# Truck Tetris: Optimizing Packaging for Transportation Efficiency

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ABSTRACT

Consumer demand for frozen products from The J.M. Smucker Company has grown dramatically over recent years, driving a need to increase total ship output. The overarching problem that we addressed in this project was how to maximize the amount of a specific frozen product loaded onto trailers in order to increase total ship output by changing carton, case, and pallet packaging dimensions and orientations without increasing the total number of trailers used. Empirical research was performed and, through TOPS optimization modeling techniques, we modified carton, case, and pallet dimensions for 4-count, 10-count, and 18-count products. Informational interviews and a facility visit were performed to identify and further explore stakeholder objectives and success criteria. Based on our findings, we provided a series of recommendations to maximize Smucker's shipping output per trailer for the given product to reduce their transportation costs while meeting all of the requirements outlined by the identified stakeholders.

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## Ch 1: INTRODUCTION

### 1.1. Capstone Sponsor Background

Our sponsor for the capstone project is The J.M. Smucker Company ("Smucker"), a leading food and beverage manufacturer of common products including coffee, peanut butter, fruit spreads, and syrups (J.M. Smucker Company, 2023). The focus of this capstone is one of their frozen products.

### 1.2. Motivation

Our sponsor was motivated to resolve existing challenges to maximizing the number of frozen products that can be shipped to stores to meet demand. Our sponsor reported that, based on increased consumer purchasing activity, demand was outpacing supply for the specific frozen food product that was the focus of this capstone project. Smucker was working to increase total shipping capacity for frozen food products to meet this increased demand by driving productivity improvements and plant investments as well as by exploring product packaging dimension alterations and rotations to increase ship output per trailer, the latter being the focus of our capstone project.

### 1.3. Problem Statement

To meet this increased demand, Smucker was looking to modify dimensions and orientations of cartons, cases, and pallets of the specific frozen product to maximize the total number of frozen products delivered to customers per trailer. Specifically, the organization was looking to increase the quantity of products shipped to maximize ship output without increasing the number of temperature-controlled trailers used for transport given the high cost implications of doing so. Existing trailers were restricted based on $volume$, not $weight$.

In terms of current packaging, the frozen product that was the focus of this project was individually wrapped in plastic pouches that contain air to cushion the product. These frozen products were placed into folding cartons ("carton") of pre-defined quantities of 4, 10 and 18. The 4- and 10-count cartons were sold to retail stores such as Wal-Mart, Target, and other grocery stores. The 18-count cartons contain larger frozen products and were shipped to club stores such as Costco and Sam's Club. Then numerous cartons were placed into corrugated or display cases ("case"), which were then loaded onto a wooden pallet ("pallet"). The sponsor company asked us to model various carton, case, and pallet dimensions and orientations to increase the number of products that could be loaded into trailers. Additionally, the company looked for us to perform a comprehensive trade-off review of each modification scenario developed for cartons, cases, and pallets across set criteria valued by brand commercialization, warehouse operations, packaging, sustainability and manufacturing teams. The key problem that was resolved in this capstone project was how to increase the total quantity of frozen products shipped regularly. We hypothesized that the use of an optimization model that maximizes shippable products based on set constraints and decision variables, in combination with visual pallet modeling techniques, would enable Smucker to increase the quantity of frozen products shipped to meet increasing demand.

Solving the central problem of the capstone, how to maximize shippable frozen products, required several steps. We learned early on that solving the central problem of the capstone would require us to think innovatively, like players in a game of tetris, solving a puzzle to maximize ship output. First, our team gained a comprehensive understanding of the firm's current packaging and pallet configuration processes through a site-tour visit. We became educated on the project by analyzing the flaws in the current packaging and trailer configuration process for frozen products and feedback through empirical research. After collecting this information, we used an optimization model to maximize loadable frozen products. We created an optimization model in TOPS Pro packaging optimization and visualization software ("TOPS") that supports this objective. TOPS allowed for the optimization of a product's packaging size, quantity, and configuration at all levels from product to carton to the case to the pallet (TOPS, 2023). TOPS optimized carton, case, and pallet dimensions and orientation while providing exact measurements and 3-dimensional models that were used to get real-time feedback from our sponsor company representatives. Once these representatives narrowed down their top 5 packaging layouts for each carton size, the informational interviews were conducted to narrow down the recommendation further considering stakeholder key criteria. By doing this, we felt confident that a new strategy could be developed to increase the quantity of frozen products shipped to customers without increasing the amount of temperature-controlled trailers used.

In regard to expected goals and outcomes, we provided the sponsor with several optimized potential configuration option recommendations with the primary objective of maximizing frozen product loading capacity. The deliverables included the capstone report readout, symposium presentation, and optimization model results. Further validation, testing, and implementation of potential packaging were out of scope for this project. We explored modifications only to the carton, case, and pallet dimensions, leaving the quantity of frozen product in each carton the same because this was an established expectation of the customer.

The main steps that we performed included defining the scope, formulating the methodology, achieving results, and formulating recommendations. We defined key success criteria and established what was in and out of scope which was completed throughout numerous meetings with sponsor representatives and MIT faculty. We leveraged empirical research to explain our methodology in the state of the practice, including a comprehensive review of all literature reviewed. After this chapter, there was a methodology segment completed by modifying Smucker's carton, case, and pallet dimensions that maximized loadable frozen products through optimization modeling techniques in TOPS. We performed a trade-off review of various assessment criteria defined through an in-person site visit and individual interviews. We analyzed numerous potential carton, case, and pallet configuration options along with finalized dimensions. We arrived at the most favorable pallet and packing configuration with reasoning and justification over alternatives. We then summarized all critical recommendations from the capstone project.

