Spring 4-17-2020

Optimization of Vinyl Flooring Packaging

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10 April 2020

Executive Summary

Mohawk Industries, Inc. is one of the leading flooring manufacturers of the world. Mohawk supplies various types of flooring to various markets around the world like the contiguous United States and Southeast Asia. A significant aspect of Mohawk that allows the organization to supply quality flooring products to various markets around the world is their packaging. Recently however, the company has been experiencing damages to their packages being shipped to Southeast Asia, specifically their vinyl flooring packaging. As a result, this team was created with goal in mind of formulating a solution to eliminate the damaging of vinyl flooring packaging transported to or from Southeast Asia. Research was conducted to determine possible causes of the problem, and to develop potential solutions to the cause of the problem. The result of the research conducted determined the most likely cause of the damaged packaging to be that the packaging lacked impact protection and/or the packaging sealant to keep packages closed was being compromised during transport. Our team developed three possible solutions that could be implemented to address the packaging impact protection and/or security:

- Solution 1: Increase the thickness of the cardboard used for packaging to increase the impact protection of packages.
- Solution 2: Use tape to secure packages to a pallet to increase the stability and security of packages on a pallet during transport.
- Solution 3: Place dunnage (bubble wrap) on the two ends of a pallet where packages experience the most damage during transport to increase the impact protection of the packages.

Our team conducted both quantitative analysis (cost-benefit) and qualitative analysis (aesthetic) to determine which of our solution could resolve the issue being experienced. We determined each solution to be a viable option to implement for Mohawk Industries to eliminate damage to their packaging. Unfortunately, we were only able to submit one of our solutions to ISTA (International Safe Transit Association) for testing of the solutions impact protection and security, so we elected to test solution 1 (thicker cardboard), prior to our designing of solution 2 (tape) and solution 3 (dunnage). The thicker carboard solution submitted to ISTA for testing was able to pass all the tests administered, and thereby being able to address the issues of insufficient packaging impact protection and insufficient packaging security. As a result, our final recommendation to Mohawk Industries was to implement solution 1 (thicker cardboard) because:

- Solution 1 was submitted and passed ISTA testing
- Solution 1 would not add additional steps to Mohawk Industries' packaging process
- The savings made as a result of implementing solution 1 were quantifiable
- More testing (ISTA) would be needed to prove the efficacy of the redesigned versions of solution 2 (tape solution) and solution 3 (dunnage solution)

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Chapter 1: General Information

1.1. Introduction

Mohawk Industries, Inc. is one of the leading flooring manufacturers of the world. The company is headquartered in Calhoun, Ga and maintains a network of facilities around the world. Locally, Mohawk Industries operates several facilities within the state of Georgia that supply flooring internationally. More specifically, Mohawk Industries operates facilities that supply flooring as local as within the contiguous United States and as far reaching as Southeast Asia. Additionally, Mohawk Industries has been able to maintain and increase their revenue stream by providing high-quality products. An instrumental part of their ability to supply high quality products to consumers is the packaging used to protect their flooring goods during deliveries and shipments. Recently, Mohawk Industries has noticed failures in the integrity of the packaging of their flooring products, specifically their vinyl flooring being delivered to Asia. As a result, a project team was created to address the packaging integrity failures of vinyl flooring packaging.

1.2. Objective

The objective of this project is to design and implement improved packaging for the cartons containing vinyl flooring being transported to Asia. The goal of improving the packaging will be to ensure that the integrity of the vinyl flooring packaging is maintained during shipments, meaning the cartons arrive at their destination unopened and the flooring inside remains intact. The method that proves to be the most cost effective as well as the most efficient in maintaining the integrity of the packaging as well as the contents of the packaging will be the method that is suggested to be implemented to reduce extraneous costs and in turn increasing revenue. Depicted in Figure 1 is an example the current packaging design and the damages that to be targeted for elimination.

Figure 1 Depicts damaged vinyl flooring packages

1.3.Justification

Mohawk Industries has had a continuous struggle dealing with damages to their vinyl flooring packaging, and thus their vinyl flooring, being shipped to Asia. These damaged products are causing a notable loss of money for the company as well as customer dissatisfaction. A more effective packaging method would reduce these losses and potentially create higher customer satisfaction in the process.

1.4. Project Background

The project involves working with the packaging engineers at Mohawk Industries to gain information on the shipping and receiving processes of the vinyl flooring produced from the facility. The packaging method is done by machines using a cardboard material. Figure 2 depicts the percentage of revenue lost due to cartons being damaged. Currently, Mohawk Industries generates approximately $12,265,000.00 in revenue annually from sales of vinyl flooring in Asia. Of the revenue generated, one percent or approximately $122,650.00 is lost due to damages and returns. Included in the amount of money lost to damages and returns is also the cost of product that is still considered sellable.

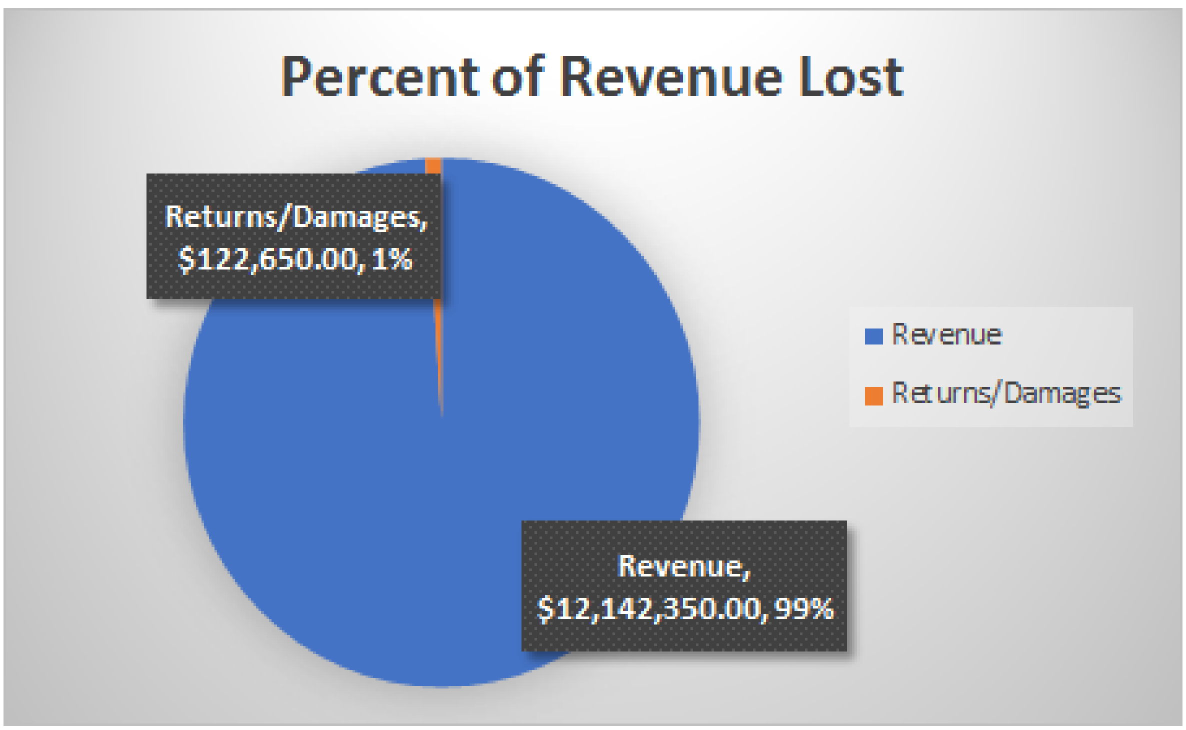


Figure 2 Annual revenue from vinyl flooring and expenditure due to damages and returns

1.5. Problem Statement

Vinyl flooring sent from China and Vietnam are being delivered to Mohawk Industries with open and damaged packaging. As a result, the vinyl flooring is also being damaged. This is a recurring issue the company has had with packaging as the role of the package is to get the product safely

Figure 3: Depict examples of current packaging and damages

through the supply chain and on to the customer's home. The purpose of this project is to optimize the packaging of the vinyl flooring to prevent or reduce financial loss and customer dissatisfaction. Figure 3 depicts damaged cartons being received.

