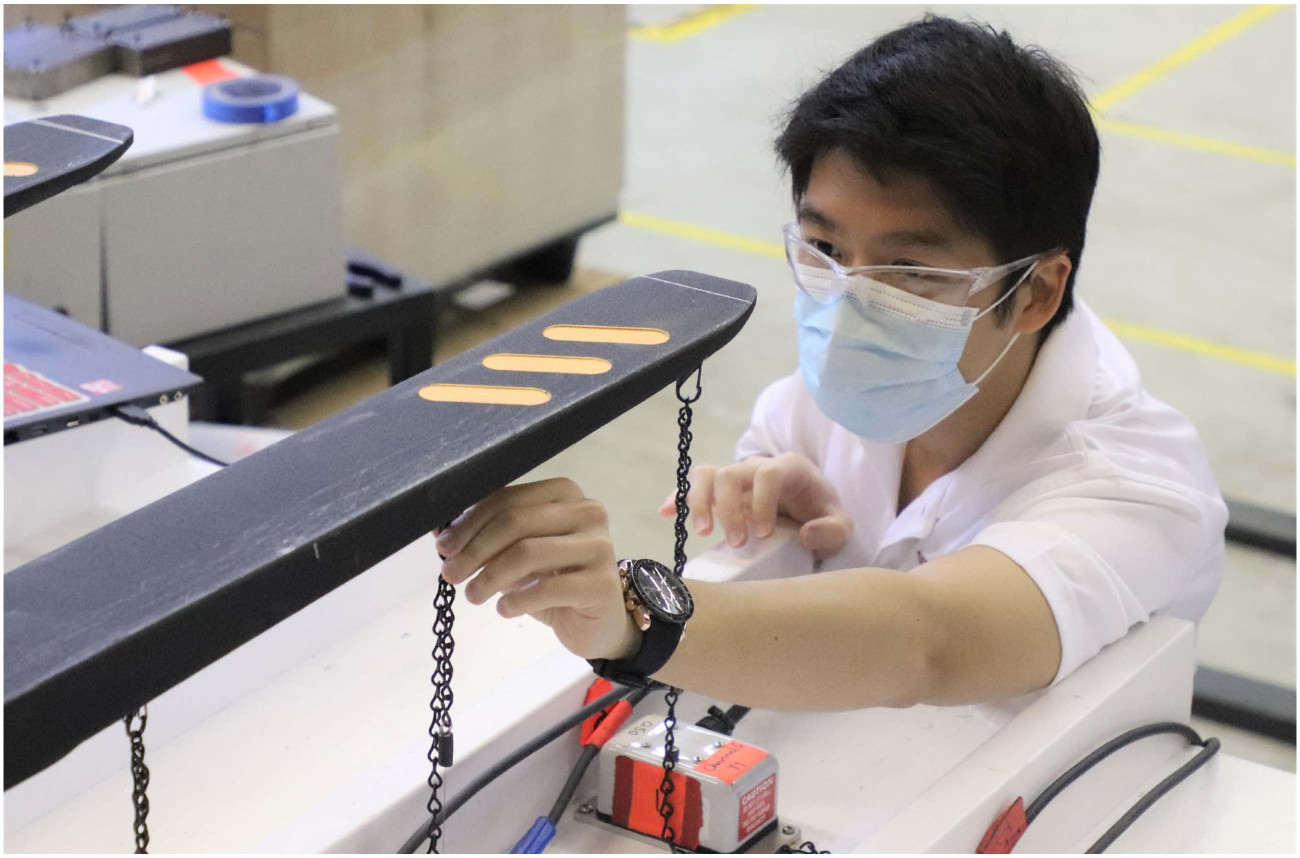
Center for Packaging and Unit Load Design

CPULD News

Quarterly Newsletter



The current edition of the newsletter contains the following exciting topics from CPULD:

- Evaluation of pallet deflection under forklift handling conditions
- Investigating the effect of pallet deckboard stiffness on the compression strength of plastic pails
- Package assessments based on consumer perceptions of e-commerce
- Many other graduate and undergraduate research project summaries
- Alumni spotlight: Tabby Partin
- Graduate student spotlight: Clark Sabattus
- Summaries and updates on CPULD's webinars, meetings, and short courses this year
- Outlines of new certifications earned and new financial software used
- Congratulations to Mary Paz Alvarez and Yu Yang Huang on graduating with their M.S. degrees

Featured Research – Evaluation of Pallet Deflection under Forklift Handling Conditions

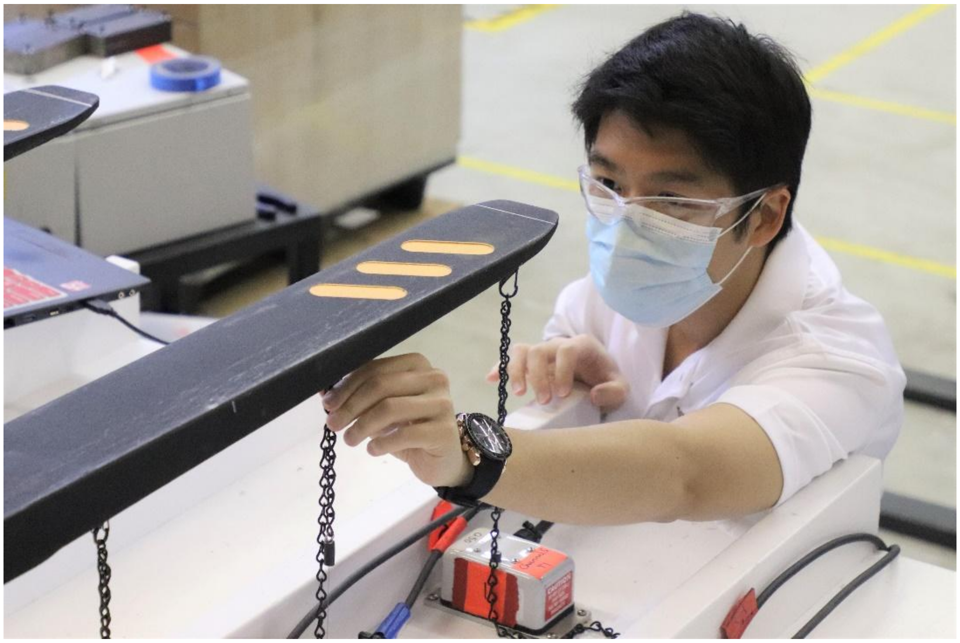


Image 1. Yu Yang setting up his experiment by attaching string potentiometers to a custom fork tine jig on the lab vibration table.

Industrial forklifts are one of the most common types of handling equipment for unit loads in warehouses and distribution centers. When unit loads are transported, the vibration caused by the different transportation modes has a major effect on the damage caused to the products transported. Therefore, vibrations caused by different common transportation modes is well-characterized. However, despite the popularity of the forklift, only a limited number of studies have researched the vibrations caused by them.

Pallets deflect while being transported by forklifts. This is caused by the weight of the unit load, with most of the deflection occurring on the outside edges and corners of the pallet. Limits for the allowed deflection of a pallet during forklift handling can be found in many international standards. However, there is still a lack of understanding about how the maximum allowed bending of the pallet influences the safety and performance of the pallet during forklift handling. Understanding pallet bending during dynamic forklift movement and how it affects the stability of a unit load will help improve the industry testing standards, and will help engineers design safer and more cost-effective pallets.

The goal of this study was to evaluate pallet deflection during static and dynamic environments, and investigate how these values are affected by factors such as fork tine orientation (level or 4° angle), unit load condition (bound or unbound), pallet orientation (across width or across length), and type of forklift handling condition (static or dynamic). Master's student Yu Yang Huang conducted this research, which was funded by the CPULD Industrial Affiliate Membership (Image 2).

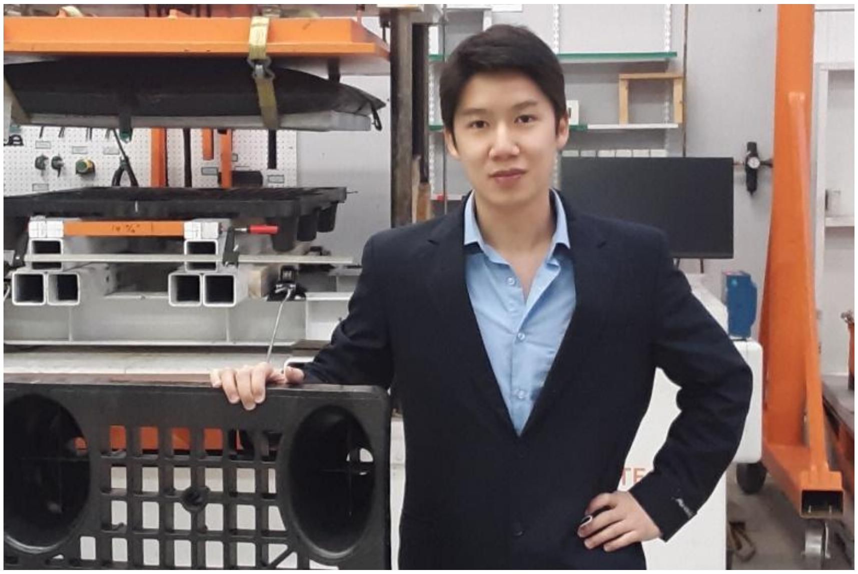


Image 2. Yu Yang Huang, Masters Student, CPULD

One plastic pallet design was used to conduct the experiments in this study. The pallet was a 48 in. x 40 in. nestable, block class, non-reversible, plastic pallet used for grocery distribution. Regular slotted container-style corrugated boxes were used. The boxes were manufactured with a Kongsberg computerized cutting table; constructed using C-Flute, single-wall, corrugated board with 32 lb./in. nominal Edge Crush Test value; and had external dimensions of 8 in. x 8 in. x 10 in. to create the most conservative setup. This study was conducted using both a stretch wrapped (bound) and an unwrapped (unbound) unit load. Both unit loads were constructed four layers tall, in a column stacked pattern, with thirty boxes per layer.

The coefficient of friction (CoF) of the pallet was determined for each of the pallets. The pallet was exposed to the test surface (corrugated), and a horizontal force was applied to the pallet at a constant rate of 1.0 in. / minute. Force was applied until motion was achieved and that force was recorded as F_h (Image 3).

Image 3. Yu Yang conducting a Coefficient of Friction test on the plastic pallet.

A custom jig was created to support the loaded pallet during dynamic testing. This consisted of a metal forklift carriage bolted to a steel assembly and a set of two 42 in. long fork tines that were hung from the carriage. The most conservative vibration profile collected during earlier research was used to simulate a dynamic forklift handling condition. To measure the deflection that the pallet experienced during the vibration test, up to string potentiometers were connected to the pallet and to the fork tines of the forklift simulator. Deflection values were recorded through a period of 30 minutes, or until the unit load collapsed.