If our recommendations are implemented, Smucker can expect an increase in the number of frozen products that can be loaded onto each trailer, and as a result, reduce transportation costs given less trailers will be needed to transport the product.

## Ch 2: STATE OF THE PRACTICE

In this chapter of our report, we summarize the sources we reviewed to learn how to maximize shipments of frozen products between manufacturing plants and end customers through a variety of research strands. We commence by reviewing Smucker's end-to-end supply chain, providing broad view of Smucker's entire global supply chain. We then review the current state of Smucker's operations, including a review of information associated with product pallet composition and trailer distribution by product type. Then we analyze the extreme-point algorithm concept briefly, with additional context provided in Appendix C. Finally we analyze product design as it relates to factors including marketing effectiveness, manufacturing efficiency, sustainability, and movement of goods efficiency, providing insight into how to ensure Smucker's continued business success. It is important to note that our sponsor requested that we maintain the current packaging materials used to protect frozen products; thus, we did not explore modifications to select packaging types.

### 2.1: Current State of Smucker Operations

#### 2.1.1: J.M. Smucker End-to-End Supply Chain

We commence this chapter by reviewing Smucker's entire global supply chain. Figure 1 is an agnostic diagram summarizing the key components of Smucker's global supply chain.

**Figure 1**

*J.M. Smucker Supply Chain Roadmap*

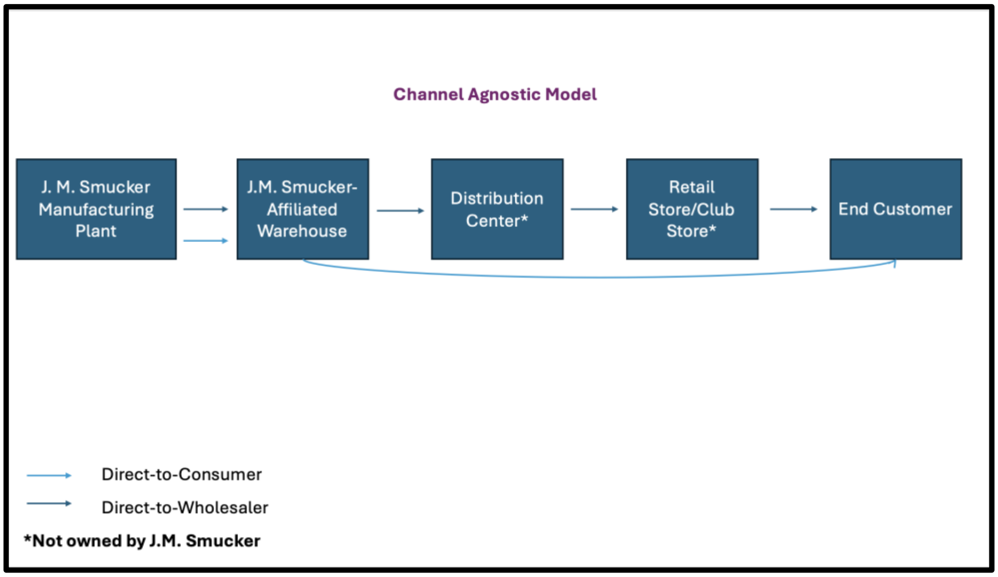



Figure 1 shows that J.M. Smucker's supply chain begins at their manufacturing plant. In the Direct-to-Wholesaler approach, product is then shipped to their affiliated warehouse. After this step, the product is shipped to a distribution center. Frozen product is then shipped to a retail or club store, where it is sold to an end customer. For select products, J.M. Smucker ships directly from their affiliated warehouse to the consumer. This roadmap provides critical background on the nature of key stakeholders associated with this project.

#### 2.1.2. Product pallet composition

Smucker rotates middle layers of cases on a pallet with an overlapping design and uses a brick-laying technique to ensure stability so that the columns do not separate. An example of the brick-laying configuration technique applied to one optimization model, stacking cases on a pallet in a brick-pattern, is seen in Figure 4 in chapter 4.1. It is important to note that Smucker currently does not mix products within the same pallet, only potentially on a single trailer. In

Appendix C, we review the optimal sorting approaches for non-mixed pallets that reflect the standard pallet type that Smucker uses. During our facility visit, we noticed that bringing boxes to the edge of a pallet base with the use of a brick-laying configuration approach can drive residual space between various cases on a pallet. While the brick-laying configuration improves pallet stability, case rotation to an alternative side can further improve pallet stability by reducing space gaps. Exploring a new case rotation approach could minimize the risk of short shipments and reduce the probability of pallet damage. Tables 1 through 3 summarize select information (frozen product $weight$, count per carton, cartons per case, cases per pallet) from Smucker in terms of quantities, dimensions, and $weights$.

**Table 1**

*Current Smucker packaging quantities*

| Frozen Product Weight | # of Frozen Products per Carton | # of Cartons per Case | # of Cases per Pallet |
|---|---|---|---|
| 2 oz | 4 | 8 | 66 |
| 2 oz | 10 | 6 | 42 |
| 2.8 oz | 18 | 12 | 10 |

**Table 2**

*Current Smucker packaging dimensions*

| Frozen Product Dimensions | Carton Dimensions (inside dimensions) | Case Dimensions (inside dimensions) | Pallet Dimensions* |
|---|---|---|---|
| 3.85” x 3.85” x 1.1” | 7.219” x 4.875” x 2.518” | 10.875” x 8” x 11.375” | 48” x 40” x 39.77” |
| 3.85” x 3.85” x 1.1” | 7.25” x 4.7” x 5.89” | 15.322 x 8.072” x 13.019” | 48” x 40.0” x 44.717” |
| 3.92” x 3.92” x 1.17” | 11.13” x 4.94” x 7.25” | 23.25” x 15.375” x 15.5625” | 48” x 40” x 36.75” |