Chapter 2: Literature Review

This project will be Mohawk Industries' first change to their packaging for vinyl flooring to reduce damages, loss, and customer dissatisfaction. Traditionally, commercial packaging was designed with the goal of the total package system and product being transported through the supply chain with minimal damage to the packaging and/or the product being housed within the packaging [1, 10]. Numerous items of countless shapes, sizes, types, and functions are transported from manufacturing plants to distribution centers, retail outlets, or in some cases directly to the consumer. Despite the frequency of the usage of supply chains, many products and/or their packaging are damaged during transportation process, handling process, or at other points within a supply chain. Each component of the supply chain package design, manufacturing, transportation, warehouse/distribution, as well as natural causes can be a source of damage [6, 11]. The material and strength of packaging and/or the design of the packaging is fortunately a possible source of damage that can and often is controllable. The more appropriately designed a packaging is the more effectively the packaging will protect the product(s) housed within. Considering the economic costs and benefits of various materials, designs, and applications, the questions that must be addressed are what the most effective packaging solution is and how can it best be implemented [1]. A sustainable packaging development model (SPD) is defined with respect to the three variables:

- Technical design - Optimization of packaging structure and material (material avoidance) to product protection.
- Supply chain design - An extension of the technical within the supply chain system (process covers from design to post- consumption) in order to reduce waste and protect the product.

- Environmental design - Increase material reuse and reduce disposal whilst reducing CO_2 emissions throughout the supply chain

In order to achieve the maximum amount of product protection (adequate amount of material) and an efficient packaging design (reduction of waste) the compression strength of the packaging design is the primary property to balance package integrity and waste [1, 4]. The technical design of the box must maintain its structural integrity in three different stages and for each of these stages there are three different impacts (Primary, Secondary and Tertiary). The primary level being the interaction between the filler and end user, the secondary is used to manage the distribution of individual units in an optimal number within a supply chain, and the tertiary packaging is mainly responsible for the logistics processes such as warehousing and transportation [1]. In addition to the packaging materials used being a potential source of damage, how shipments are transported can influence if packages become damaged. A common source of damage related to transportation are shipments being damaged due to being improperly secured. Specifically, during ocean voyages it is common for cargo to shift due to turbulent waters if not secured properly [11, 12]. Shifts in the cargo being transported could potentially lead to damaged packages. Unitization is typically an effective method utilized to assist in the proper loading and securement of cargo during transport along with the addition of securing aids like tape and dunnage, and if done correctly can be very effective [12].

Packaging influences a consumer’s purchase. Consumers desire packaging that is effective in its purpose (shield purchased goods) but is aesthetically pleasing as well [5, 7, 10, 15]. Though the packaging may not affect the product being housed in some cases, consumers have a tendency to gravitate towards products with aesthetically appealing packaging [5, 15]. Based on the responses of 395 consumers to a survey focused on highlighting the effects of packaging quality on consumer purchases, 86% agreed that quality influences their buying process [14, 15]. The term quality is applicable to every aspect of the packaging, including, but not limited to, the appearance of the packaging [14, 15]. Evident in the results of the survey, consumers desire packaging that is safe, functional and aesthetically pleasing. Table 1 illustrates the results of the survey.

		Frequency	Percent
Valid	Strongly disagree	9	2.0
	Disagree	28	7.0
	Neutral	20	5.0
	Agree	170	43.0
	Strongly agree	168	43.0
	Total	395	100.0

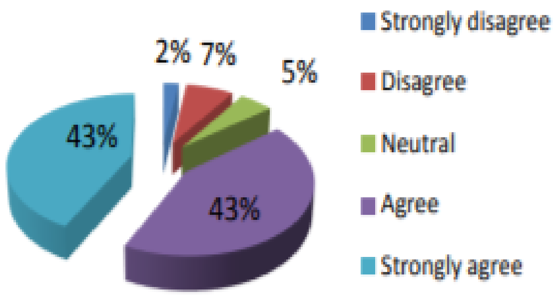


Table 1: Results from study conducted by source

One of the most widely utilized methods for packaging is utilizing corrugated fiberboard. Since the legalization of corrugated box in packaging, corrugated box packaging has been in use for over 100 years [2, 4, 8]. Corrugated fiberboard is used to transport a variety of goods including, but not limited to, electronics, cosmetics, pharmaceuticals, flooring, etc. Corrugated board is a widely used form of packaging due to its light weight, low cost, anti-vibration ability, good-sealing performance, amongst numerous other qualities that are unique to corrugated board [2]. Due to the usage of corrugated board for packaging in a wide variety of fields, copious amounts of research has been conducted to determine an optimal method to utilize corrugated board since its legalization for packaging [4, 8].

In addition to the usage of corrugated fiberboard, unitized loads are also a common tactic employed in supply chains to increase the number of products that can be transported in a single shipment and increase the ease of handling a product. Unitized loads typically refer to a pallet containing a quantity of individual units of a single commodity secured together to be handled as a single unit for transportation purposes [12]. Unitized loads typically require the usage of materials to properly secure units together, including but not limited to tape and dunnage. Dunnage refers to the various materials or devices used to keep cargo secure during transport. Bubble wrap is a common form of dunnage used in transportation due to its relatively inexpensive cost, lightweight, and its provision of impact protection to products [3, 9, 12]. Due to the shipping of unitized loads, products can be more easily transported in greater quantities across various modes of transportation.

Chapter 3: Measurement

3.1. Problem Solving Approach

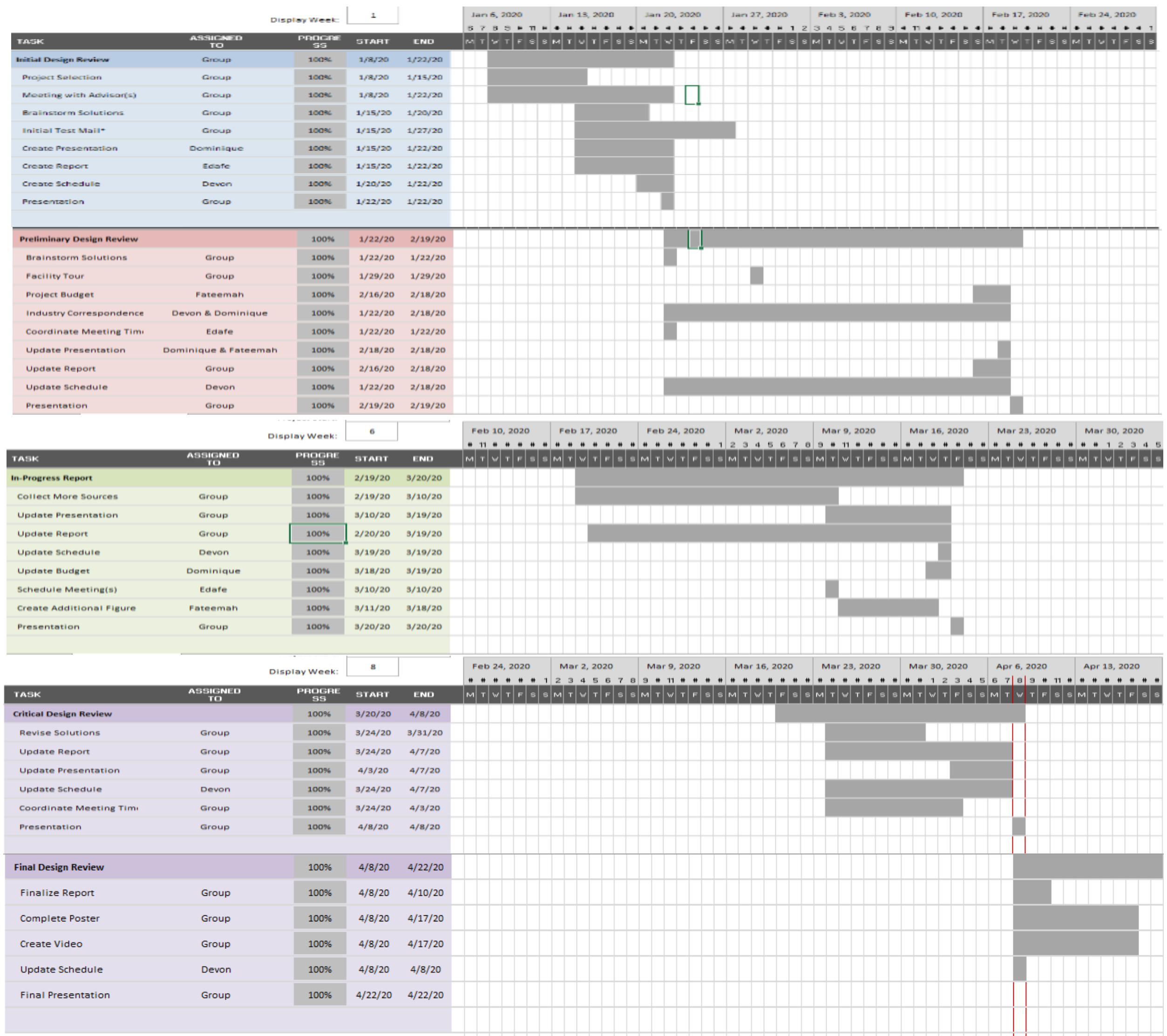
The first step taken to solve this issue was inspecting the packaging used for the vinyl flooring. We will be able to physically see and feel the packaging to get a better understanding of the materials we would be working with. After analyzing the packaging, we will research and contemplate alternate packaging methods that could be utilized effectively. Once we have brainstormed, we will minimize our possible solutions to three optimum solutions. The goal of each possible solution will be to increase the impact protection of the product and packaging and/or increase the secureness of the product and packaging to limit the packaging and thus the product from being damaged. For each of our three possible solutions a cost analysis will be completed to see the cost difference. Once the cost analysis is completed it will be compared to the amount of revenue lost due to damage. The product will also be sent to an ISTA facility to measure durability under multiple conditions to see which method is most durable. Once all analyses are conducted then we will compare each to see which will be most effective and/or beneficial to the company.