The pallet deflection was measured and analyzed using three different variables (pallet orientation, unit load containment, and fork tine configuration). Then, an analysis of pallet deflection was conducted for each of the tested scenarios. A summary was provided with all the deflections observed at the beginning, at 3 minutes, and at 30 minutes of testing for those cases that the unit load survived for those amounts of time. For those cases where the unit load did not survive the entire test, the reported deflection was based on the time at which the unit load collapsed.

After 30 minutes of dynamic testing, the creep amount observed on the pallet for the bound unit load ranged from 15% - 33%. The creep deflection observed for the dynamic testing was much greater than it had been during the static testing (6%-13%). This indicated that the additional dynamic movement increased the creep and deflection of the pallet. A previous study conducted by Neville showed that when mechanical vibrations are applied to materials, it reduces the stress necessary to initiate yield strength in materials. In short, vibrations reduce the strength of materials. It follows that when vibrations were applied to the unit load, there was a jump in measurable deflection.

The creep amount for the pallet carrying the unbound unit load ranged from 36%-50% which is much higher than what was observed during the testing of the bound unit loads. This can be explained by the fact that the stretch film used for the bound unit load constraints the movement of the boxes, as well as the bending of the pallet. All three replicates of the unbound unit load under dynamic testing conditions did not survive the 30-minute test. Boxes fell off of the unit load at different timestamps, and it was observed that the failure of the unit load was usually seen on both sides of the pallet. The combined effect of the pallet and fork tines bending creates instability of the unit load (Image 4).

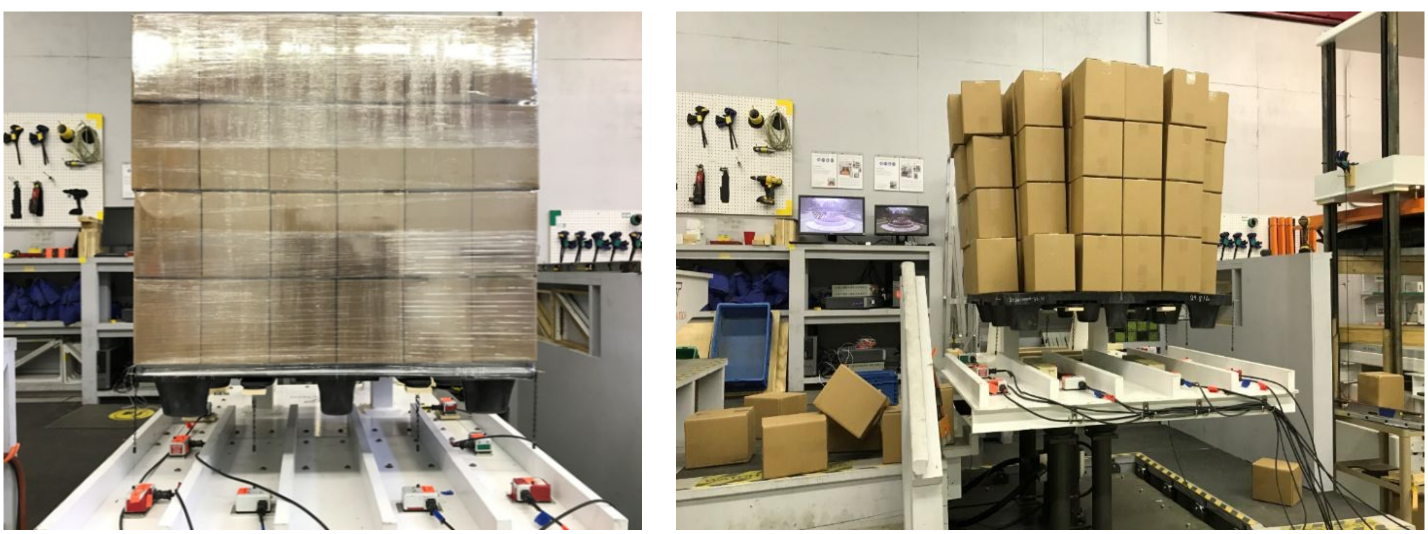


Image 4. Example of (left)bound and (right)unbound unit loads during dynamic testing.

Forklift drivers have a tendency to tilt up the fork tines in order to create more stability on the unit loads. The maximum tilting of the fork tines measured for the forklifts was around 4°. Thus, in order to simulate this handling condition, both bound and unbound unit loads were tested in a static and dynamic conditions with level and with 4° angle fork tines. Overall, when comparing the creep deflections between level and 4° fork tines, it was observed that less deflection was measured using 4° fork tines in most of the locations on the pallet. This could be explained by the fact that the center of gravity was shifted towards the rear end of the pallet, and since there is no cantilever on the rear side of the fork tines it might have reduced pallet deflection.

Two out of three unbound unit loads under dynamic conditions with 4° fork tines did not survive the 30-minute test. The unbound unit loads with 4° fork tines only showed a creep deflection of between 17% and 23% which is less the same unit load on level fork tines. This could be explained by the fact that the center of gravity of the unit load is shifted towards the rear end of the pallet. Therefore, when dynamic motion is applied, part of the side bending of the unit load is distributed towards the rear end.

The conclusions obtained through the study were that:

- The highest deflection values were observed to occur on the front corners of the pallet due to the combined effects of deflection due to the cantilever of the fork tines and of the pallet.

- Vibration increases bending due to the magnification in the movement of the pallet.

- Fork tines do not creep during the different tests due to their rigidity, while pallet creeps over time, especially in the case of the unbound unit loads.

- Deflection limits proposed in the ISO 8611 standard are appropriate and potentially even too conservative for bound unit loads, but they are not appropriate for unbound unit loads.

- When the fork tines are not adjusted to stabilize the load (when they are level), the unit loads became unstable for both across the width and across the length orientations.

- When the operator tilts the fork tines back 4° the unit load was stable for the across the width orientation but not for the across the length orientation.

- Finally, the applicability of the ISO deflection limit depends on how the pallet is handled in the distribution.

Alumni Spotlight — Tabby Partin, Director of Operations, Solar Insure

Image 1. Tabby Partin

Tabitha Partin came to VT from the Eastern Shore area of Virginia because she wanted to pursue a degree that could help change the environment. She was particularly looking for a school that had great STEM resources as she knew that would equip her with the tools she'd need to make a difference in the real world. Tabby graduated from CPULD in 2019 with her bachelor's degree and moved across country to a warmer climate. She currently lives in Huntington Beach, California, where she enjoys the beautiful weather and sunny outdoors every day. Her hobbies include learning how to surf and salsa dance and socializing with her circle of friends.

"The most valuable knowledge I received in my four years at Virginia Tech were my undergrad research classes with Dr. Laszlo Horvath and Dr. John Bouldin," Tabby said. "The practical knowledge of real industry experience helped me learn my strengths and weaknesses, and how to focus on my strengths."

Tabby has always enjoyed learning what goes into making things work. "When Dr. Horvath gave a presentation on what packaging is, I became interested from a systems perspective. He would say, "Name one thing that doesn't come in a box." or ask, "How do things go from point A to point B with no damage and arrive in a timely manner?" Figuring out the mechanics, systems, and level of engineering that goes into a simple box intrigued me. I knew there was going to be an immense level of opportunity for me in this field."

Tabby has already earned her green belt in Lean Sigma Six, a method that combines lean manufacturing and six sigma techniques to provide a framework for organizational change, and she is currently working on her black belt in the same system.

Tabby states that she learned the importance of Lean Manufacturing from her project-based class and internship. "This is one of the main reasons I was able to secure two internships and get right into my field after graduating. Lean Manufacturing is how I have helped increase our revenue by over 400% in a short time span. We are now providing protection for 1,000-1,500 homeowners on a monthly basis, and we are continuing to grow. Learning about Lean Manufacturing also afforded me the opportunity to make a difference in the renewable energy sector. I love how my current employer, Solar Insure, is helping the environment and the fight against climate change by insuring the alternative energy sector and helping homeowner have peace of mind and protection on their solar systems."

"I've worked as the Director of Operations for the renewable energy company, Solar Insure, since late 2020," Tabby said. "As Director of Operations, I implement Lean six sigma to create and oversee the day to day of the business. This means, production, account management, customer service and the day to day business metrics (such as accounting and growth plans). My responsibilities include studying our Key Performance Indicators (KPIs) to identify areas for continuous improvement. One of my core roles is to build our current systems to scale and grow our company. In short, this means I map out and analyze all processes to ensure operational excellence. Being in this position requires the ability to spot and act on opportunities – my role was designed to reduce wasted time and pain points, and to increase profitability."

On the current business and job market, Tabby believes: "There are opportunities everywhere! Amidst the pandemic, it became apparent that many businesses were not equipped to face challenges. The pandemic forced businesses to do a deep dive and drive systematic changes to improve their current processes. Right now, every business wants to cut costs and increase productivity. But if you can do those things, there will always be roles available. I am extremely grateful for the time I have previously spent learning about the implementation of Lean Six Sigma and operations."

Tabby had this advice for any future students coming to CPULD: "I would advise future students to try everything. People in the packaging industry at Virginia Tech have an amazing opportunity to try so many different paths in packaging. From large-scale industrial distribution systems with Dr. Horvath, to testing food and pharmaceutical packaging with Dr. Kim, the knowledge and practical knowledge that you stand to gain is limitless. Being a part of the CNRE school has so many advantages including many wonderful people who are there to help you succeed."


Image 2. (left and right) Tabby hiking along the coast.

Research Highlight – Investigating the effect of pallet deckboard stiffness on the compression strength of plastic pails

Image 1: Jordan Wells & Cameron Fischi conducting pail compression strength tests.

The objective of this undergraduate project conducted during the spring 2021 semester was to measure how pallet deckboard stiffness affected pail compression strength in a unit load. Testing was conducted using the ASTM D642 guidelines combined with custom-made pallets, 5-gallon plastic pails, and an MTS testing machine.

Three undergraduate students were selected to conduct this research project. Victoria Dashevsky graduated in May 2021 and was from Alpharetta, Georgia (Image 2). Jordan Wells, a senior from Roanoke, Virginia, and Cameron Fischi both also worked on this project (Image 3). This research was supported by the National Wooden Pallet and Container Association for use in their unit load design software.