*Please note that the wood pallet dimensions are 48” x 40” x 5.66”

**Table 3**

*Current Smucker packaging weights*

| Frozen Product Weight | Carton Weight | Case Weight | Pallet Weight* |
|---|---|---|---|
| 2 oz | 10.03 oz | 5.615 lbs | 440.487 lbs |
| 2 oz | 23.853 oz | 9.71 lbs | 477.717 lbs |
| 2.8 oz | 58.347 oz | 45.401 lbs | 527.053 lbs |

*Total $weight$ of the product and the wood pallet (60 lbs) combined

To minimize product damage, the organization uses an overlapping brick-laying technique when loading pallets currently, which lowers the risk of boxes tipping over or sliding during transit. It can be paired with select rotation of cases on a new dimension to further enhance product stability. However, there is an opportunity to understand how space can be most efficiently utilized within a loaded bin, in this instance, within cartons, cases, pallets, and trailers supported through our configuration research. In our methodology, we balance critical objectives related to space optimization based on loaded product $volume$.

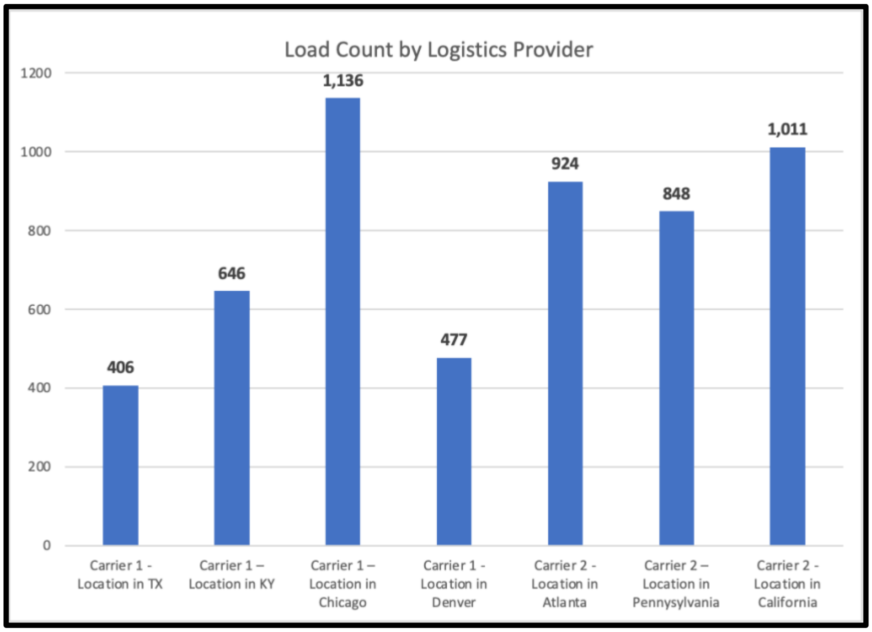
**2.1.3. Trailer distribution by box type**

In this chapter, we review the overall trailer distribution by box type for 53' trailers that Smucker utilizes within their current fleet. This research plays a critical role in understanding the overall utilization of downstream loads during the last-mile delivery. The dimension and orientation modifications driven by our models must be able to ensure maximal load efficiency not only for shipments made between plants and warehouse distribution centers (DC's), but also between warehouses and final customer distribution centers.

Figure 2 outlines the total number of sample loads of frozen products for two primary carriers and their ship points shipped quarterly.

**Figure 2**

*Frozen Product Trailer Distribution Analysis*

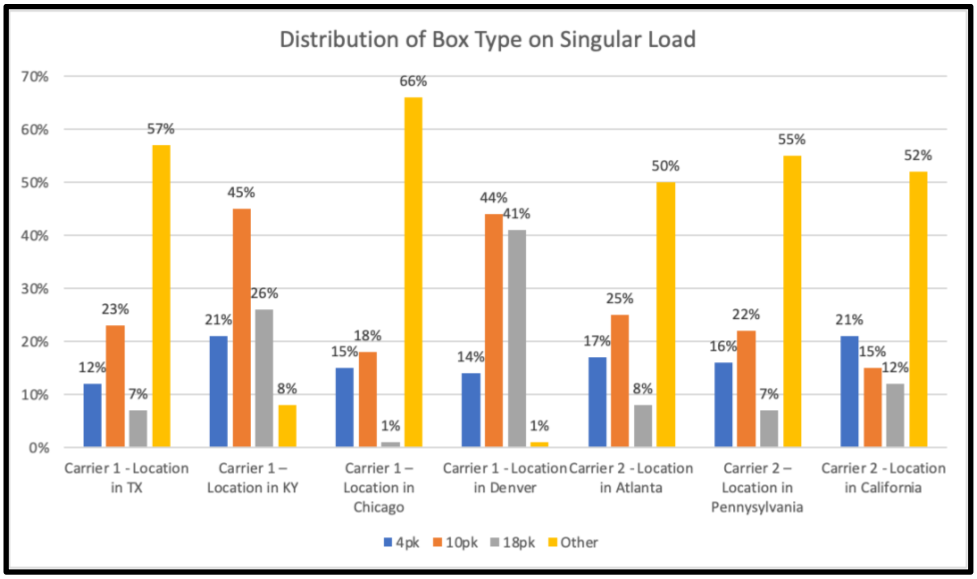



Carrier 2 appears to ship moderately more frozen products to locations across different regions relative to Carrier 1, with a difference of 118 total loads. The average number of loads shipped by Carrier 1 is 666 across all 4 locations, and the average total number of loads shipped by Carrier 2 is 927 across three locations. Because Smucker only has two downstream carriers performing final deliveries, there is an increased likelihood of smooth process implementation based on our recommendations. Our analysis also shows that all loads that the above carriers ship are fully utilized; thus, by changing the dimensions of cases, cartons, or pallets, we impact the total $volume$ of product loaded onto downstream loads and the total of product that these providers can ship outside of frozen product on pre-existing loads.