3.2. Requirements

The requirements for the project include dimensions, weight of material, durability of the package such that it can protect the vinyl tile from damage. The ease of transportation of the product is another factor that will be considered. It is required we maintain consistent contact with the advisor, Wes Rager, at Mohawk Industries to maintain a mutual understanding of the progress of the report. An additional requirement is that the solution to be implemented will be constrained by the current machinery in place, meaning a design overhaul of the current packing will not be possible to implement.

3.3.Gantt Chart/Schedule

The Gantt chart below (Figure 4) shows the present status of the project, task assigned to team members as well as task completion dates and estimated project completion dates. The schedule has been updated to reflect the tasks and work done during our project.



TASK	ASSIGNED TO	PROGRESS	START	END
Initial Design Review	Group	100%	1/8/20	1/22/20
Project Selection	Group	100%	1/8/20	1/15/20
Meeting with Advisor(s)	Group	100%	1/8/20	1/22/20
Brainstorm Solutions	Group	100%	1/15/20	1/20/20
Initial Test Mail*	Group	100%	1/15/20	1/27/20
Create Presentation	Dominique	100%	1/15/20	1/22/20
Create Report	Edafe	100%	1/15/20	1/22/20
Create Schedule	Devon	100%	1/20/20	1/22/20
Presentation	Group	100%	1/22/20	1/22/20
Preliminary Design Review		100%	1/22/20	2/19/20
Brainstorm Solutions	Group	100%	1/22/20	1/22/20
Facility Tour	Group	100%	1/29/20	1/29/20
Project Budget	Fateemah	100%	2/16/20	2/18/20
Industry Correspondence	Devon & Dominique	100%	1/22/20	2/18/20
Coordinate Meeting Tim	Edafe	100%	1/22/20	1/22/20
Update Presentation	Dominique & Fateemah	100%	2/18/20	2/18/20
Update Report	Group	100%	2/16/20	2/18/20
Update Schedule	Devon	100%	1/22/20	2/18/20
Presentation	Group	100%	2/19/20	2/19/20

TASK	ASSIGNED TO	PROGRESS	START	END
In-Progress Report		100%	2/19/20	3/20/20
Collect More Sources	Group	100%	2/19/20	3/10/20
Update Presentation	Group	100%	3/10/20	3/19/20
Update Report	Group	100%	2/20/20	3/19/20
Update Schedule	Devon	100%	3/19/20	3/19/20
Update Budget	Dominique	100%	3/18/20	3/19/20
Schedule Meeting(s)	Edafe	100%	3/10/20	3/10/20
Create Additional Figure	Fateemah	100%	3/11/20	3/18/20
Presentation	Group	100%	3/20/20	3/20/20

TASK	ASSIGNED TO	PROGRESS	START	END
Critical Design Review		100%	3/20/20	4/8/20
Revise Solutions	Group	100%	3/24/20	3/31/20
Update Report	Group	100%	3/24/20	4/7/20
Update Presentation	Group	100%	4/3/20	4/7/20
Update Schedule	Devon	100%	3/24/20	4/7/20
Coordinate Meeting Tim	Group	100%	3/24/20	4/3/20
Presentation	Group	100%	4/8/20	4/8/20
Final Design Review		100%	4/8/20	4/22/20
Finalize Report	Group	100%	4/8/20	4/10/20
Complete Poster	Group	100%	4/8/20	4/17/20
Create Video	Group	100%	4/8/20	4/17/20
Update Schedule	Devon	100%	4/8/20	4/8/20
Final Presentation	Group	100%	4/22/20	4/22/20

Figure 4: Gantt chart and schedule of tasks

3.4. Budget

Below is the tentative budget for the project (future expenses will be added as they are incurred):

- Shipping the package to ISTA Testing facility: Approximately $50
- Shipping the package to California: Approximately $60
- Shipping back to Georgia: Approximately $60
- Mohawk Industries waived the ISTA Testing fee.
- <$122,650 annually
- Must stay below cost of damages

3.5. Resources

Below is a tentative list of the resources that will be utilized (future resources may be added during the project's duration):

- ISTA Testing facility
- Mohawk Industries Inc. Calhoun Staff
- Wes Rager CPP Purchasing Packaging Engineer at Mohawk Industries

3.6. Responsibilities

During this project the roles currently established are Dominique Donahue will be the Project Manager. She will be the primary point of contact between the project group and Mohawk Industries and assists in the creation of the schedule. Edafe Oyibo will be the Project Coordinator. His tasks will include ensuring the project team is on track with schedule and assisting in the formulation of the project's budget. Devon Holloway will be the Technical

Expert which is the leading role in data analytics aspects of the project. Fatemeh Mafikouhini will be the Financial Officer. She will be overlooking the cost analysis and budget of the project. Any possible future roles will be determined and designated appropriately, if necessary.

Chapter 4: Proposed Solutions

4.1. Design Limitations

Before formulating the possible solutions to address the problem, we first identified the limitations proposed by Mohawk Industries. The primary limitation given to us by Mohawk Industries was that the new solutions proposed not require the purchase of new machinery. An ideal solution for the company would thus mitigate their recurring issues with damaged packaging while utilizing the machinery available. In addition to the limitations given to us by the company, there were additional limitations we had to account for during our formulation process: the weight of implementing our solution and the aesthetics of our solution implementation. Utilizing the current packaging process, a current truck load for transport consists of 22 pallets of 60 cartons of vinyl flooring and each pallet weighs approximately 1.9 tons. As a result, 1 truckload weighs approximately 41.8 tons, utilizing the current packaging methods. A truck has a maximum weight limit of 42 tons, so the current packaging method allows for the addition of approximately 0.2 tons or 200 lbs. (42 – 41.2 = 0.2). Therefore, any solution we would propose would be able to add no more than 9 lbs. per pallet or approximately 2 oz. per carton. The additional limitation our solutions had to account for was the aesthetics of implementing said solution. The aesthetics of an items packaging affects the likelihood of a consumer purchasing a product [5, 7, 10, 15]. Consequently, our team had to be sure to develop and implement our solutions in a way that would not negatively impact the aesthetics of the cartons. After contemplating our limitations, we then considered ways to solve our problem.

4.2. Solution Formulation

The current design of the packaging utilizes corrugated fiberboard. Corrugated fiberboard is a very popular packaging material due to its relatively light weight, durability, and countless other packaging advantages it offers over other packaging methods [2, 8]. During our solution formulation process, we decided to identify some of the possible causes for the packages being damaged. We were able to eliminate the possibility of customs damaging cartons. Since the cartons were palletized, one pallet containing 60 cartons was shrink wrapped, handled, and shipped as one-unit load, so customs agents were not opening unit loads to inspect cartons. The cause that we determined to be the most likely culprit, after meeting with our industry contact as a group, was that the packages being damaged lacked sufficient impact protection or were not being properly secured to avoid damages. As previously mentioned, one of the limitations of our solutions was the weight limit of approximately 2 additional ounces added to each package, so the materials we could use to aid in impact protection were limited based on the weight of adding the materials. After accounting for our limitations and determining our solution needed to increase the impact protection and/ or security of the cartons and their contents, our group formulated 3 separate solutions.