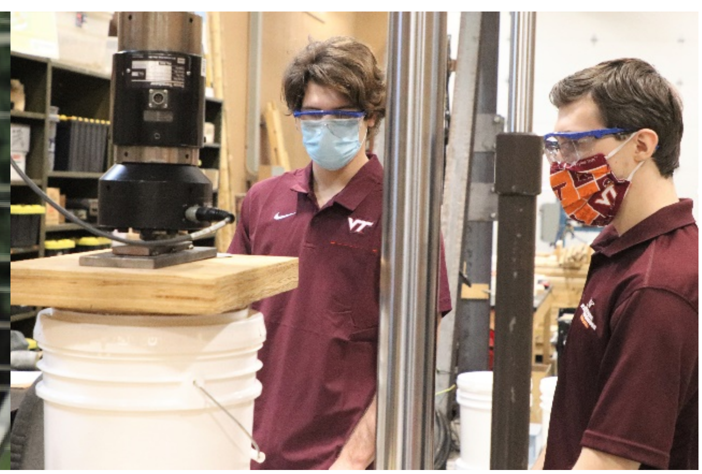


Image 2. Victoria Dashevsky. Image 3. (left) Cameron Fischi, and (right) Jordan Wells.

A considerable variety of containers are transported using pallets in global markets. Although, corrugated boxes are the most commonly transported packaging types, pails are commonly used to transport smaller quantities of liquid for industries. The main pail user industries include food, paint, and chemicals. The pail industry is projected to grow in their market at a high rate of 4.7% by 2027. Additionally, industrially used pails are predicted to reach an overall market value of $9.82 billion in the same timeframe. The most common pail design in the supply chain is the 5-gallon open-headed plastic pail. Pallet software cannot be used to properly evaluate the effect that pallets have on pails as this interaction has never been studied before. Due to their frequent use in distribution channels, it is important to fully understand how pallets interact with pails.

The main objective of the study is to investigate how pallet stiffness affects the strength of plastic pails using 2” double overhang and two different pail locations (center and edge) (Image 1). Two wooden pallet simulators were constructed for testing purposes. The pallet simulators were simulating a 48” x 48” stringer-class pallet design that is commonly used to transport pails. The pallet simulators were made from defect-free, southern yellow pine and had overall outer dimensions of 23.5” x 36”. All deckboards were spaced evenly, and four different deckboard thicknesses were investigated: 3/8”, ½", 5/8” and ¾". The pails used for testing were 5-gallon open-headed plastic pails (Uline model S-7914W). They were constructed from High Density Polypropylene (HDPE), and their wall thickness was .090”.

The test procedure was conducted according to the guidelines of ASTM D642. An MTS universal testing machine equipped a 5,000 lb. load cell was used for the testing. The pails were loaded using a custom loading jig manufactured from the bottom section of a pail reinforced with plywood to mimic the interaction between stacked pails (Image 5).

The samples were loaded until visual failure of the pail (such as buckling [Image 4]) and/or a ~10% decline of the load curve was observed. The load and deflection were collected using a digital data acquisition system. Ten pails were tested on a rigid support to provide a baseline. Then, ten replicates of each condition (center and edge for each deckboard thickness) were tested and used to calculate the average values for each.

Image 4: Test setup picture showing the (left) pail-to-pail connection and (right) example of pail failure.

The results of the investigation are presented in Table 1.

Condition	Center Location		Edge Location	
	Average Load (lbs)	Change (%)	Average Load (lbs)	Change (%)
Rigid full support	2689.32			
3/4" deckboard	1535.76	-43%	1305.39	-51%
5/8" deckboard	1533.77	-43%	1355.58	-50%
1/2" deckboard	1458.73	-46%	1051.55	-61%
3/8" deckboard	1550.36	-42%	991.5	-61%

Table 1: Average pail strength as a function of pail location on the pallet and deckboard stiffness.

The data was analyzed to show general trends across the location conditions. After the statistical analysis it was found that there was a significant reduction in pail strength for all deckboard thicknesses. However, decreasing the deckboard thickness did not have an effect on the results for the Center condition and only had a slight effect for the Edge condition. In addition, the strength of pails supported at the edge of the pallet where one side of the pail was on the stringer and the other side was on the deckboard, reduced as much as 37% compared to the pails that were supported on the Center for the pallet. Similar findings were found by Quesenberry et al. for corrugated boxes. The current results further validate that when packages are asymmetrically supported, the effect of deckboard stiffness has a more prominent effect of their strength.

The major conclusions from this research study include the following:

- The average of strength of 5-gallon open-headed plastic pails is around 2,700 lb.
- The strength of pails supported asymmetrically on the edge of the pallet decreased with the decreasing deckboard thickness.
- The mode of failure for the pails supported on the edge was the bucking of the side that was on the top of the stringer.
- The variation in deckboard thickness had no effect of the pail strength when the pails were centered on the pallet.

Research Highlight – Package Assessments Based on Consumer Perceptions of E-Commerce

Image 1. Rosa Williams and Julia Barbosa making initial notes about different e-commerce packages.

A group of CPULD's undergraduate packaging students have completed a research project that focused on improving the sustainability of e-commerce packages. The main goal of this project was to understand what elements of the package are more important for customers who purchase their goods through an e-commerce channel.

In recent years, e-commerce is a rapidly growing industry that has amassed remarkable attention. In fact, by the end of 2020, US e-commerce made up 21.3% of total sales compared to only 15.8% in the year prior. This nearly 6% jump is strikingly significant considering that, within the last decade, the yearly percent increase was consistently 1.4% or less. Unfortunately, packages designed for an in-store, retail setting are frequently repurposed for e-commerce distribution, despite the different demands and logistics of each distribution system.

The logistics of in-store retail systems are often simpler, and therefore, require less handling, while the marketing demands of in-store shopping call for a package that aids in attracting the attention of consumers. For e-commerce systems, packages are not used primarily as marketing tools prior to the consumers' first purchase like they are for in-store, retail shopping. Additionally, the logistics of e-commerce retail systems are much more complex, thus requiring more handling.

In a retail setting, a package is designed to withstand only one shipment from the manufacturer to the store because, even if returned, that package will not enter the distribution system again. Alternatively, online orders must be able to withstand two possible shipments: one from the manufacturer to the consumer and a second shipment back into the distribution system. Comparing these two systems, it is clear that an e-commerce package is required to be tougher and more thoughtfully designed. If a retail package is not redesigned for e-commerce but is sold via e-commerce regardless, it may result in the failure of the package which has negative consequences such as product damage, customer dissatisfaction, and increased environmental waste.

The goal of this research project was to understand which elements of a package are perceived as more important by the customer. This information will allow packaging designers to create more effective packaging designs by focusing on the elements that are perceived as more valuable by the customer.

Elements of packaging within the e-commerce supply chain can be broken down into three main categories: Marketing, Environment, and Flow Functions. Marketing Functions of a package aid in creating value and branding for the product and company. Environment Functions aim to reduce the negative effects of the packaging system on the environment. Lastly, Flow Functions promote areas such as better logistics, handling, and efficiency.

The student team developed an online survey to help increase our understanding of how consumers value each packaging element within the context of e-commerce. Respondents were asked to consider their past experiences with e-commerce - what they liked, and what they disliked. Respondents were explicitly asked to rate the importance of many different elements within the three main packaging function categories (Image 2). This was done to finalize what the consumer ultimately looks for in an ideal package.

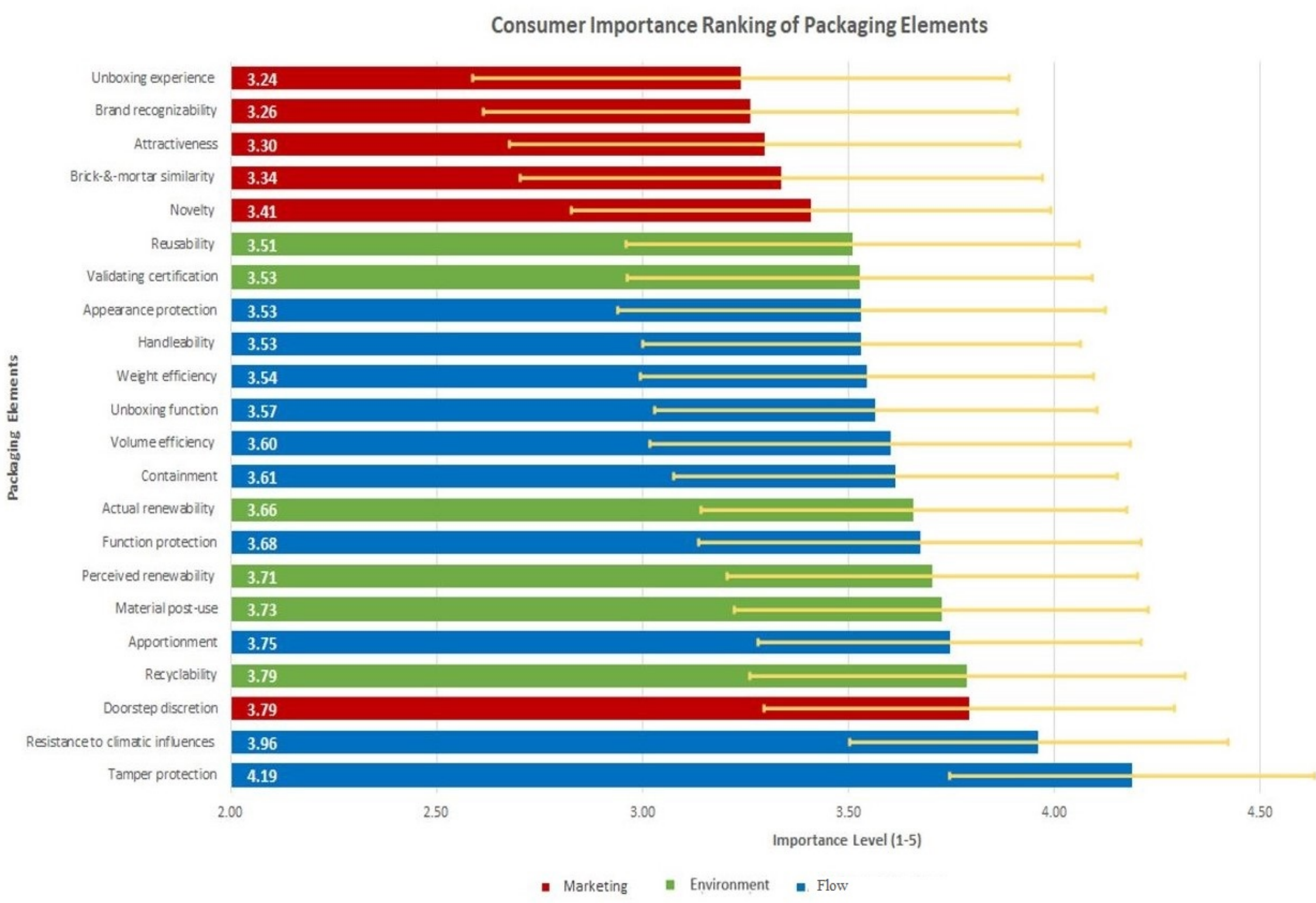


Image 2. Graph depicting consumer importance ranking of packaging elements based on survey data.