Figure 3 illustrates the sample $volume$ of each carton size of frozen product across its two primary carriers relative to the total.

**Figure 3**

*Frozen Product Distribution of Product Type*




We can see that the frozen product that is least typically shipped and built into existing loads on a quarterly basis is the 18-count frozen product box, with an average percentage of the total shipped product on a singular load of 14%. For the 4-count frozen product box, the average percentage of total shipped product on a singular load is 17%. For the 10-count frozen product box, the average percentage of total shipped product on a singular load on a quarterly basis is 27%. Assuming that specific loads are built based on customer specifications, it seems that the 18-count frozen product box is not shipped as regularly through these sample shipment records provided. The average percentage of product on a current load outside of the 4-count, 10-count, and 18-count box is driven by other products outside of frozen products (43% overall). Our optimization model experimentation impacted the total product shipped for pallets on an existing trailer; thus, the potential metrics listed above might change depending on the future maximal number of pallets that third-party logistics (3PL) providers can ship to final customer DC's. Additionally, in our approach, we considered the potential compromises in overall load factors based on exact customer orders. Regardless of dimension or configuration strategy modifications, potential trailers could have unutilized space depending on the nature of customer orders, final delivery locations, and order timing.

### 2.2: Extreme-Point Algorithm Research

#### 2.2.1. Extreme-Point Principles

The extreme-point heuristics algorithm is an algorithm that provides insight into how to place specific items in larger objects to achieve maximal product safety, stability, and efficiency. The core principles of the algorithm minimize the risk of product damage and maximize product stability that inform our methodology. We sought models that minimize product damage risk and maximize total stability. In Appendix C, we summarize the research performed related to this algorithm along with optimal sorting and configuration approaches. Select recommendations in our recommendation chapter stem from the research included in Appendix C.

### 2.3: Impact of product design on business priorities

#### 2.3.1: Corporate sustainability

We broadened the scope of research to understand the impact that transportation has on sustainability. A *2023 MIT capstone report* written by Nauryzkhan Dildabekov and Ritesh Rai contains a formula outlining the factors driving carbon emissions from transportation. The formula elements are listed below:

- *Sum mass of goods purchased/shipped (tonnes or vol)*
- *Distance traveled in transport leg(km)*
- *emission factor of transport mode or vehicle (type(kgCO2e)/tonne)*

The packaging box used in this formulation impacts the total emission factor of transport modes or vehicles as goods move in transit. The research also indicates that vehicle emissions impact carbon emissions from transportation. As total product $volume$ increases the total generated carbon emissions from transportation increases (Dildabekov & Rai, 2023). During our sustainability interview, we learned that when total product $volume$ increases the total $volume$ of used packaging materials increases which was proven to drive minor changes in actual material use. Depending on how revised pallet sizes impact total pallet-per-trailer counts, there may be instances where total customer order quantities cannot be supported using a fixed number of assets. Additional trucks may then be acquired that are likely under-utilized. Under-utilized trucks create space inefficiencies and drive higher total carbon emissions. When case-to-pallet counts increase, the total size of pallets loaded onto trailers increases, increasing material use. An additional benefit that was highlighted in our sustainability interview was the ability to reduce carbon emissions by utilizing fewer trucks to support orders when total product

$volume$ is maximized. Total idle truck runtime, reviewed in the next paragraph, also impacts supply chain sustainability.

If trucks remain running while pallets are being delivered to trailer dock doors, total idle truck runtime will increase. This generates increased carbon emissions that can negatively impact the environment. As the total number of trucks employed to support orders increases, the total idle truck runtime will increase, driving worsened environmental impact. This relationship was explored in our sustainability interview. Ensuring timely delivery of pallets to trailer dock doors supports the reduction of idle truck runtime as trucks can complete trips faster with a lower total operating time. A *McKinsey* article states that usage of single-use packaging containers can drive negative environmental impacts. The article confirms that the management of packaging waste is facing a crisis due to packaging recyclability, recycling, and leakage concerns (Berg et al., 2020).

The capstone report also suggests that the most evident opportunity to reduce total carbon emissions from transportation is to reduce emission factors of transport modes or vehicles and use fewer assets to support orders. This can be achieved by not over shipping, prioritizing adoption of the models listed in chapter 4.1, and by aligning total ship quantities with customer order expectations. It can also be achieved by minimizing the distance between origin and destination points and by eliminating idle truck runtime.

**2.3.2: Impact of product design on customer and retail satisfaction**

Smucker must ensure that product dimension changes do not impact retail and customer satisfaction. A *DotActiv* article states that the below adaptations to product dimensions drive corresponding retailer impacts:

- Decreases in product $height$ & $width$ drive an increased number of facings/shelves
- Increases in product $height$ cause potential shelf removal
- Increases in product $width$ drive product fitting challenges (DotActiv, 2023).

The research confirms that increasing product $height$ and $width$ drives the potential risk of shelf removal and inefficient packing of products on a retail shelf. If retailers face increased challenges in fitting new products on store shelves, they may grow dissatisfied. Identifying the solution that enables the maximal number of facings per shelf with minimal risk of shelf removal or fitting challenges was a critical objective evaluated during our interviews. We further elaborate on the impact of dimension changes on customer satisfaction in the next paragraph.