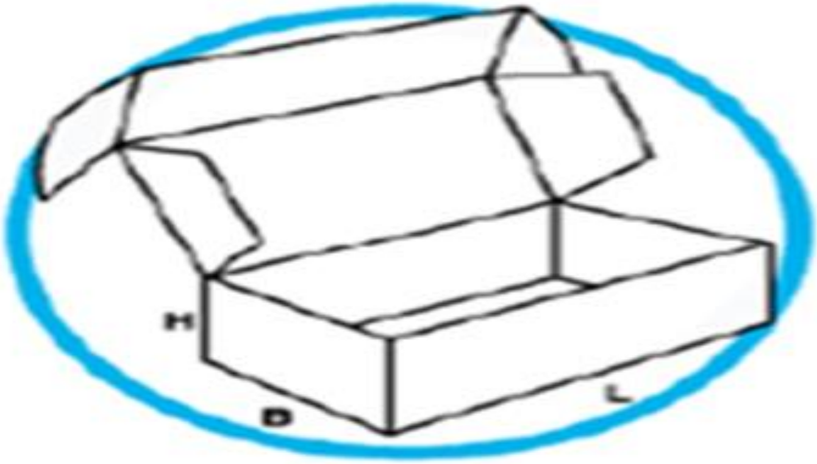


Figure 5: Model image of new design of packaging

4.2.1. Solution 1: New Design

The first solution we formulated was to come up with a new design for the packaging being used. Due to the limitation of not requiring the purchase of new machinery, our design would not be a complete re-design of the packaging, but instead our proposed design would require slight modifications to the current design (Figure 5). More specifically, our newly designed packaging would consist of using thicker cardboard for the current design, so the company would still be able to utilize the packaging machines currently in use and not require any costly changes to their packaging process. Our thought process behind using thicker packaging was based on the fact that the current material in use (corrugated fiberboard) is known for its impact protection [2, 8], so adding more of the current material may be an adequate solution to the problem of insufficient impact protection.

Figure 6: Model image of taped package

4.2.2 Solution 2: Tape

The second solution we formulated was to use tape to more adequately secure the cartons by wrapping cartons in tape as depicted in Figure 6. The thought process behind our taping solution was that perhaps the current packaging does provide enough impact protection under normal conditions, but cartons could be shifting within a unitized load during transport [6, 11] or the sealant used to keep cartons closed is being compromised during transit, which could in turn provide the necessary conditions for packaging integrity to become compromised. The basis for our thinking was that packaging can become damaged when it is not palletized properly or secured properly for transport [11, 12]. Additionally, tape is relatively inexpensive and widely available [13]. As a result, we decided we could wrap the packaging in tape to ensure the sealant used to keep packaging closed did not become compromised to secure the packaging and in the process add an additional material to the outside of the cartons that could aid in impact protection.

Figure 7: Model image of package wrapped in dunnage (bubble wrap)

4.2.3. Solution 3: Dunnage

The third and final potential solution we developed was to use dunnage to aid in the impact protection of the packaging. More specifically, our solution was to secure bubble wrap to or around the packaging to increase impact protection. Depicted in Figure 7 is an example model of the dunnage solution. Bubble wrap is a relatively lightweight form of dunnage used to aid in the impact protection of products [9, 12]. Initially, our thought process was to include bubble wrap inside of the cartons, however due to insufficient space within the cartons, we decided to focus on formulating a method to secure bubble wrap to the outside of the cartons. Additionally, we were able to find bubble wrap at a relatively low cost [3]. Consequently, we decided we could achieve the most impact protection for each individual carton by wrapping each carton in bubble wrap.

Chapter 5: Analysis

5.1. Cost Benefit Analysis

Before conducting any cost benefit analysis, the number of cartons of vinyl flooring sold annually in Asia was determined by using the annual revenue generated from vinyl flooring and the price per carton of vinyl flooring. Mohawk Industries sells 1 carton of vinyl flooring in Asia for $85.76. The annual revenue produced from the sale of vinyl flooring in Asia is $12,265,000.00. Therefore, the number of cases of vinyl flooring sold annually in Asia is 143,015 cases ($12,265,000.00/$85.76 per carton = 143,015). The calculated number of vinyl flooring cases sold annually were used in the cost benefit analysis estimates.

5.1.1. Cost Calculations for Solution 1: New Design

Due to the limitation of having to utilize current machinery for any new design, the new design consists of increasing the amount of cardboard used in the packaging. The current design of the packaging costs $1.23 per carton, which translates to an annual cost of $175,909. The cost of the proposed addition of cardboard for the new design would cost $1.56 per carton or $0.33 more than the current design, which would mean an annual cost of $223,104. Although the new design presents a greater annual cost, the addition of more cardboard is projected to save approximately 90% of the current cost of damages and returns, as depicted in Figure 8. The current cost of damages and returns is $122,650 annually and the projected amount to be saved with the new design is $110,385 per year.

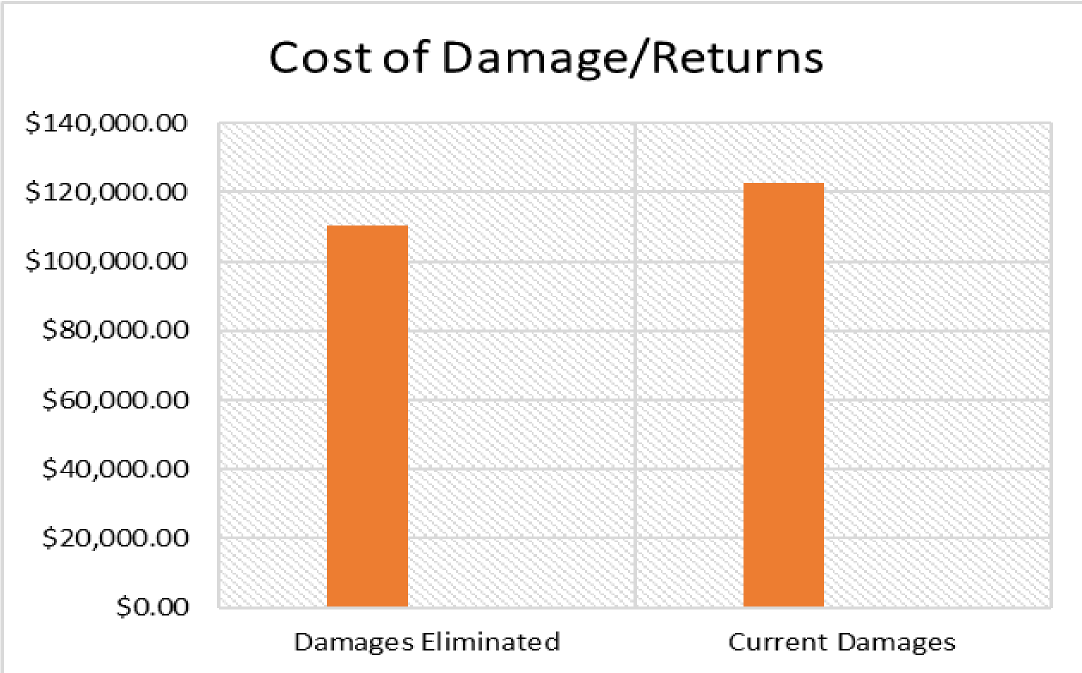


Figure 8: Compares the revenue lost due to current damages to the estimated revenue to be saved with new design

5.1.2. Cost Calculations for Solution 2: Tape

1. 6 x 48 planks =23.24 sq. ft/ctn
2. Tape price = $36 for 18 rolls of 27.5 square feet of tape
3. $36/18 = $2 per roll
4. 27.5 sq. ft. ÷ 23.24 sq. ft = 1.18 (approx. 1 carton)
5. $2/1 ctn = cost per carton
6. 143,015 cartons per annum × $2.00 per carton = $286,030.00 annually

The first step was to determine the square footage of one carton of 6 in. x 48 in. planks, which was 23.24 sq ft/ctn. Next, the unit cost of each roll was calculated by dividing the amount of money paid for the rolls by the number of rolls ($36/18 rolls = $2 per roll). Next, the area of the tape (square feet) was divided by the area of the carton (square feet) to approximate the number of cartons that could be serviced using the allotted amount of tape (1 carton). The number of cartons was rounded from 1.18 to 1 to be used in the next calculation to determine the amount of money spent to tape one carton ($2 per carton). Lastly, the number of cartons sold annually in Asia (143,015 cartons) was multiplied by the cost to tape one carton ($2.00) to estimate the amount of money that would be spent on taping cartons annually ($286,030.00).

5.1.3. Cost Calculations for Solution 3: Dunnage

7. 6 x 48 planks = 23.24 sq ft/ctn
8. Dunnage price: $22.99 for 4 30 sq. ft. rolls
9. $22.99/4 rolls = $5.75 per roll
10. 30 sq ft/23.24 sq ft = 1.29 (approx. 1 carton)
11. $5.75/1 ctn = $5.75 per carton
12. 143,015 cartons annually × $5.75 per carton = $822,336.25

For the Dunnage alternative solution, The square footage of one carton was determined as 23.24sq ft/ctn in solution 1 above, The price of Dunnage was determined to be $22.49 for 4 30 sq. ft roll which gives $5.75 per roll when divided by 4 rolls in the pack. The next step was to calculate the square footage of one carton by dividing the 30sq ft by 23.24 sq. ft which equals 1.29 approximately 1 carton. This gives a price of $5.75 per carton. Finally, the total price for 143,015 cartons in a year is calculated by multiplying 143,015 by the unit price of $5.75 per carton to be $822,336.25.