Unboxing experience and brand recognizability both have the highest standard deviation which shows that respondents were not as united in these choices. Tamper protection was the most agreed upon element. An average of the average importance values for each of the three main packaging function categories was calculated and used as a comparison to the importance allocations. This demonstrated that respondents placed more value on elements that belonged to Flow Functions, and placed the least value on elements belonging to Marketing Functions. This portion of data, with respondents rating five-out-of-six packaging elements in Marketing as the least valuable, demonstrated that consumers are more concerned with the basic functional, protective, and safety aspects of a package. Consumers sampled want the safe delivery of their product more than the aesthetic aspects of receiving a package.

The data also showed a discrepancy between how packaging professionals and the general public perceived the importance of the different factors. Respondents with experience in the packaging industry regarded the marketing and appearance aspects of packaging highly, whereas from a non-industry perspective, a functional and protective box was more of a priority.

Research Highlight - Investigating the Effect of Pallet Top Deck Board Stiffness on Corrugated Box Compression Strength as a Function of Several Variable Factors *by Saewhan Kim*

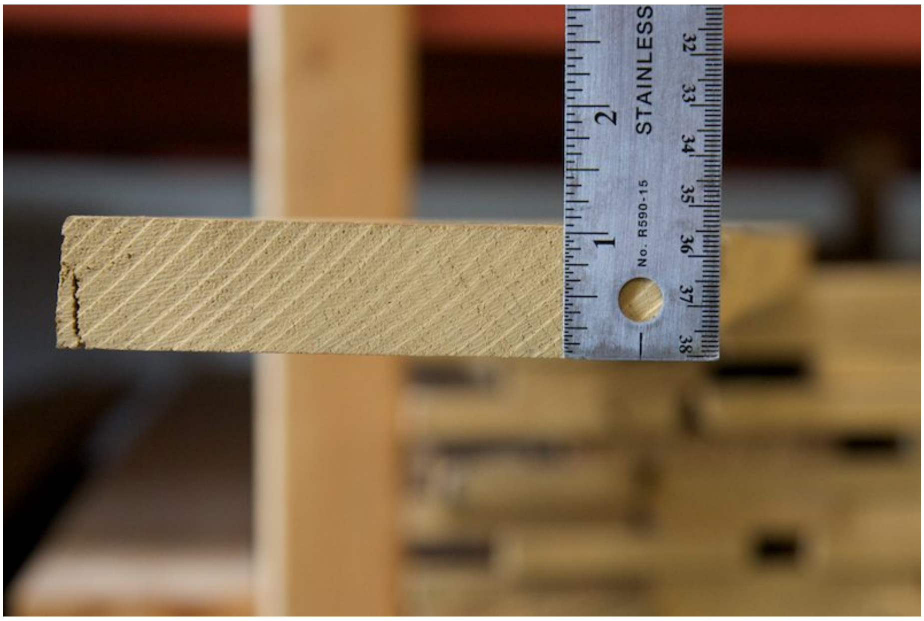


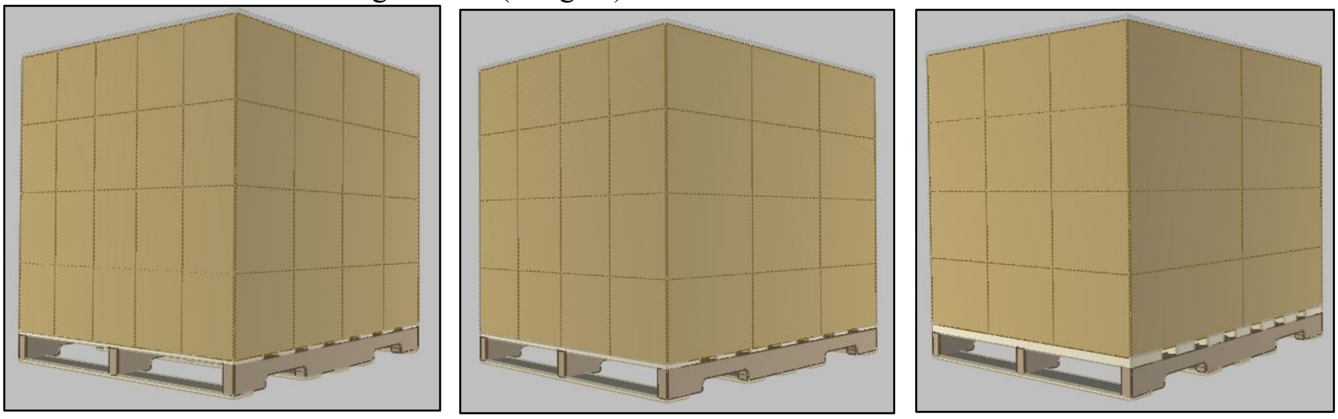
Image 1. Example of board thickness/stiffness

Historically, the distribution packaging industry has adapted the method of unitizing single, multiple, or bulk products on a solid platform in order to ease handling, storing, and transporting. Unit loads dominate today's product distribution and storage format in the United States by 80%, and most of these unit loads are carried on pallets. Just as pallets have become one of the essential elements of a unit load, corrugated boxes also play a crucial role in the unit load system. Corrugated boxes are the most used type of primary and secondary packaging; in fact, 72% of pallet loads consist of stacked corrugated boxes. When designing a unit load, accurately predicting corrugated box compression strength is crucial to avoid package failure from vertical compression. Numerous studies have investigated the factors that affect the compression strength of corrugated boxes, including material properties, manufacturing methods, and environmental condition factors.

In recent years, researchers have endeavored to correlate the effect of pallet top deck stiffness (Image 1) to corrugated box compression strength. Researcher Quesenberry found that a stiffer top deck board could increase the compression strength of asymmetrically supported corrugated boxes up to 37% when the unit loads are double stacked on the floor. He also discovered that the effect of pallet top deck stiffness on box compression strength could be utilized to lower the cost of a unit load by decreasing the required board grade of corrugated boxes and increasing the top deck thickness. Their experimental unit load designs were enough to see the trend of this phenomenon, yet a limited number of designs for understanding other factors that may affect the result. Therefore, this current research project investigated the interaction between pallet top deck stiffness and box compression strength as a function of variable factors such as starting top deck thickness, pallet wood species, box size, and board grade, in order to suggest an effective way of applying the unit load optimization method.

This study consisted of two main sections: validation of the analytical pallet design software, and unit load scenario analysis. The commercially available pallet design software Pallet Design System™ (PDS™), created by NWPCA, was utilized to replace numerous physical experiments in this study. The box performance data predicted from PDS™ and Quesenberry were compared using the *Pearson correlation coefficient*.

After the software validation process, a total of 288 unit load scenarios were simulated using PDS™ for unit load analysis to investigate the effect of four variable factors. The pallet designs for these unit load scenarios were varied by four initial top deck thicknesses and four wood species. The corrugated box designs were altered by three box sizes, two flute sizes, and three ranges of board grade reduction for each flute size. Finally there were three unit load configurations (Image 2).



(a) (b) (c)

Image 2. *Image of investigated unit load configurations (image generated using PDS™). (a) unit load with small boxes, (b) unit load with medium boxes, and (c) unit load with large boxes.*

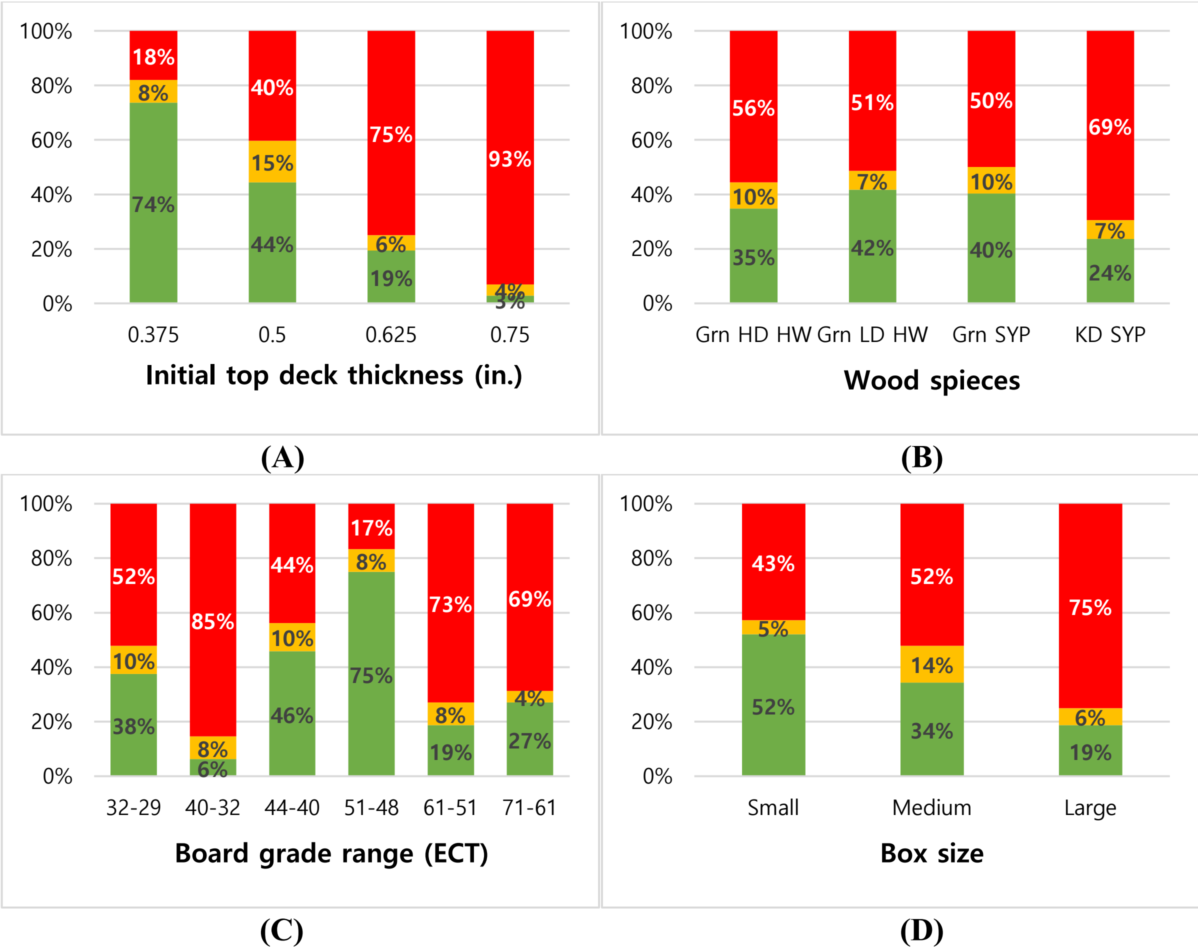
The concept of a unit load cost optimization method that allows for the use of corrugated boxes with decreased board grade by increasing the pallet's top deck thickness was adopted from Quesenberry as a way of modifying each unit load scenario. In other words, the analysis was done by determining how much the top deck thickness needed to increase in order to lower the board grade by one level from the initial unit load scenario's specific deck board thickness and board grade. Finally, the amount that the top deck thickness increased was color-coded into one of three grades for better visualization and identification of the level of top deck thickness increase: green for less than 0.5 in. increase, yellow for 0.5 in. to 1 in. increase, and red for beyond 1 in. increase. Figure 2, below, displays changes in the proportions of the differently colored scenarios as a function of investigated variable factors.