Product dimension and display positioning changes not only impact retail operations but also customer satisfaction. If customers observe differences in product dimensions, it can impact their buying behaviors. In turn, changes in consumer purchasing behaviors can impact firm revenue. An *HBR* article confirms that when product dimensions are shrunk, customers notice it immediately, demand a discount, and potentially complain to retailers that they are getting less for the same price (Chandon, 2017). An article published by the *Journal of Marketing Research* suggests that horizontal positioning as opposed to vertical positioning of products supports improved processing of varied products on store shelves. This is because consumers are forced to examine products side-to-side on a shelf, enabling them to detect more product variety (Deng et al., 2016). An article on *QUT Business News* confirms that consumers adopt new purchase behaviors specifically when product dimensions change. When size falls further than price but both factors decline, consumers view that change more positively than when the price rises faster than size (Wang, 2021). In the next paragraph, we further discuss the difference between four-way and two-way pallet bases, a key difference that impacts retail satisfaction depending on the pallet base used.

Two-way pallet bases are more likely to create retailer dissatisfaction due to potential rejection compared to four-way pallet bases. Two-way pallets are pallets that can only be accessed by a forklift from two locations. Four-way pallets are pallets that can be accessed by a forklift from four locations. Pallets with significant overhang create retail space and door overhang concerns that could drive immediate retail rejection, a relationship highlighted in our marketing interview. Increases in pallet overhang increase the risk of retail pallet rejection.

Tables B9-B11 summarize critical product shelving, product facing, and vendor packing information for Wal-Mart, Target, and Meijer that supplements our assessment in chapter 4.2.1.

### 2.3.3: Product design on manufacturing efficiency

Smucker must comprehend the impact of product design changes on cycle time and manufacturing efficiency. Any adaptation of product dimensions modifies the overall product design, which impacts manufacturing efficiency. Ensuring that Smucker's key operational processes remain efficient based on dimension changes was a primary objective throughout the capstone. According to an article by Mandar M. Chincholkar, the concept of Design for Production (DFP) "...evaluates product design by comparing its manufacturing requirements to available capacity and estimating manufacturing cycle time. DFP can be used to design the product in a way that decreases required capacity, reduces the manufacturing cycle time, or otherwise simplifies production" (Chincholkar, 2002, 5). Based on Chincholkar's theory, the more practical the product design is based on how closely design details align with manufacturing requirements the more likely the product can be produced without exceeding capacity requirements and the more likely production cycle times can be minimized. A different article by an undisclosed author at the *East West Manufacturing* company states that there are five principles of DFM ranging from process and design to environment and compliance. The manufacturing blueprint of a product should be easily understood by manufacturers and comply with specific manufacturing, quality, and safety standards (East West Manufacturing, 2020). In the next paragraph, we review how dimension changes impact the probability of manufacturing failure events that can weaken manufacturing efficiency.

Since Smucker uses robots to configure cases on a pallet and cartons in cases, there is an increased risk that certain dimension changes increase the risk of robotic failure when configuring products. When failure events occur, it weakens total manufacturing efficiency and the ability to meet order timing. According to a *DCS* article, "[R]ight now, that technology [robotic arm picking] is most effective when it can be applied to picking items that are relatively similar and consistent in size, shape, packaging, *weight*, and so on" (Knudsen, 2023, 1). One relevant relationship discussed in great detail during our manufacturing interview was the impact that picking and packing complexity has in driving potential equipment failure requiring machinery re-purchasing.

The concepts of design alignment for products and size consistency from the *DCS* article are further reinforced through a *Master Gage & Tool Co* article. Product and size consistency directly impacts manufacturing efficiency. Product design should enable manufacturers to accumulate precise measurements that can lower production costs, improve customer satisfaction, and meet quality regulations when executed successfully (Master Gage & Tool Co, 2023). An article by *Keller Technology Corporation* confirms that while producing based on precise dimensions is preferred, some manufacturing processes cannot support producing products per exact dimensions, driving a high risk of rejection, rework, and scrap. When manufacturers produce products based on set dimensions, the dimensional tolerances should be as large as possible. This ensures that products are produced at both high quality and low cost (Keller Technology Corporation, 2023). Smucker can measure the amount of acceptable dimensional tolerance by understanding the sales impact of deviated product dimensions. A different source reinforces that the relationship between dimensional tolerance and manufacturing cost is inverse. Manufacturers typically pay more to purchase machinery with lower dimensional tolerance or higher precision accuracy. Tighter tolerances, outside of raw equipment cost, can add processes and drive additional inspection and testing. These additional steps lead to increased total manufacturing costs (Woodland, 2018).

**2.3.4: Product design on movement of goods and operations**

Product design has an impact on transportation efficiency. Product dimension changes should not decrease the speed with which products are transported in a distribution environment. This was a critical factor evaluated throughout the capstone process. During our facility visit, we learned that pallet dimensions should not exceed the dimensions of available storage spaces. It is ideal for pallets to be held in storage locations close to the point of usage, which are typically trailer dock doors. A *DMG-Freight* article mentions that it is most cost-efficient to stack pallets in storage locations on top of each other as opposed to placing them on new shelves. If pallets can be placed on top of each other before storage equipment has been purchased, purchase costs are avoided. If storage equipment has already been purchased at the time that floor stacking is explored, additional pallets can be stored. Short pallets enable the implementation of block stacking, stacking pallets on top of each other on a warehouse floor, which could eliminate the costs of purchasing storage racks (DMG-Freight, 2022). Shorter pallets also enable increased storage flexibility in locations without present racks. During our facility visit, we noticed that frozen product pallets with lower heights were often stored closest to dock doors providing increased forklift accessibility. In our interviews, we reviewed the impact that product dimension changes have on the ability to store products in convenient storage locations. We also learned, in our warehouse interviews, the importance of maximizing product $weight$ and ship output to drive transportation cost savings. Pallet size and pallet condition also have the ability to maximize transportation efficiency.