5.2. Qualitative Analysis

The three different options were ranked from low to high using these three aspects of quality. Depicted in table 2 below are the results of the ranking system used for each different design.

	Aesthetic	Safety	Functionality
Thicker Package	High	High	High
Tape	Low	High	Medium
Dunnage	High	High	High

Table 2: Quality analysis of proposed packaging solutions

The results show that using thicker packaging or using dunnage would be more ideal solutions for qualitatively. Aesthetically, the thicker packaging would minimize the change of the current packaging that is already in high demand. Taping the box would add an additional layer to the outside of cartons and the possibility accumulating a buildup of dirt on the outside of packages, making the package less appealing to customers [5, 15]. The tape would also make it more difficult for the customers to open cartons. The dunnage solution would not change the outer packaging of the carton since the dunnage would not be applied to cartons using adhesive unlike the tape solution. However, similar to the taping solution, the dunnage solution would cause the cartons to be slightly larger, which could potentially affect the unitization of cartons and compromise the stability of a unit load and thus the security of a unit load [11, 12]. All the different packaging solutions were rated with high safety because the current packaging has not had safety recalls, and each solution only involves minor changes to the current packaging design. Functionality is one of the most important factors of each design solution as it relates to whether or not the solution in question can fulfill its intended purpose. The thicker packaging and dunnage solution were given high functionality because they would directly increase the amount of impact protection of the packaging in comparison tape solution. The tape solution was given a medium level of functionality as it would provide a thin layer, which could potentially increase impact protection, and the taping solution would potentially help keep packages sealed and secure. However, the possibility of damage to the contents of the packaging and the packaging itself would still be present despite the addition of a layer of tape to the outside of the packaging.

5.3. Effects on Process

Under the current production process, the facility produces 1,650 pallets per shift on average, and each pallet is composed of 60 cartons. Utilizing thicker cardboard solution, the changes or effects on the production process are negligible due to there being no additional steps or changes

Solution Time Study				
Tape			Dunnage	
Trial	Time (s)		Trial	Time (s)
1	52		1	39
2	84		2	66
3	49		3	55
4	47		4	83
5	49		5	73
6	69		6	50
7	59		7	47
8	60		8	46
9	56		9	79
10	75		10	62
Average	60		Average	60

Table 3: Time study of taping solution and dunnage solution

in the palletization process. Therefore, the estimated number of pallets produced per shift on average would be expected to remain the same (1,650 pallets). To estimate the effects of the dunnage solution and taping solution on the production process a time study was conducted. A carton was used to approximate the amount of time needed to tape one carton and a separate carton was used to approximate the amount of time needed to wrap one carton with dunnage. A basic time study was conducted to determine how long it would take to manually implement the taping solution and dunnage solutions because one of the stipulations given was for the solution to not require the implementation of new machinery into the process. The results from the time study for taping solution and wrapping solution for one carton were that it would take an average of 60 seconds to fully tape or wrap one carton (depicted in the Table 3). The next step taken was to convert the hours that would be spent implementing the solution by a worker from hours to seconds. A worker at Mohawk Industries would work an 11 hour and 30-minute shift (12 hours total including breaks). In seconds a worker would be working 41,400 seconds. It would take a worker an average of 60 seconds to tape or wrap one case, so during a shift a

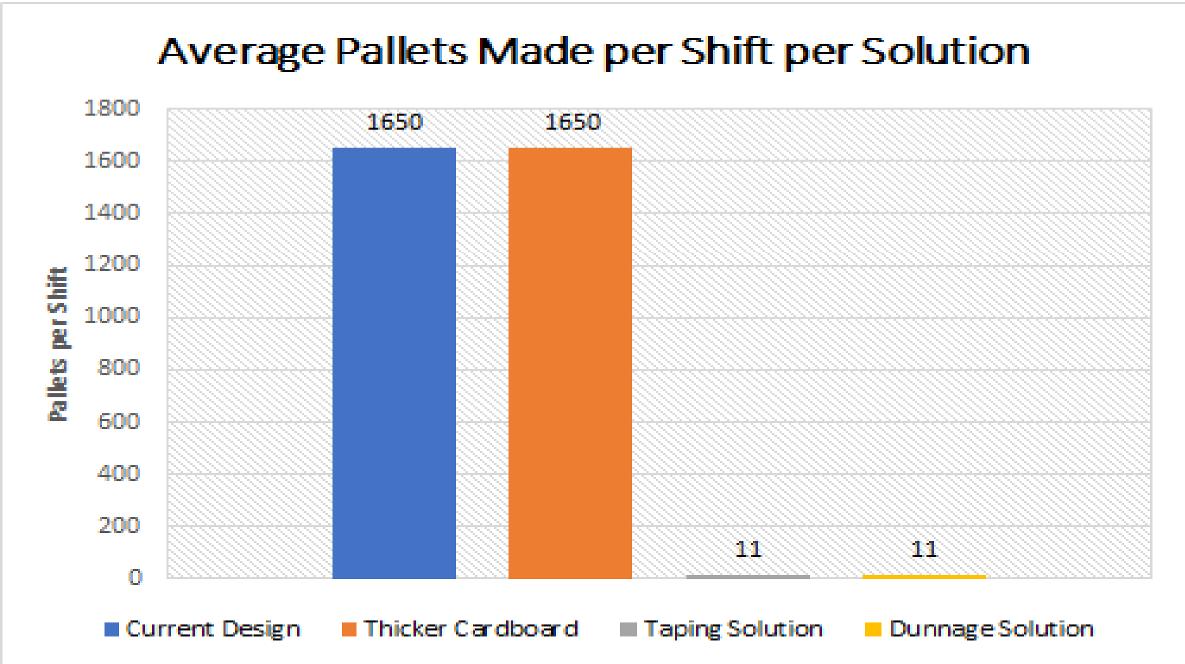


Figure 9: Depicts the average number of pallets produced per shift using each solution and the current design

worker would be able to tape or wrap an estimated 690 cases. Illustrated by Figure 9 are the average number of pallets that would be produced per shift with each solution. Each pallet contains 60 cases, so over the course of one 12 hour shift one worker would be able to tape or wrap cases for approximately 11 pallets, which would mean a drop in production of approximately 99% (shown in figure 6) based on the average number of pallets produced by the current design and thicker cardboard solution (1,650 pallets). Depicted in Figure 10 are the estimates of the annual cost for each solution. To account for the loss in production Mohawk Industries would have to employ approximately 150 more employees per shift, which would lead to an additional labor cost of approximately $20,527.51 per shift (12 hour shift × $11.90 (hourly pay)), and approximately $14,985,079 annual labor cost ($20,527.51 × 2 shifts per day × 365 days per year).