- **Initial top deck thickness effect (Image 3A):** It was observed that as the initial top deck thickness increased, there were significant reductions in the proportions of green scenarios. Correlatingly, a considerable increase in the ratio of the red scenarios was found as the initial top deck thickness increased. This result revealed that when the boxes are shipped on pallets with thinner top deck thickness, increasing the the thickness of the top deckboard could be justified by the cost savings achieved by the reduction of the corrugated box board grade.

- **Wood species effect (Image 3B):** It was found that, as the lower stiffness wood species are used for pallet material, a larger number of them fell under green scenarios than the scenarios built with relatively stiffer species. This result indicates that pallets built with lower stiffness wood such as low-density green wood tends to have more opportunities to reduce the packaging cost by utilizing the effect of top deck stiffness on box compression strength. The optimization of pallets made of KD Souther Yellow Pine tends to be less feasible due to the stiffness of the material and also the limited deckboard thickness options available.

- **Board grade range effect (Image 3C):** It was discovered that as the difference in ECT levels between the two consecutive board grades increases, the proportion of green scenarios significantly drops, and the ratio of red scenarios increases. These results also indicate that the higher the initial board grade is, the more opportunities there are to reduce the board material with minor top deck thickness, mostly due to the heavier weight of the higher board grade boxes which will bend the pallet more initially. The higher initial board grade denotes a heavier unit load which bends the pallet more, leading to the same effect as a lower stiffness pallet.

- **Box size effect (Image 3D):** Finally, it was observed that as the packaging size increased, the ratio of green scenarios gradually decreased whiles the proportion of red scenarios increased. These results suggest that unit loads built with small-sized boxes will have more opportunities to experience significant changes from the effects of the top deck stiffness on the compression strength of asymmetrically supported boxes than unit loads consisting of larger boxes due to the lighter weight of the unit loads with larger-sized boxes.



* Green: less than 0.5 in., yellow: 0.5 in. to 1 in., red: beyond 1 in. increase.
** Grn HD HW: green high-density hardwood, Grn LD HW: green low-density hardwood, Grn SYP: green southern yellow pine, KD SYP: kiln-dried southern yellow pine.

Image 3. *Changes in the proportion of green, yellow, and red scenarios in response to the initial top deck thickness (A), wood species (B), board grade range (C), and box size (D).*

Conclusions:

The main conclusions of this study were as follows:

- The benefit of increasing a pallet's top deck thickness in order to reduce the corrugated board grade diminishes as the initial top deck thickness increases.
- The benefits of increasing the top deck thickness diminishes as stiffer wood species are used to build a pallet. The number of opportunities to improve unit load design was similar among the three green species, but it significantly declined when KD SYP was used.
- The effects were more conspicuous when the initial pallet was very weak, which meant that improved pallet quality and decreased unit load cost could be achieved using this approach.
- There were more possibilities of decreasing board grade when initial board grade variation was lower, or the initial board grade was higher mostly due to the heavier weight of the higher board grade boxes which will bend the pallet more initially.
- The benefits of increasing the top deck thickness decrease as larger-sized boxes were used due to the lighter weight of the unit loads with larger-sized boxes.
- The effects were more pronounced when the unit load had initially been designed with a heavier top load due to more severe initial pallet bending.

In conclusion, supposing that a company already uses unit loads consisting of lower stiffness pallets or small-sized, high-grade board, corrugated boxes, this study suggested that increasing top deck thickness and reducing board grade will provide extra cost-benefits and better pallet quality. The next phase of this project will focus on characterizing the environmental impact of the effect of increasing pallet top deck stiffness on box compression strength.

Research Highlight - Analysis of the Deck Board Stiffness Effect and the Location Effect on Unit Loads of Plastic Pails on Wooden Pallets *by Mary Paz Alvarez*

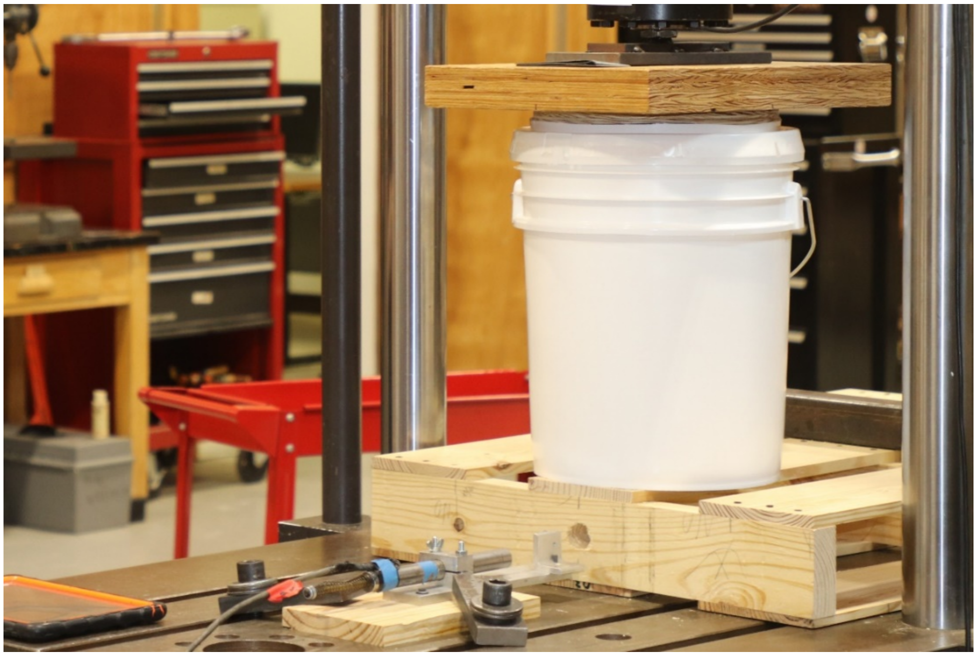


Image 1. Plastic pail supported on mini-pallet in MTS machine.

The supply chain is composed of three physical components: packages, transportation, and pallets. In order to efficiently design unit loads, it is integral to understand the interactions between these components. Previous studies have been done looking at how corrugated boxes interact with pallets throughout the supply chain. Flutes, box sizes, stacking patterns, and unit load containment have all been previously studied for corrugated boxes.

However, plastic pails are a different type of package that is mainly used to ship liquids and powders. The most common pail size is 5-gallons. Plastic pails are different than corrugated boxes in their geometry, materials, and stacking patterns. There is a lack of information about pails; unit load designers are unaware of how the plastic pails will interact with the same pallets that corrugated boxes are shipped with. The Center for Packaging and Unit Load Design conducted a previous study on unitized pails, but at that time, did not investigate the effect of plastic pail placement or how it relates to the deck board stiffness effect.

Image 2. Mary Paz Alvarez, PhD student

Mary Paz Alvarez, a Ph.D. student with CPULD (Image 2), is funded by the Pallet Foundation and the National Wooden Pallet and Container Association (NWPCA), and she has begun a new research project. Understanding how plastic pails interact with pallets will be useful information for designers, as they can use the info to design safer, more cost effective, sustainable unit loads. With that in mind, the objectives of this study were first to understand how pallets' deckboard stiffness affects the failure of unit loads of plastic pails. Second, they investigated how the amount of overhang of the plastic pails could affect the failure of unit loads of plastic pails.

The pails utilized in this study were 5-gallon open headed plastic pails. The test was conducted in an MTS machine which used a 5,000 lb. load cell to measure the amount of load forced onto the pail before it failed. Failure load was determined as being the highest amount of load that the plastic pail could handle before buckling; hence, no longer being able to handle any further increase in load.

The plastic pails were tested on a "small-scale pallet segment" that was composed of three stringers and two deck boards that had varying thicknesses of 0.375 in., 0.5 in., 0.625 in., and 0.75 in. Deck boards were placed on the stringers in such a way as to create gaps. The plastic pail location was investigated first in order to understand which locations presented the best- and worst-case scenarios for the plastic pail. They were tested in five locations; centered on the pallet, centered between stringers, on the edge of the pallet, 1.5 in. offset from the center stringer, and 2.6875 in. offset from the center stringer (Image 3). Five replicates were conducted for each location. Once the best and worst location were determined, which was the center of the entire pallet and the edge, an additional 5 replicates were conducted using the four different deck board thicknesses. An ANOVA analysis was also conducted using the failure mode data from testing.

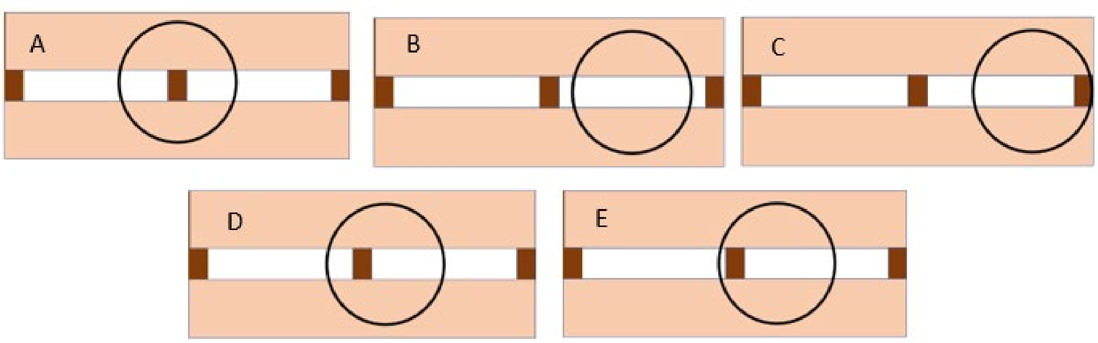


Image 3. A) Pail placed in center of pallet B) Pail placed in center of deck boards C) Pail placed on edge D) Pail with 1.5 in. offset from center E) Pail 2.6875 in. offset from edge.