An article by *Shipping & Handling of Texas* states that pallets with excessively high stacks, improper wrapping, and poor condition impact the ability to efficiently transport them in a warehouse environment and store them for periods before loading trailers. Pallet overhang and underhang cause warehouse workers to place their hands on pallets which also increases the risk of product damage. Sheer evidence of overhang and underhang increases the risk of damage on racks, shelves, or warehouse walls (Young, 2023). An article by *DARR Equipment* confirms that even small instances of pallet overhang and underhang can cause problems. Pallet overhang increases the risk of forklifts running into pallets that extend past the sides of the racking system, toppling the shelving unit. The overhang can also lead to shelving collapse. Additionally, allowing pallets to hang over the edges of warehouse racking systems violates OSHA regulations (DARR Equipment, 2022). Our interviews reinforce the solution that reduces product damage risk and ensures maximal worker safety. According to an article by *iGPS*, the type of pallet base used impacts durability, transport, and operational efficiency. Four-way pallets are more optimal than two-way pallets because they drive improved operational efficiency, space utilization, increased pallet-per-trailer count, and enhanced supply chain speed (iGPS, 2023). During our facility visit, we noticed that frozen products were held on four-way and two-way pallets. Two-way and four-way pallets can be accessed by a forklift in two and four locations respectively. We discuss how these findings are applied through our recommendations.

**2.4: Summary**

In this chapter we have summarized the relevance of the empirical research performed and re-confirm how this research supports our methodology. The brick-laying configuration approach used is effective at minimizing overall product damage promoting maximal stability. When paired with case rotation on an alternative dimension per instance of residual space on a pallet, overall product stability is maximized. The findings from the trailer product distribution analysis suggest a fair and even distribution of total ship quantities across carriers. The frozen product distribution of product type analysis suggests a widespread and even distribution of product types across select carriers. Based on the literature review and the current state of the organization, we considered the extreme-point algorithm research, product distribution by box type, and trailer distribution analyses as potential solutions to address the identification of optimal product configuration and sorting approaches.

## Ch 3: METHODOLOGY

In this chapter, we summarize the analysis procedures related to the entire optimization modeling process executed throughout the project, leveraged through TOPS modeling techniques.

### 3.1: TOPS Model Experimentation Process

In this chapter, we summarize the analysis procedures related to the modification of case and pallet dimensions. We then summarize the analysis procedures related to the modification of carton dimensions. We then summarize the analysis procedures related to physical carton testing and informational interviews. We lastly summarize the analysis procedures related to the freight load reduction analysis.

Throughout our model development, we were subject to a series of evaluated constraints seen in Table B12 in Appendix B. Within our TOPS constraint limits, we were subject to a series of automation constraints seen in Tables B13 and B14 in Appendix B.

In our first analysis procedure, we generated thirty-eight 4-count models that each drove different impacts on carton-to-pallet counts that were under the three major categories of conservative, requested and extreme. We only modified case and pallet dimensions when performing this step. Conservative models allowed no pallet overhang, requested models provided minimal overhang, while extreme models provided additional overhang and potential narrower automation gaps in the packaging. Exact count differences can be seen in Table B2 in Appendix B. In our second analysis procedure, we generated twenty-eight 10-count TOPS models that drove differences in ship output based on modifying only case and pallet dimensions but still allowing for rotation of cartons in cases and cases on pallets so that the top of the package was not always facing upward. Table B3 in Appendix B summarizes exact differences in carton-to-pallet counts based on experimented models. In our third analysis procedure, we generated thirty-five 18-count models, modifying only case and pallet dimensions but still allowing for rotation of cartons in cases and cases on pallets so that the top of the package was not always facing upward. 18-count models drove differences in ship output, with exact differences summarized in Table B1 in Appendix B.

In our fourth analysis procedure, we sought to develop additional models (see Tables B7 and B8 in Appendix B). Our sponsor organization wanted to determine whether modifications to carton dimensions drove a higher ship output than those already presented. We generated twenty-five additional 10 and 18-count models, modifying select carton dimensions only. We did not explore the modification of carton dimensions for 4-count products due to many factors, largely due to the amount of unused space we observed during our site visit. Many models included in Tables B7 and B8 in Appendix B were not received well by our sponsor organization, but three were. We discuss interview feedback related to the three carton-modified models in chapter 4.2.2.

We then performed a fifth analysis procedure to test the feasibility of the three chosen carton-modified models seen in Tables 5 and 6 in chapter 4.1. In this analysis, we performed physical testing to understand the impact that carton dimension changes have on automation constraints and physical sizing. This was performed because of the concern of company representatives that the physical carton dimension changes were not feasible. The representatives were fearful that smaller carton sizes would comprise total frozen product count. They were also concerned that smaller sizes would impede box closure capabilities, drive cardboard damage, and lead to automation constraint violation. Using physical equipment, we were able to eliminate many risks, but not all. Other risks were noted for the carton-modified models, which are discussed in greater detail in chapter 4.2.2.

Our sixth procedure was conducting interviews with company representatives (reviewed in chapters 4.2 and 4.3). The interviews enabled us to gain feedback on our optimal models, seen in Tables 4-6 in chapter 4.1. We spoke with a marketing representative focusing on brand commercialization and a manufacturing representative who is an expert in manufacturing process efficiency. We spoke with two warehouse operations representatives who specialized in maximizing warehouse efficiency in distribution environments as well as with a sustainability representative who supports Smucker's carbon emissions and idle time reduction goals. We also spoke with a packaging representative who supports packaging efficiency at Smucker.

Upon identifying our best solutions from these informational interviews, we executed a freight load reduction analysis discussed in greater detail in chapter 4.4 that highlights load reduction opportunities for all fifteen models seen in Tables 4-6 in chapter 4.1, with special emphasis on the top two models for 4, 10, and 18-count frozen product types, disclosed at the end of chapter 4.3. We discuss in chapter 4.4 how greater load reduction opportunities translate into higher annual cost savings.