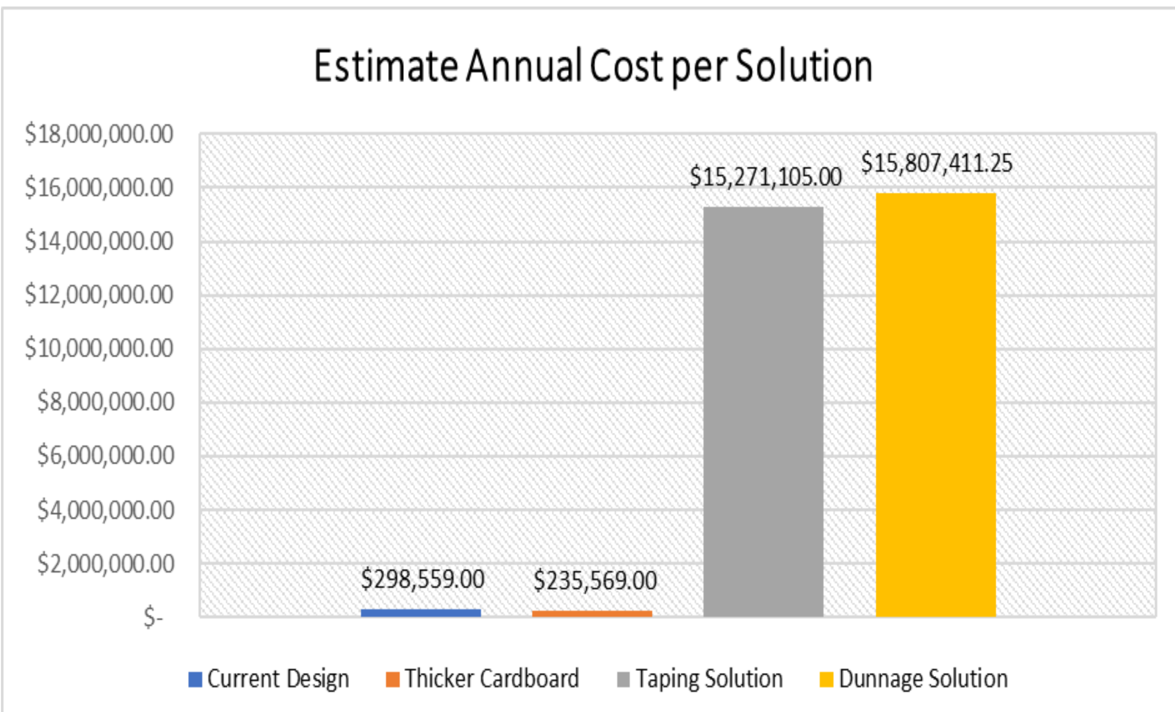


Figure 10: Estimated annual cost of current design and each solution

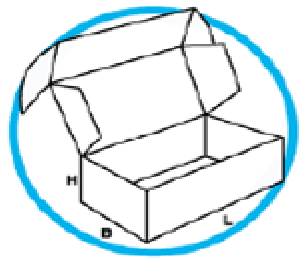
Taping	Dunnage	Thicker Cardboard	Current Packaging
			
• Estimated Annual Cost: $286,030.00 • Approximately 11 pallets produced per shift (avg.) • Estimated annual manual labor cost: $14,985,075.00	• Cost: $822,336.25 • Approximately 11 pallets produced per shift (avg.) • Estimated annual manual labor cost: $14,985,075.0	• Estimated Annual Cost: $223,104.00 • 1650 pallets produced per shift (avg.) • N/A • Savings: $110,385	• Estimated Annual Cost: $175,909.00 • 1650 pallets produced per shift (avg.) • N/A • Damage Cost: $122,650

Table 4: Cost comparison of initial solution implementations and current design

Detailed in Table 4 is a comparison chart used to identify which option would be most beneficial to the company. The cost to implement the taping solution and the dunnage solution in their current form would ultimately be infeasible as the estimated annual labor cost ($14,985,075.00) would be significantly more than the annual cost of damage using the current design ($122,650). However, the new design solution would cost approximately $47,195 more than the current design but present an annual savings of approximately $110,385.

5.4. Revised Solution Implementation and Analysis

As a result of the infeasibility of the first iterations of the dunnage solution and the tape solution a more efficient and refined method was formulated to implement each solution. We were concerned that the cost to implement solutions 2 or 3 could be lowered if we applied them more efficiently and the possibility that truckloads could exceed their weight limits if each carton was wrapped in bubble wrap or tape. We were also concerned that the losses that would be experienced in production would not make solution 2 or solution 3 feasible to implement in their current form. Initially solutions 2 and 3 involved wrapping each individual case in tape or dunnage, respectively. We revised each solution to attempt to optimize each solutions implementation and thereby optimizing their effects on the process. Originally, we were implementing our solutions by thinking of each individual carton as its own separate cuboid rather than each carton being a part of the whole cube that is used to compose a palletized load. By focusing on the entire palletized load, we were able eliminate waste in our original implementations of our solutions.

A great way to exemplify our revised solutions would be the black and white Rubik's cube (Figure 11). In the figure below, 4 of the faces of the cube are black, which represents the locations where our solutions would not be applied to a cubed unit load, and the remaining 2 parallel faces are white, which represents the locations where our solutions would be implemented on a pallet load. Applying tape or bubble wrap to only the 2 parallel faces (damage zone) of a 6 sided pallet rather than applying tape or bubble wrap to each face of each individual carton allows for a decrease in the amount of surface area, which leads to a decrease in the amount of materials needed, a decrease in application time and manpower, and does not remove machinery from the process, thus vastly decreasing the cost of implementing solution 2 or solution 3

Figure 11: Revised solution implementations modeled using Rubik's cube

Figure 12: Model image of revised taping solution

5.4.1. Revised Solution 2: Tape

Our initial implementation of the taping solution was to wrap each individual carton in tape. Due to the company's desire to not purchase new machinery, we decided each case would have to be manually wrapped in tape. As a result, the production process was negatively impacted by having each case wrapped and palletized by a person, rather than each case being palletized by a machine. Similar to the model depicted in Figure 12, our new implementation of solution 2 is still centered on ensuring cartons are adequately secured within a unitized load, but instead of securing the cases individually we decided to focus on securing the cases together within a unitized load. Our revised solution 2 would be for an employee to use tape to secure the palletized cartons on the 2 ends being damaged by taping each column of cartons to the pallet with a single line of tape on both ends. The resulting solution would allow us to use less tape thereby saving money. A pallet of cartons contains 5 columns and 12 layers (60 cartons total). Each carton is approximately 2 inches in height and 8 inches in width and 48 inches in length, so one end of a unitized pallet would be approximately 6.7 square feet ((12 × 2 in) × (8 in × 5) = 960 sq. in. ≈ 6.7 sq. ft.). Therefore, both ends of a pallet together would equate to approximately 13.4 sq. ft. of area. 1 roll of tape contains 27.5 sq. ft. of tape. Instead of using the tape to tape the entire area of an end of the unitized load, only 4 strips of tape would be used on each side of the pallet to secure both ends of the pallet. Utilizing this method with the taping solution, 1 roll of 2 in by 55 yd tape could be used to secure approximately 6 pallets. There are 5 columns per pallet each 24 inches in height, a total of 8 strips of tape would be used per pallet. Each strip of tape would be approximately 30 inches in length, so securing both ends of 1 pallet would require approximately 8.3 yards of tape ((((30 × 10) ÷ 12) ÷ 3) ≈ 8.3). Each role of tape is 55 yards long, thus 1 roll of tape would be enough to secure 6 pallets (55 ÷ 8.3 ≈ 6). Since approximately 143,015 cases were sold this past year in Asia or approximately 2,384 pallets (60 cartons per pallet), it would cost approximately $794 in materials annually to implement the revised tape solution ((2384 ÷ 6) × $2 ≈ $794). The annual labor cost of implementing the tape solution would decrease to $104,244 (2 × 12-hour shift × $11.90 hourly pay × 365 days ≈ $104,244). The extreme decrease in the estimated annual labor cost can be attributed to the revised solution not interrupting the palletization process by having an individual manually palletize and wrap each individual case. Therefore, extra employees would not be needed to account for a loss in production as the revised version of solution 2 would not be implemented until after pallets have been made, and thus decreasing the estimated annual labor cost by over 90 % ($104,244 ÷ $14,985,075 ≈ 0.007). The total estimated annual cost of the revised tape solution is approximately $105,038.

Figure 13: Model image of revised dunnage (bubble wrap) solution

5.4.2. Revised Solution 3: Dunnage

Our initial implementation of the dunnage solution was to wrap each individual carton in bubble wrap. Due to the limitation of not purchasing new machinery, we decided each case would have to be manually wrapped in bubble wrap. As a result, the production process was negatively impacted by having each case wrapped and palletized by a person, rather than each case being palletized by a machine. Similar to the model depicted in Figure 13, our new implementation of solution 3 is still focused on ensuring there is an adequate amount of impact protection for cartons, but instead of wrapping the cases individually we decided to focus on wrapping the cases together within a unitized load. Our revised solution 3 would be for an employee to add bubble wrap to the palletized cartons on the 2 ends being damaged by placing a layer of bubble wrap on both ends of the palletized cartons. The resulting solution would allow us to use less bubble wrap thereby saving money. A pallet of cartons contains 5 columns and 12 layers (60 cartons total).

Each carton is approximately 2 inches in height and 8 inches in width and 48 inches in length, so one end of a unitized pallet would be approximately 6.7 square feet ((12 × 2 in) × (8 in × 5) = 960 sq. in. ≈ 6.7 sq. ft.). Therefore, both ends of a pallet together would equate to approximately 13.4 sq. ft. of area. 1 roll of bubble wrap contains 30 sq. ft. of bubble wrap. Utilizing the revised method for the dunnage solution, 1 roll of bubble wrap could be used for approximately 2 pallets (30 ÷ 13.4 ≈ 2). Since approximately 143,015 cases were sold this past year in Asia or approximately 2,384 pallets (60 cartons per pallet), it would cost approximately $6,854 in materials annually to implement the revised tape solution ((2384 ÷ 2) × $5.75 ≈ $6,854). The annual labor cost of implementing the tape solution would decrease to $104,244 (2 × 12-hour shift × $11.90 hourly pay × 365 days ≈ $104,244). Similar to solution 2, the noticeable decrease in the estimated annual labor cost can be attributed to the revised version of solution 3 not interrupting the palletization process by having an individual manually palletize and wrap each individual case, so extra employees would not be needed to account for a loss in production as the revised version of solution 3 would not be implemented until after pallets have been made. Additionally, the estimated annual labor cost decreased by over 90 % ($104,244 ÷ $14,985,075 ≈ 0.007). The total estimated annual cost of the revised tape solution is approximately $111,098.