The results indicate that the largest difference between locations was seen between the plastic pail that was centered on the pallet and the plastic pail placed on the edge of the pallet. This is due to the difference in where the load is being transferred. When the pail is in the center, the pressure from loading is distributed evenly on the pallet's center stringer while the pail on the edge is forced to unevenly distribute the force onto the end stringer on which it rests. The more symmetrically a pail can distribute its pressure, the higher the failure load (Table 1).

Plastic Pail Location on Mini Pallet

	Edge of Pallet	Centered on Pallet	Centered between Stringers	1.5 in. Offset	2.6875 in. Offset
Average Failure Load (lbs.)	1304.72	2188.4	1837.58	1861.52	1720.41
Coefficient of Variance	1%	3%	2%	2%	4%
Statistical Level	D	A	B	B	C

Table 1. Results from the location effect testing on pails on the 0.375 in. thick small-scale pallet segment.

Once the best- and worst-case locations were determined, both locations were tested with all four pallet deckboard thicknesses. When analysis was conducted, it was found that the location of the pail, the thickness of the deck board, and the interaction between the two were all statistically significant. Also, the effects of the varying thicknesses of the pallet deck boards were all statistically different, but the 0.625 in. and 0.5 in. thicknesses produced similar average failure loads. When the pails are supported around the edge of the pallet, the effect of deckboard stiffness is more prominent, causing a 32% reduction compared to the 15% reduction when the pails were supported around the center for the pallet. The failure loads of each location illustrate a trend where the stiffer the deck board, the more load that the pail can receive before failing (Table 2 and Table 3).

	Deck Board Thickness of Tested Mini Pallet			
	0.75 in. (Control)	**0.625 in.**	**0.5 in.**	**0.375 in.**
Average Failure Load (lbs.)	1,910	1,665	1,663	1,298
Coefficient of Variance	6%	3%	5%	4%
Difference compared to control		-13%	-13%	-32%

Table 2. Results from the deck board stiffness effect testing on pails when placed on the edge of the small-scale pallet segment.

	Deck Board Thickness of Tested Mini Pallet			
	0.75 in. Control	**0.625 in.**	**0.5 in.**	**0.375 in.**
Average Failure Load (lbs.)	2,474	2,345	2,355	2,097
Coefficient of Variance	3%	3%	3%	3%
Difference compared to control		-5%	-5%	-15%

Table 3. Results from the deck board stiffness effect testing on pails when placed on the center of the small-scale pallet segment.

Based off of the sets of experiments that were conducted for this research project, the conclusions that have been determined revolving around plastic pail performance on mini pallets are as follows:

- The location of the pail on the pallet has significant effect on the pail strength. This phenomenon could be explained with the asymmetric load distribution observed when one edge of the pail was supported on the stringer of the pallet. The finding is similar to what was observed for corrugated boxes.

- Deck board thickness is statistically significant and can affect the performance of a plastic pail. However, the magnitude of the effect is more pronounced when the pail is asymmetrically supported around the edge of the pallet.

The results of the experiment indicate that unit load designers can incorporate the concepts of pail placement and pallet deckboard thickness into the unit load design process. This will help designers use the stiffness of pallet top deck to reduce the amount of plastic used for pails.

Graduate Student Spotlight – Clark Sabattus, M.S. candidate

Image 1. Clark Sabattus, Arlington, TX

Clark Sabattus came to CPULD after getting his undergraduate degree at NC State in Sustainable Materials and Technology. Clark started out getting a business degree, but found his passions lay in learning more about sustainability. He grew up in Arlington, Texas with two brothers and four sisters. Due to his father's work, they transferred back and forth between TX and Raleigh, NC during Clark's growing up years, and many of his siblings still reside in NC. Clark's hobbies include hiking and playing basketball. He also enjoys watching baseball, and he enjoys learning.

When asked what brought him to VT, and to CPULD in particular, Clark told us, "My professors at NC State had mentioned the Center for Packaging and Unit Load Design at Virginia Tech and had told me to research and see if I was interested in the possibility of obtaining my master's degree. Needless to say, after looking into the Department of Sustainable Biomaterials, and more specifically CPULD, I was more than impressed with the amount of real-world applications and hands-on experience that the graduate students experience."

Clark will be helping CPULD update our FasTrack testing procedures by investigating the magnitude of impacts that pallets experience during material handling operations. He explained further by saying, "I expect to discover a wide variation in the magnitude of impacts from warehouse to warehouse, as each warehouse has its own system of operations. I expect to see warehouses operating under heavy time constraints to have harsher impacts on a pallet."

When asked how his research will help the industry, Clark explained, "this data will give an insight into the real-world application of the durability of pallets in industries supply chains. The results from this research will allow industries to make informed decisions on which pallets they want to use for distribution. Pallets are a vital part of large-scale distribution, being able to make the correct decision on pallet design will improve the efficiency of distribution as a whole."
The data Clark collected will allow the Center to develop better pallet durability testing standards, and help companies to both better estimate the durability of their pallets and design more efficient pallets.

Lastly, we asked Clark what were his future career goals. He told us, "my current career goal is to be able to work in some aspect of supply chain management and distribution. Working in the CPULD lab will prepare me for my future career as it provides for me the opportunity to understand testing procedures, and how they are implemented. CPULD and the Department of Sustainable Biomaterials do a fantastic job of making sure that their students are well-networked, giving them as many opportunities to pursue their goals as possible."

News - CPULD using new software, PowerBI, to analyze finances & prepare for future projects

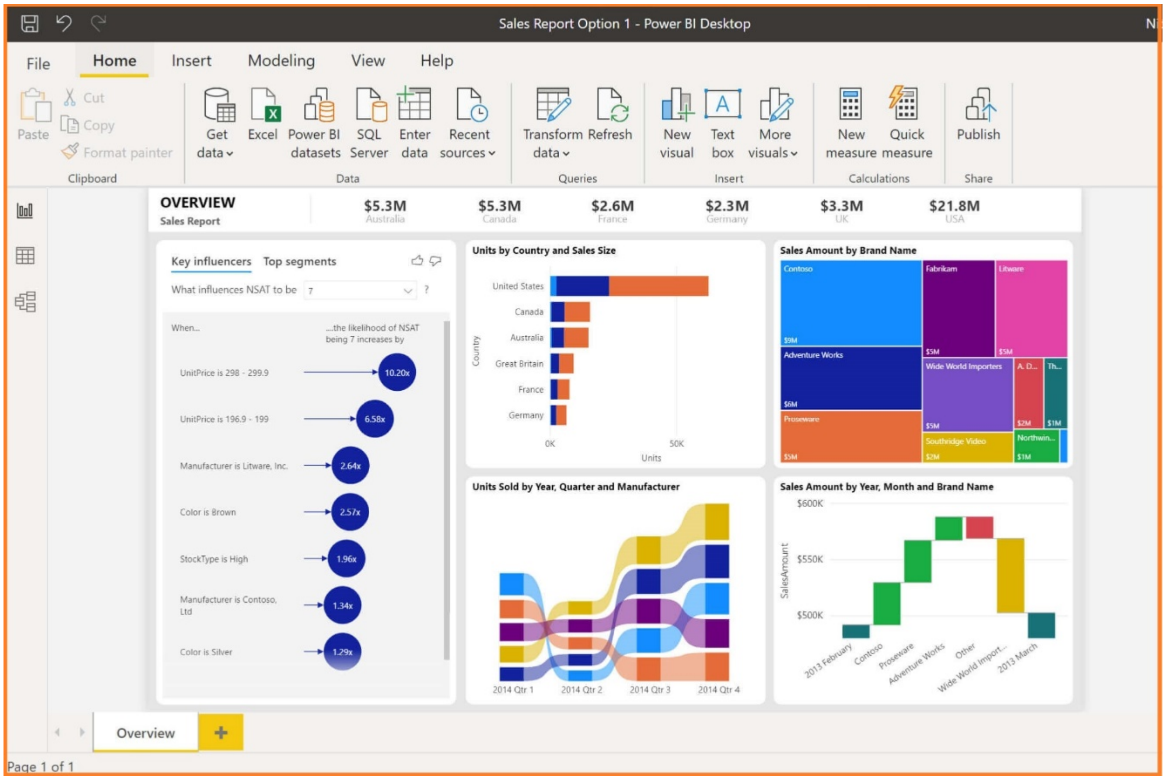


Image 1. PowerBI screenshot showing various graphs and pictograms pulled from excel sheets of data.

The Center for Packaging and Unit Load Design (CPULD) has always been committed to providing our industry partners with the best possible testing services at the best possible prices, while also remaining focused on teaching our students to be great future employees with all the skills necessary to function productively in an industry role. One of the recent upgrades that we've implemented into our system is the use of the PowerBI software to analyze our finances – both our spending and our income – as well as using this software to help plan the future of our testing labs!

As described on a PowerBI webpage: "Power BI is a collection of software services, apps, and connectors that work together to turn your unrelated sources of data into coherent, visually immersive, and interactive insights. The data may be an Excel spreadsheet, or a collection of cloud-based or on-premises hybrid data warehouses. Power BI lets you easily connect to your data sources, visualize and discover what's important, and share that with anyone or everyone you want."

As with most data crunching softwares, the data itself comes in the form of many different types of files, though CPULD uses mostly Excel, with different variables for each data point. PowerBI is able to combine and link these files (Image 2) and prepare various types of graphs and pictograms which make the data easy to understand (Image 1) for a user who may not be as familiar with in-depth financial spreadsheets.

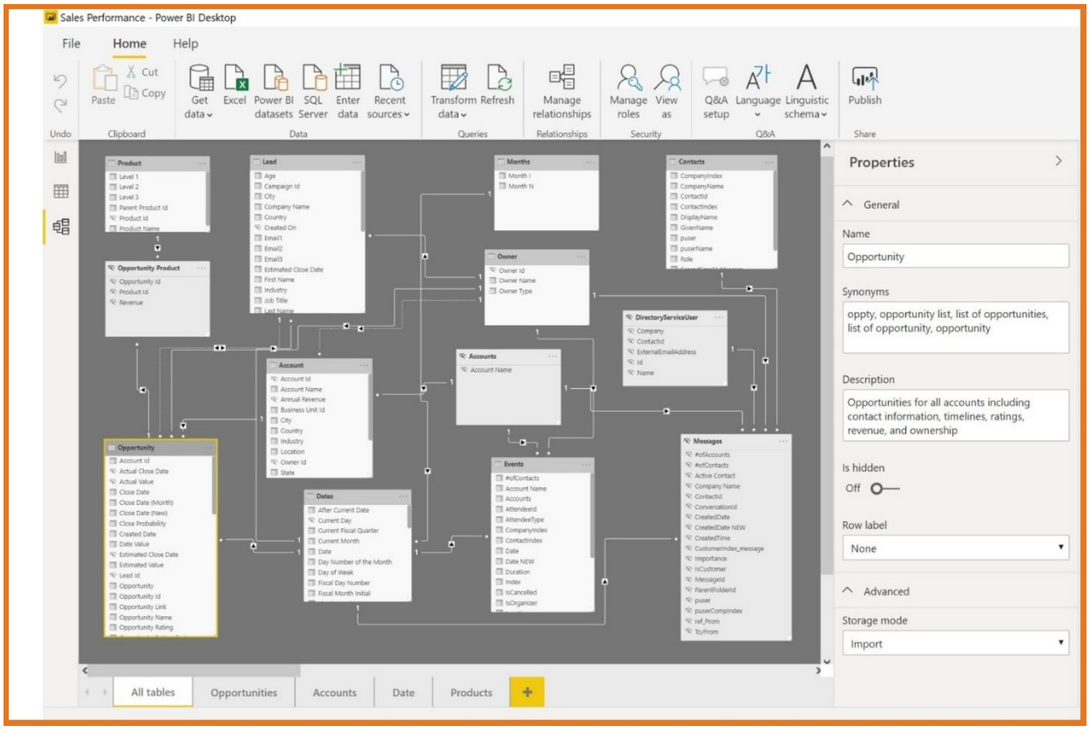


Image 2. PowerBI screenshot showing linking capabilities between various files and data points.