## Ch 4: RESULTS

We summarize the key findings from our sensitivity and optimization model analyses performed in TOPS in chapter 4.1. We then review our preliminary informational interview results in chapter 4.2. We provide a summary of our major insights from the interviews with stakeholder feedback in chapter 4.3. We lastly summarize the findings from our freight load reduction analysis in chapter 4.4, emphasizing load reduction and cost savings opportunities for our best models.

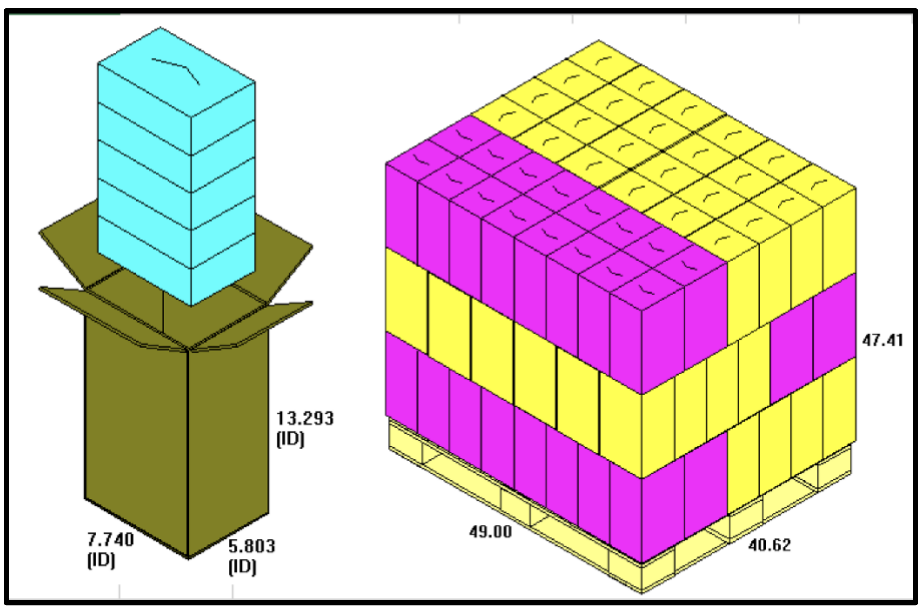
### 4.1: Sensitivity Analysis and Optimization Model Results

We first summarize two select sample visuals for the 4-count frozen product, then for the 10-count frozen product, and finally for the 18-count frozen product.

**Figure 4**

*TOPS Carton and Pallet Visualizations (4-Count, Models D and E)*

**Model D:**



**Model E:**

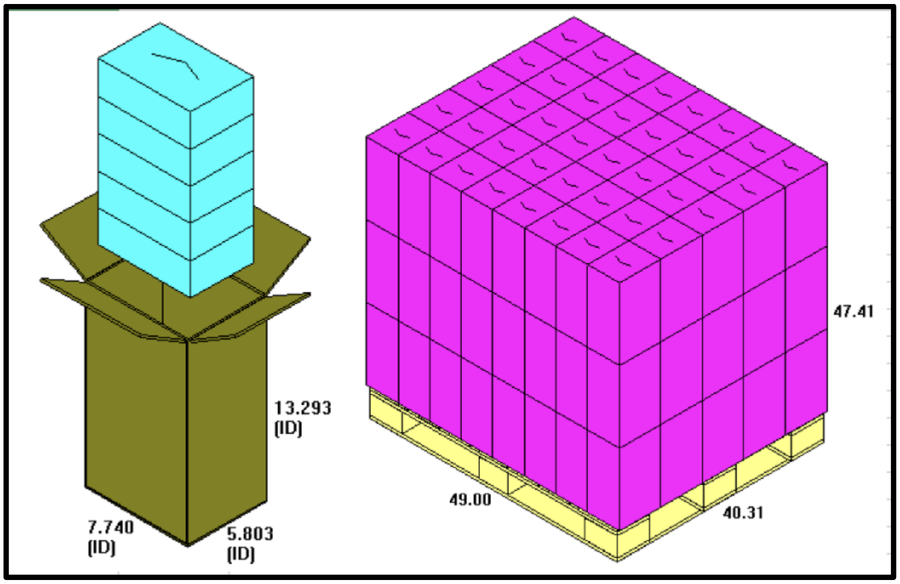


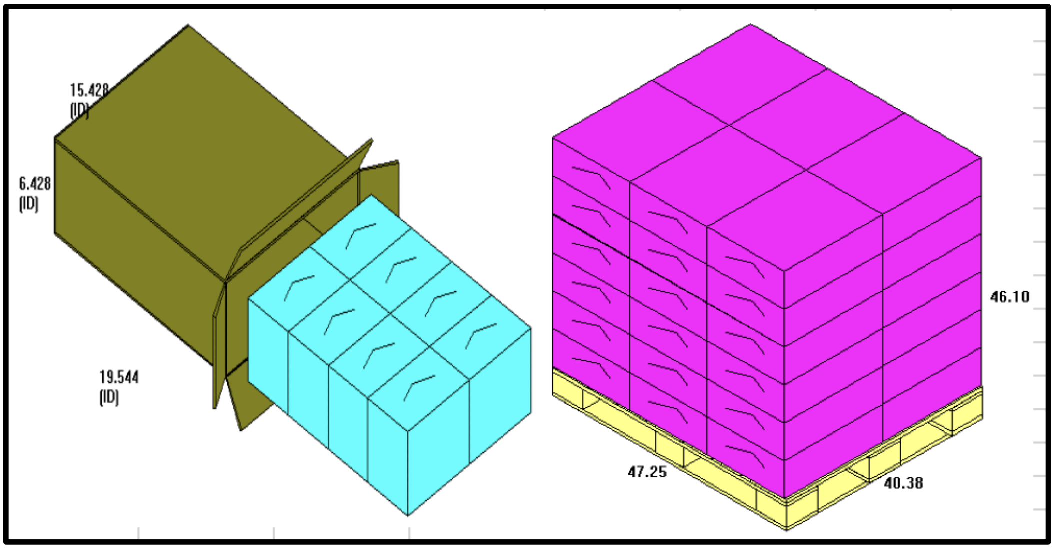

Figure 4 shows 4-count models D and E, two sample 4-count optimization models that were derived from our sensitivity analysis and were displayed in our interviews.