5.4.3. Updated Model Analysis and Comparison

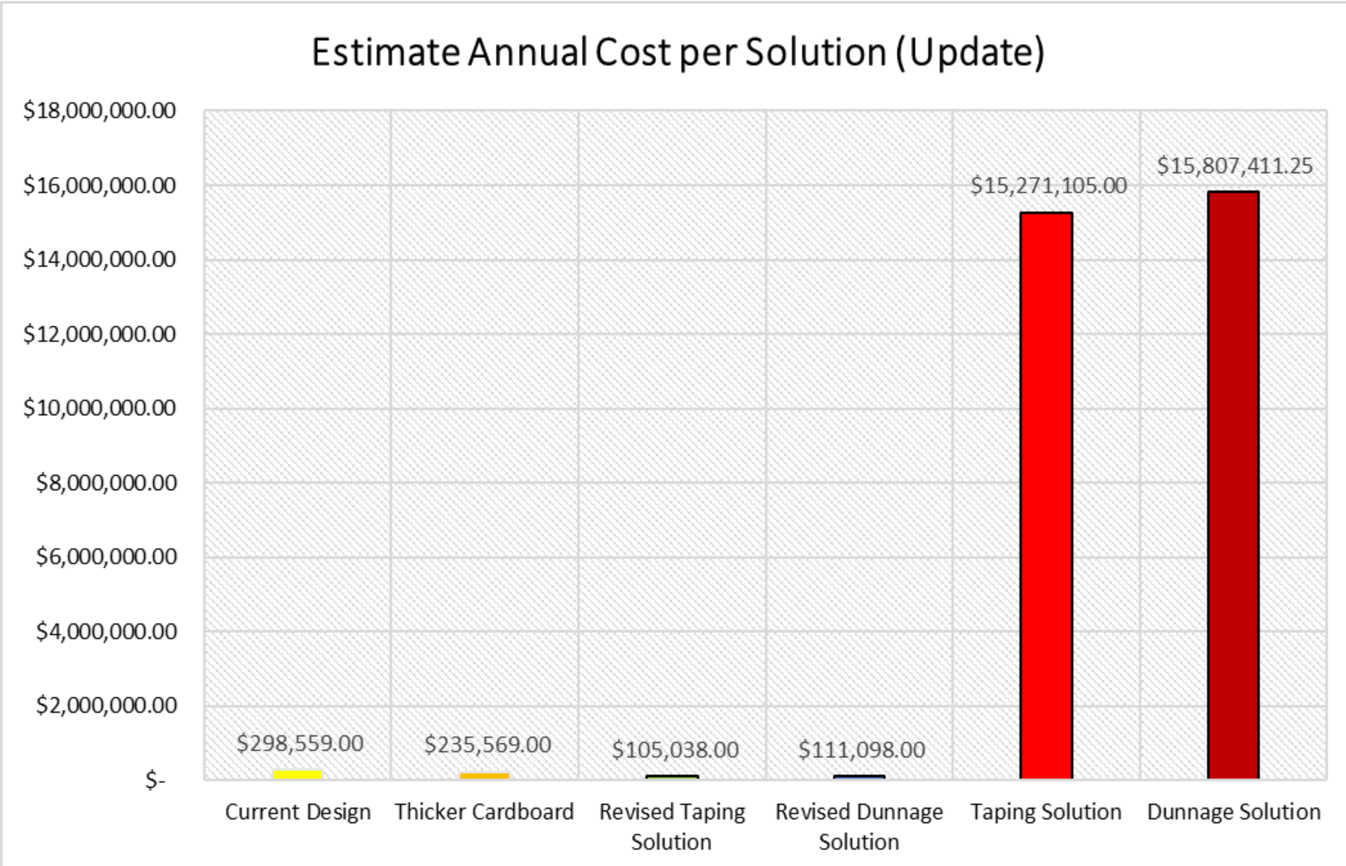


Figure 14: Updated estimated annual cost for each solution, current design, and revised solutions

Figure 14 is an estimated look of the total cost of the current design and implementing solution 1, solution 2, solution 3, revised solution 2, and revised solution 3. After implementing revisions to our application process, solution 2 and solution 3 become economically feasible due to the elimination of the need for additional manpower to account for production losses and a more focused and waste conscious application method for each solution.

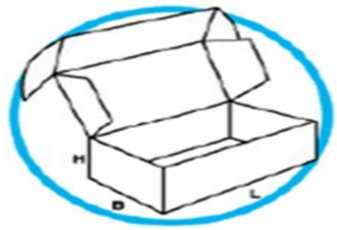
Taping	**Dunnage**	**Thicker Cardboard**	**Current Packaging**
			
• Estimated Annual Cost: $794.00 • 1650 pallets produced per shift (avg.) • Estimated annual manual labor cost: $104,244.00	• Estimated Annual Cost: $6,854.00 • 1650 pallets produced per shift (avg.) • Estimated annual manual labor cost: $104,244.00	• Estimated Annual Cost: $223,104.00 • 1650 pallets produced per shift (avg.) • N/A • Savings: $110,385	• Estimated Annual Cost: $175,909.00 • 1650 pallets produced per shift (avg.) • N/A • Damage Cost: $122,650

Table 5: Cost comparison of including revised solutions 2 and 3, solution 1, and current design

Table 5 depicts a cost comparison of implementing solution 1, revised solution 2, revised solution 3, and the current design. Assuming the taping solution and the dunnage solution decrease the damage cost of the current design ($122,650), the cost to implement the revised versions of solution 2 and solution 3 would be economically feasible as the cost of damages under the current design is greater than the estimated total annual cost of either solution ($105,038.00 for the taping solution and $111,098 for the dunnage solution). Additionally, by moving the application point of the taping solution and the dunnage solution the average number of pallets produced per shift would be able to be maintained (1650 pallets per shift).

	Aesthetic	Safety	Functionality
Thicker Package	High	High	High
Tape	Medium	High	High
Dunnage	High	High	High

Table 6: Qualitative analysis of solution 1 and the revised solutions 2 and 3

Table 6 depicts our updated qualitative analysis table. There were a few notable changes in our qualitative table after revising our application of the taping solution and the dunnage solution. Aesthetically speaking, the tape solution increased in rating from low to medium since it would no longer be applied to every carton, however it could not be rated high as the adhesive side of the tape would still be applied to some cartons, which could leave behind residue on cartons or possible cause minor damage to the package. Another notable change was that the functionality of the tape solution was rated higher as it would be increasing the security of cartons in a unitized load and thus more likely to decrease the potential damage to cartons than in its prior application. The ratings for our thicker package solution and the dunnage solutions in our updated table were consistent with the ratings seen in our previous qualitative analysis table (Table 2).

Chapter 6: Results and Discussion

6.1. ISTA Testing Results

ISTA is the International Safe Transit Association. ISTA conducts ASTM (American Society for Testing and Materials) testing on packages and products for Mohawk Industries. ASTM tests can include, but are not limited to, drop, vibration, shock, temperature and impact [12]. Due to cost restrictions, Mohawk Industries was only able to submit one of our offered solutions to the ISTA for testing. After careful deliberation, the solution we chose to have tested was the modified packaging option. Modified packaging solution (solution 1) was chosen for testing because solution 1 was our least expensive solution based on our initial cost benefit analysis and we also

REQUESTED BY:

WestRock Company –

Certification Type:	PACKAGE CERTIFICATION	**No. Samples Tested**
Overall Test Results:	**PASSED**	1

TEST PERFORMED BY: - WestRock Company –Package Performance Testing Laboratory (ISTA Lab Number: ST2079)

Table 7: ISTA testing results for new design (thicker cardboard solution)

ranked solution 1 highly in all 3 categories of our qualitative analysis (safety, functionality, and aesthetics). The modified packaging solution passed all ASTM tests, and most importantly it passed the drop and impact tests (Table 7).

6.2. Summary of Analysis

Based on our qualitative analysis in section 5.4.3, we determined that all 3 of our solutions would provide a high level of functionality and a high level of safety. However, we rated only solution 1 (thicker cardboard) and solution 3 (dunnage) to have high aesthetic value due to the possibility of some cartons being damaged by the adhesive side of the tape used in solution 2 (tape). Based on our quantitative analysis in section 5.4.3, we determined that either of our 3 solutions would be economically feasible for Mohawk Industries to implement since our tape solution or dunnage solution could be implemented for less than the current cost of damages and our thicker cardboard solution was determined to be able to limit approximately 90 % of the cost of damages after testing.