Being able to see all of our financial and lab data combined and displayed through PowerBI means that we can easily tell which tests are the most requested by our clients, which tests are the most financially productive for our labs, and which sections of the lab and which specific equipment would most benefit from upgrading. We are also able to see which of our customer types are utilizing which testing services most often. All of this info was always buried in the data, but knowing it will help CPULD better plan for the future!

News – ISTA Certifications for CPULD Graduate Students

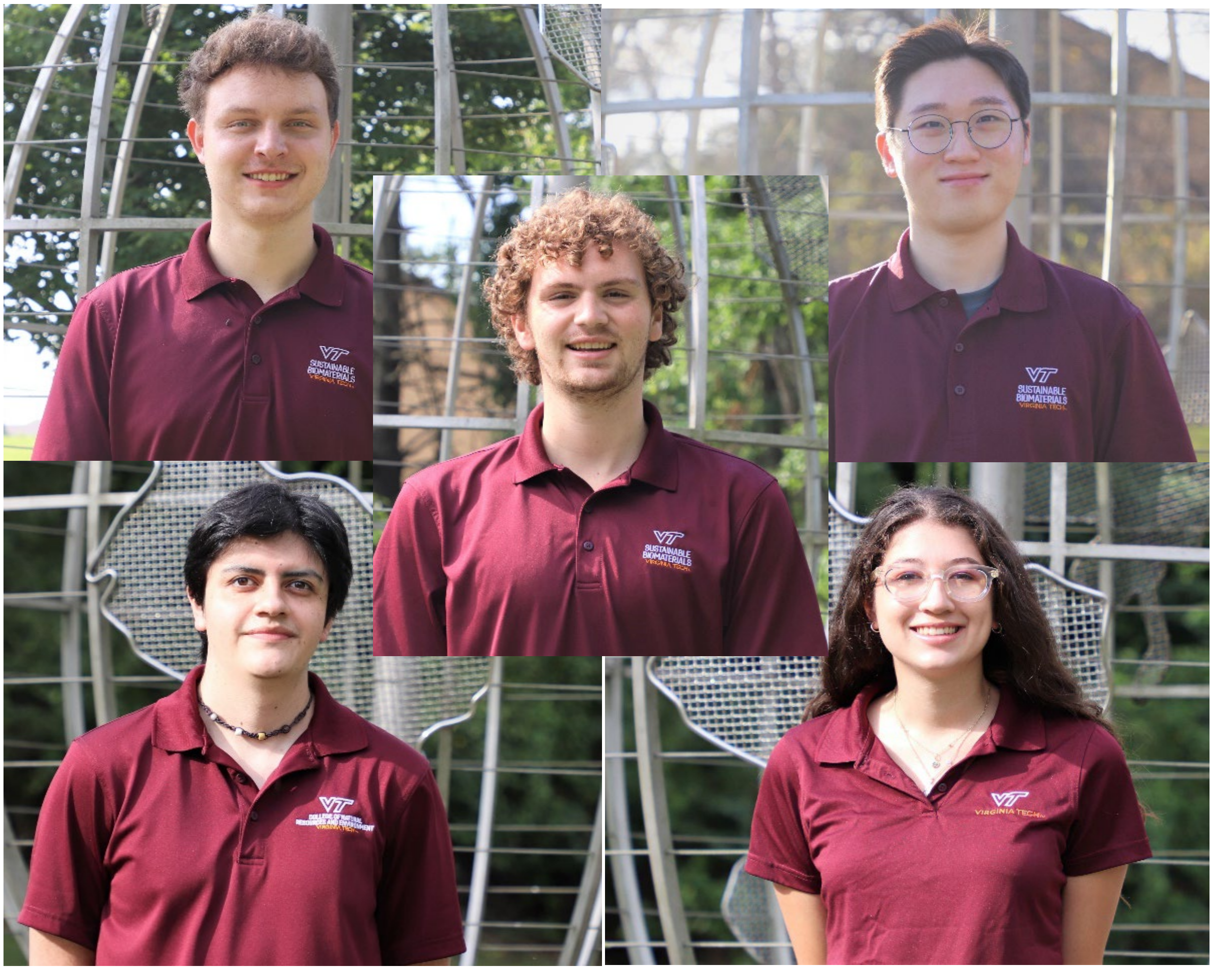


Image 1. (center) Joe Keller, (top left – then clockwise) Clark Sabattus, Saewhan Kim, Mary Paz Alvarez, and Jorge Masis

The Center for Packaging and Unit Load Design (CPULD) is always striving to make sure our workers are the most knowledgeable around. Our goal is for all of our students to graduate as excellent future employees for our industry members. They receive training and attend courses both through the university and through industry partners in order to stay current with the knowledge and procedures needed to benefit the packaging and distribution industries. The Certified Packaging Laboratory Professional certification offered by the International Safe Transit Association (ISTA) is an excellent way for packaging professionals to showcase their understanding of the distribution packaging design and ISTA testing process.

Usually, these certifications are completed by industry professionals, but years ago, CPULD decided that all of its undergraduate student would complete the training needed to receive the basic level of certification, called the Technician Level. After receiving the Technician certification and the necessary lab experience, all of our graduate students will move up to the Technologist Level of certification. This ensures that when an industry member brings a question or project to CPULD, they know that it will be researched or completed by individuals who are qualified and certified to find the answers they need.

This year, we have already had graduate students, Mary Paz Alvarez, Jorge Masis, Saewhan Kim, Clark Sabattus and Joe Keller earn their Technologist level certificates thru ISTA. Congratulation to all of our talented students.

News – CPULD’s annual membership meeting was held virtually again in 2021

Image 1. CPULD’s Gold and Silver level member company logos.

During the Center for Packaging and Unit Load Design’s annual Industrial Affiliate Membership meeting, held virtually during the first week of August, 2021, our graduate students gave presentations about research completed over the last year, members gave their input on what directions they’d like research to go in the future, and everyone was updated on the state of CPULD due to COVID-19, as well as the past year’s renovations and budget.

Most of our students’ research projects are done at the request of industry partners, and are usually designed to satisfy questions or issues that have arisen in our partners’ supply chains. These leading companies are working with us to be at the forefront of innovative pallet and package research. We are collaborating to develop new, innovative ways to design pallets and unit loads, as well as finding ways to improve the sustainability of the packaging supply chain.

Over the past year, our graduate students have been researching the following topics, while also leading groups of undergraduate students who were conducting the research:

- Evaluation of the maximum pallet deflection under forklift handling conditions. (Yu Yang Huang)
- Investigation of impacts and damages observed by pallets during physical distribution. (Jorge Masis)
- Evaluation of the environmental benefits of increasing the stiffness of pallet top deck. (Saewhan Kim)
- Characterizing the environmental impacts of common e-commerce packaging options for sustainability-minded stakeholders. (Saewhan Kim)
- Evaluation of customer perceptions of e-commerce packaging. (Eduardo Molina)
- Evaluation of the effect of pallet top deckboard on pail compression strength. (Mary Paz Alvarez Valverde)

Each of the graduate students gave a presentation to the membership outlining the results of their research. The recordings of these presentations were uploaded to a shared, members-only folder. The results have already been made available as well.

During the second day of the meeting, our members had the chance to offer suggestions for the focus of next year's research projects. Eight graduate research initiatives were proposed and have been put to the membership for a vote, as well as five undergraduate research topics. The topics for CPULD's upcoming research projects have been decided upon and will be announced to the membership soon. Students will start working on the projects ranked first and work down the list until either all research options are complete, or the list is adjusted by another membership vote.

Our industry affiliate membership is a three-level program offering industry promotion, discounts on CPULD's services, and access to a wealth of knowledge and world-renowned experts. In addition, we foster a close relationship between our membership companies and their potential future employees — companies are regularly connected with our students during research projects, internship opportunities, and networking events.

CPULD is very excited about our 2021 research projects and the membership program's momentum. Join other worldwide companies in benefiting from an Industrial Affiliate Membership with the Center for Packaging and Unit Load Design at Virginia Tech.

News – CPULD partnered with ISTA for a webinar

Image 1. Opening screen of ISTA webinar given by Dr. Laszlo Horvath.

Dr. Laszlo Horvath, Director, Center for Packaging and Unit Load Design, partnered with the International Safe Transit Association (ISTA) over the summer to provide the industry worldwide with a webinar on the Measurement and Analysis of Industrial Forklifts Vibration Levels. During this webinar, Dr. Horvath summarized the results of his graduate student, Yu Yang Huang's, research on industrial forklift vibrations.

Forklifts are one of the most common material handling equipment used in warehouses and distribution centers. Vibration generated by forklifts may have an effect on the performance of unit loads and product damage rate. Historical research projects focused predominantly on the measurement of vibration for over-the-road transportation. Thus, there is a lack of understanding of the level of vibration caused by forklifts as a function of different factors such as speed, surface quality, forklift type and unit load weight.

The goal of this study was to understand how vibration experienced by forklifts is affected by factors such as speed, road conditions, unit load weight, type of forklift, and sensor location. For the study, power spectral density (PSD) was collected using data loggers. Vibration levels were measured for three different industrial forklifts (gas-powered forklift, electric-powered forklift, and reach truck) under two different types of surface (concrete and asphalt). The forklifts were driven at two different speeds (2mph and 3mph) while carrying two different unit load weights (1,500 lbs. and 2,500 lbs.). For all the conditions, the vibration levels were measured at the forklift carriage and fork tine tips.

The results obtained showed that the highest vibrational intensity occurred at 3-4 Hz, while the highest Grms value observed was 0.145 G2/Hz. An increase in the forklift speed caused an increase in vibration intensity. In contrast, an increase in the unit load weight carried by the forklift caused a decrease in vibration intensity. Among the three forklifts studied, the gas-powered forklift had the highest vibration intensity, and forklifts driven on asphalt experienced more vibration. The obtained forklift profile will be used to generate a dynamic test to assess the performance of the pallet on the forklift.

ISTA reached out to us about giving this webinar as this research project fell perfectly into ISTA's mission, vision, and values. ISTA strives "to empower organizations and their people to minimize product damage throughout distribution and optimize resource through effective package design and to be the leading inspiration and resource for improving our world through transport packaging globally. ISTA helps members control costs, damage, and resources during the distribution of packaged products by creating and publishing packaged-product test procedures; certifying packaging laboratories, packaged-products, and professionals; and by providing education, training and support."

News – Mary Paz Alvarez and Yu Yang Huang graduated this semester with Master's degrees

Image 1. a.) Mary Paz Alvarez with Dr. Laszlo Horvath and b.) Yu Yang Huang with Dr. Laszlo Horvath

The Center for Packaging and Unit Load Design congratulates Mary Paz Alvarez and Yu Yang Huang for passing their Master's defenses earlier this semester!

Mary's research was titled "Investigation of the interactions between the components of palletized drums and pails throughout storage and distribution." Her research was featured in a previous CPULD News article, which showed that wooden pallets should be designed for the specific type of packages they will be carrying in order to optimize the cost of the pallet and reduce the amount of raw materials used to manufacture wooden pallets.

After graduating in August, Mary stayed on here at CPULD as a Ph.D. student, where she is now focusing on building a Finite Element model to predict the effect of pallet stiffness on plastic pails strength. The results of her new project will be built into the Pallet Design System computer software, which will allow pallet designers to further optimize the pallets supporting plastic pails.

Yu Yang's research had focused on the "Evaluation of the maximum pallet deflection that occurs under forklift handling." His work was also featured in a previous CPULD News article, with results showing that an increase in forklift speed increases vibration intensity, while an increase in the forklift load weight decreases vibration intensity.

Yu Yang accepted a position as a Logistics Engineer with Alstom in Hornell, NY, and moved there a few months ago. CPULD misses him, but we know that he's a great addition to their team!

"I had a privilege to work with these exceptional students," said Laszlo Horvath, CPULD director and an advisor to both students, "and I am looking forward to see the difference that they will make in the packaging industry."

News – CPULD's first in-person short course since 2019 was a great success!

Image 1. Short course classroom

In November 2021, The Center for Packaging and Unit Load Design (CPULD) offered its first in-person short course since 2019. The newly developed Advanced Wood Pallet Design short course was held in conjunction with the National Wooden Pallet and Container Association (NWPCA) and was an intensive three-days of classes that taught attendees techniques that could help them save money when designing pallets by considering the interactions between all of the components of the material handling system.

The instructors (Dr. Laszlo Horvath, CPULD Director; Dr. Brad Gething, VP NWPCA; and Kristen DeLack, professional engineer, NWPCA) informed attendees about the advanced principles of pallet design, how to conduct material handling audits, and the basics of packaging and pallet design as well as material handling systems. They learned about the interactions between material handling equipment, packaging, and pallets, as well as how to diagnose and solve their material handling problems. The course used a state-of-the-art pallet design software called the "Pallet Design System" (PDS) to better demonstrate the steps that go into the pallet design process.

This course had 34 people registered for it. Attendees were from all over the USA, including CA, FL, GA, KY, MN, NC, NY, OH, PA, SC, TX, WI, as well as from Canada, Scotland, and Mexico. Everyone had great discussions about pallets! And while this course was designed to be delivered in-person, CPULD also offered a virtual option with live participation. Webcams and virtual meeting softwares were used to include the approximately 50% online attendees in the live assignments and discussions.

The Advanced Wood Pallet Design short course received high grades on the satisfaction survey that was conducted after the course. Of those who responded, 94% felt that the course provided all the knowledge they had come to learn, and said that they would be recommending the course to others in their company and industry.

Pallet design is an integral part of the material handling system. Wood pallet suppliers, designers, and sales professionals, professionals responsible for pallet purchasing, packaging engineers and pallet specifiers, as well as corrugated box designers all benefited from gaining an understanding of how to design pallets that last longer and perform better.

If you are interested in learning more about the short courses that CPULD offers, please visit the continuing education page: https://www.unitload.vt.edu/education/continuing-education.html

Sign up for CPULD's mailing list: http://eepurl.com/db45eD

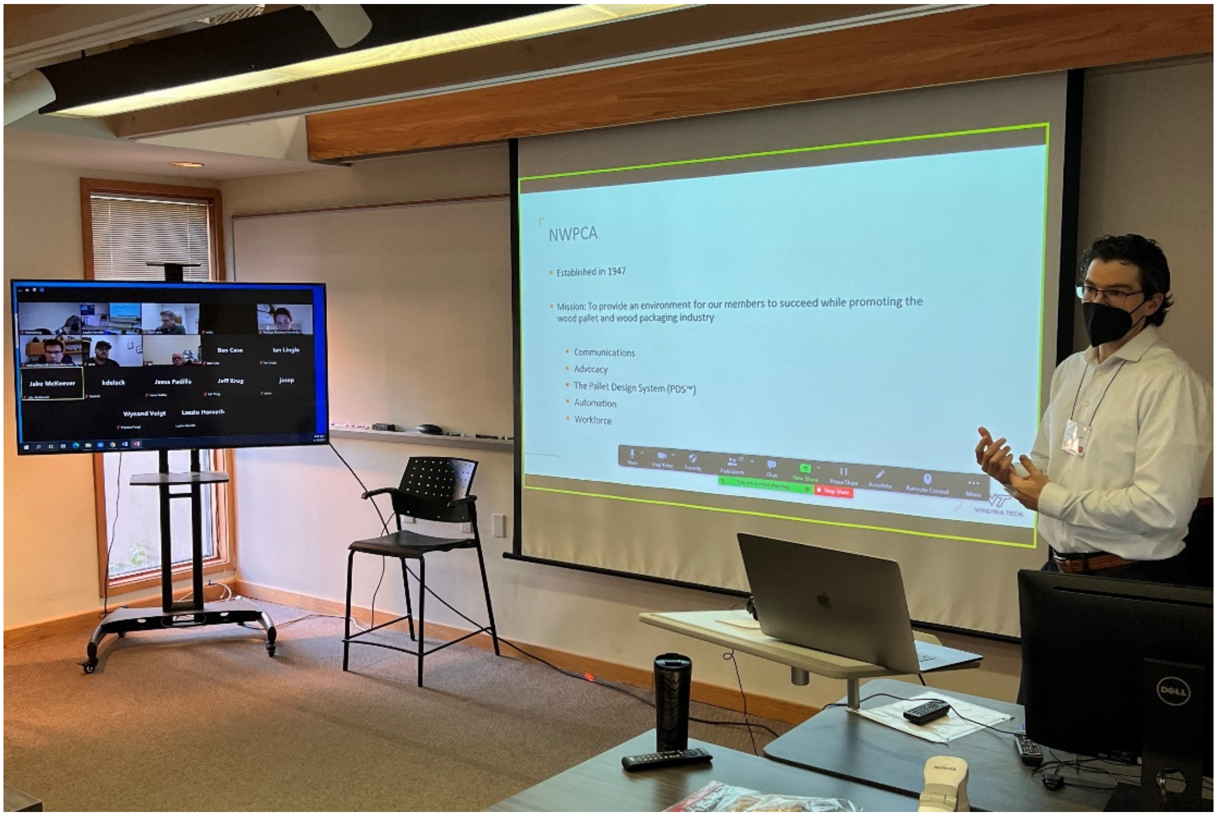


Image 2. Brad Gething speaking about NWPCA

News - COVID Update

Image 1. Hokie Bird

https://www.unitload.vt.edu/about-us/covid-19-updates.html

Message from the Director, Dr. Laszlo Horvath.

Currently, CPULD is open and working with full speed. The safety of our students and staff is our utmost priority; therefore, to protect our staff and students, we have implemented many safety measures such as enhanced cleaning of the laboratory, required mask wearing, and social distancing.

The current lab safety protocols are outlined below:

- We are observing social distancing and limiting contact between technicians.
- All technicians are required to wear masks at all times.
- We are disinfecting regularly touched surfaces every morning.
- We are open to outside visitors, but we require all visitors to wear a mask.
- For clients who would like to see the testing process but cannot travel, we have the ability to show the tests through video calls.

If you would like to learn more about our labs' availability, please contact me!
And / Or check back here for regular updates!

Thank you!
Laszlo Horvath

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~ Continuing Education Opportunities ~

2021-2022 Webinars

CPULD is pleased with the response to our webinars. Over 2021, Director Laszlo Horvath gave multiple separate lectures, which were free to our members. In 2020, CPULD partnered with NWPCA in offering a series of webinars designed to help train the industry on various new aspects of NWPCA's Pallet Design System (PDS) software which is regularly updated with research findings from CPULD projects. Overall, our webinars have reached over 680 attendees in 17 countries. If there are any topics in particular that you or your company would be interested in, please feel free to suggest them to us! Stay tuned to learn when 2022 webinars are announced!

Wood Pallet Design and Performance Short Course, TBD 2022

Pallet design is an integral part of the material handling system. Wood pallet suppliers, sales professionals, professionals responsible for pallet purchases, packaging engineers, and pallet specifiers will all benefit from an understanding of how to design pallets that will last longer and perform better.

This intensive three-day short course will teach techniques that pallet designers can use to save money when designing pallets by considering the interactions between all of the components of the material handling system. The course will use state-of-the-art pallet design software called the Pallet Design System (PDS) to better demonstrate the steps that go into the pallet design process. You will also be taken on a tour of a working, state-of-the-art, pallet testing laboratory!

Unit Load Design and Performance Short Course, TBD 2022

Unit load design is a revolutionary, systems-design approach that significantly reduces the cost of distributing products to consumers by understanding how pallets, packaged products, and handling equipment mechanically interact. Unit load design is a new and valuable service that pallet, packaging, and handling equipment suppliers can offer their customers.

This intensive three-day short course will teach techniques that pallet and packaging designers can use to save money on corrugated board and plastic packaging materials when designing pallets and packages by considering the interactions between all of the components of unit loads. The course will use a state-of-the-art unit load design software called Best Load to better demonstrate the steps of the unit load design process. You will also be taken on a tour of a working, state-of-the-art, packaging and pallet testing laboratory!

To learn more or register for these courses, visit:
www.unitload.vt.edu/education/continuing-education/

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