6.3. Problems Encountered

There were many challenges faced during the completion of our project. Our access to the ISTA testing facility was limited in that we were only able to submit 1 of our 3 solutions to ISTA for testing, so we had to decide and select which of our options we would submit for testing. Unfortunately, this did not allow us to utilize ISTA to test our 2 remaining solutions, so instead we tested our remaining solutions separately. The separate impact testing we conducted was successful in terms of minimal damage to the packaging. Another problem faced was Mohawk not wanting to add any additional machinery to the production process. This increase the difficulty of implementing our dunnage solution (solution 3) and taping solution (solution 2), purchasing new machinery would allow us to more efficiently implement our dunnage solutions or tape solution. Despite this limitation, we were able to calculate the cost of manpower to apply the dunnage solution and the tape solution. After analyzing the cost of manpower to implement solution 2 or solution 3, we encountered another issue. The cost of manpower to implement either solution caused both solutions to be much more costly than the potential savings that either solution could generate. To mitigate this problem, we revised our applications of solution 2 and solution 3 to decrease the amount of manpower required and to prevent either solution from negatively impacting production.

Chapter 7: Conclusion and Recommendation

We were tasked with reevaluating Mohawk Industries' packaging processes and materials to eliminate damage to the vinyl flooring packaging. The damages being incurred resulted in a loss of inventory and revenue. Our team formulated three possible solutions that could be implemented to address the issue being experienced. Our solutions were increasing the thickness of the current packaging to increase the impact protection of the packaging, utilizing tape to increase the security of packages during transport, and adding dunnage to increase the impact protection of cartons. When analyzed qualitatively, we determined that increasing the thickness of the packaging or wrapping the package in dunnage would be the best solutions to implement, when applying a solution to each individual carton, as it provided a high level of safety, functionality, and security. We also determined that the taping solution increased in its levels of functionality and aesthetics when applied to a pallet rather than to each individual case, but still fell short of our ratings for the individual application of the thicker packaging solution and our pallet application of the dunnage solution. The cost analysis proved thicker packaging to be the most cost-effective solution when implementing a solution to each individual case. When utilizing the tape solution or dunnage solution, additional machinery (limitation) or workers are required to implement either solution. Due to the need of additional manpower, implementing the dunnage solution or the tape solution to individual packaging causes either to solution to be considerably more costly than implementing the thicker packaging solution. After noticing that the tape and dunnage solutions had much higher costs in their current form, we contemplated an alternative application for both solutions. Consequently, our findings were that when the taping solution or the dunnage solution were applied to a pallet rather than individual cartons, both solutions cost less than implementing the thicker packaging solution, even after accounting for the cost of labor. Additionally, we discovered that the production of the taping and dunnage solution would allow the facility to maintain the production levels seen with the current design and thicker packaging solution. Unfortunately, the only solution that was submitted to ISTA for testing was the thicker packaging solution. The thicker packaging solution passed all the ASTM tests meaning it is more durable than the original packaging. Based on our analysis and testing, we found that increasing the thickness of the packaging would be the best solution to utilize if a solution was implemented to each individual carton. We determined our revised version of solution 3 (adding bubble wrap to pallets) would be the best option tested when implementing a solution to a pallet instead of each individual case, however more testing (ISTA) would be required to determine if our revised solution 3 would prevent damage to cartons during shipments. Therefore, our recommendation would be for Mohawk Industries to implement solution 1 (increasing the cardboard thickness of the current design) because:

- Solution 1 was submitted and passed ISTA testing
- The savings made as a result of implementing solution 1 were quantifiable
- Solution 1 would not add additional steps to Mohawk Industries' packaging process
- More testing (ISTA) would be needed to prove the efficacy of the redesigned versions of solution 2 (tape solution) and solution 3 (dunnage solution)

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Appendix A: Acknowledgments

Team Vine Flow would like to thank Mohawk Industries for giving us the opportunity to work with their packaging engineers on what we consider to be a project that was a phenomenal learning experience for each of us. Special thanks to Wes Rager, Packaging Engineer, Mohawk Industries Calhoun, for all his assistance to our team along the way, including but not limited to assistance in the design and development process and submission of our solution to ISTA for testing.

Appendix B: Contact Information

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Appendix C: Reflections

Edafe Oyibo: Working on this Senior Design Project was a good experience for me. The ability to work as a team of diverse students to reach a common goal was rewarding. During this time, I learned and appreciated the Idea behind teamwork. After learning so much in class as an Industrial engineering student, it was a great experience to carry out a real live project where we optimized and designed a system. I want to thank my team members for their individual contributions and hard work to make this project a success. I also want to thank Mohawk Industries for giving us the opportunity to work with them and be a part of this project.

Devon Holloway: Working on our Senior Design Project has been a very unique learning experience for me. I believe the lessons and experience I have gained over the course of my group's project will translate to my post-undergraduate endeavors. I would like to say thank you to all my team members for your contributions throughout the course of our project, and that hopefully this was as a phenomenal learning experience for you all as it was for me. Thank you.

Dominique Donahue: This project was a real eye opener. I have had many group projects in the past, but never one on this large of a scale. This project allowed me to utilize the different techniques that I have learned throughout my college career. This was my first project working with a real-life facility to help them optimize a process. I learned more and more about my field as the project progressed, as well as about myself. One of the biggest challenges faced was trying to finish the project remotely instead of face to face. We were able to overcome that by consistent communication and hard work. I am appreciative for Mohawk Industries allowing us to work with them, with a special thanks to our advisor Wes Rager. I would also like to thank my group members from Team Vine Flow for working hard on this project and finding a solution Mohawk Industries is able to use in their facility.

Fatemeh Mafikouhini: That was steps into the real world. I found out how much knowledge I gained during my college years. I could solve real problems in the real world. During this project, I gained a lot of experiences that can be used in other courses. I had a good experience with wonderful group mates. We divided tasks equally and did them without complaints. The project was on a very huge scale that can help the Mohawk industry to save thousands of dollars. This project convinced me that I have chosen a major that is the best fit to my interests and capabilities. We had a wonderful tour to Mohawk facility. They were kind and showed the production process from first to last step. Our tour guide answered to our questions patiently. We needed to search and collect information for each small part of the project. I appreciate my professor Dr. Khalid, Mohawk Industry security (plant safety officer), our project advisor Wes Rager, and our group members.

Appendix D: Contributions

Name	Chapter/Section Contribution(s)
Devon Holloway	**Chapters:** 4, 5, 6, 7 **Sections:** 1.1, 3.1, 3.3, 4.1, 4.2, 4.2.3, 5.1, 5.1.2, 5.1.3, 5.4, 5.4.3, 6.2
Edafe Oyibo	**Chapters:** 1, 2 **Sections:** 1.1, 1.2, 1.3, 1.4, 3.3, 4.2.3, 5.3, 5.4, 6.2
Dominique Donahue	**Chapters:** 1, 6, 7 **Sections:** 1.4, 1.5, 3.2, 3.6, 4.2.1, 4.2.2, 5.1.1, 5.2, 5.4.1, 5.4.2, 6.1, 6.3
Fatemeh Mafikouhini	**Chapters:** 2, 3 **Sections:** 1.3, 3.4, 3.5, 3.6, 4.1, 5.2, 5.4.1, 5.4.2, 6.3

Name	Contribution(s)
Devon Holloway	• Assisted in creation of the presentation • Created figures for the report and presentation • Created team schedule (Gantt Chart) • Contributed to the writing of the report • Led revising and editing of the report • Led creation of project video • Assisted in creation of project poster • Corresponded with industry contact • Aided in the collection of report references
Edafe Oyibo	• Assisted in creation of the presentation • Created figures for the presentation • Contributed to the writing of the report • Assisted in revising of report • Assisted in creation of video • Assisted in creation of project poster • Coordinated group meeting times • Aided in the collection of report references
Dominique Donahue	• Assisted in creation of the presentation • Created several figures for the report and presentation • Contributed to the writing of the report • Assisted in revising of report • Assisted in creation of video • Assisted in creation of project poster • Led correspondence with industry contact • Co-led collection of report references • Designated platform for group communication
Fatemeh Mafikouhini	• Assisted in creation of the presentation • Created figures for the presentation • Contributed to the writing of the report • Assisted in revising of report • Assisted in creation of video • Assisted in creation of project poster • Led the creation of the project budget • Co-led collection of report references