Table B2 in Appendix B summarizes all 4-count optimization models generated that explore the modification of case and pallet dimensions. We experimented with the presence of space gaps, case directions on a pallet, automation constraints, and total product $weight$ in generating the thirty-eight models in this analysis procedure. We also experimented with the modification of case and pallet dimensions, as previously indicated. Not all modifications performed were implemented in our recommendations for all product types.

**Figure 5**

*TOPS Carton and Pallet Visualizations (10-Count, Models D and E)*

**Model D:**




**Model E:**

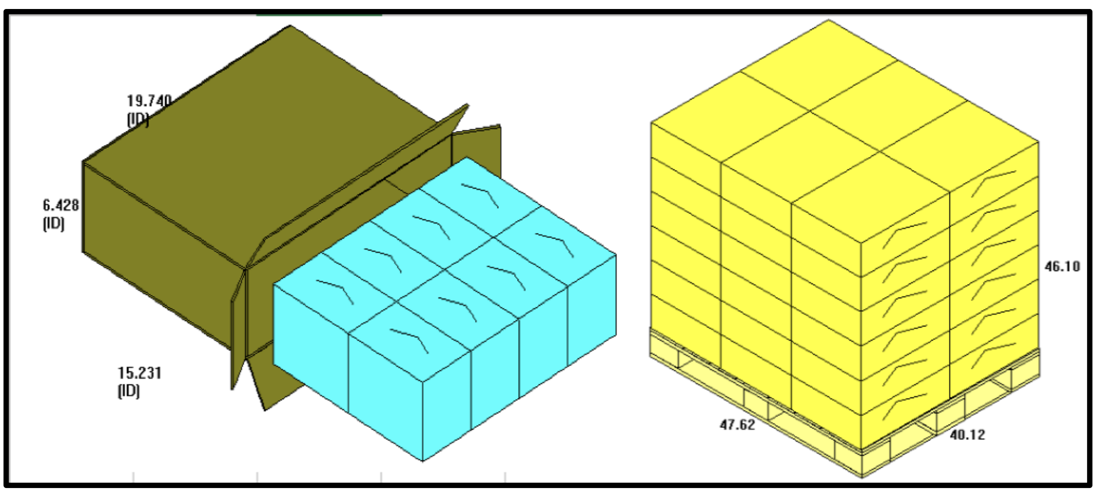


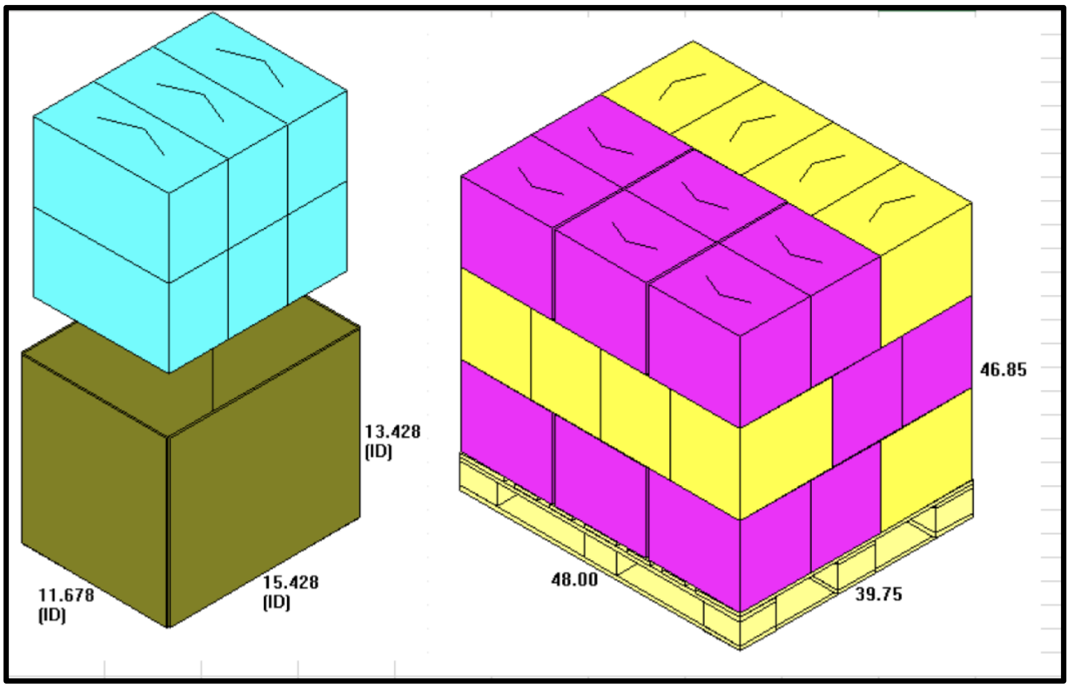

Figure 5 shows 10-count models D and E, two 10-count optimization models that were derived from our sensitivity analysis procedure and were displayed in our interviews.

Table B3 in Appendix B summarizes all 10-count optimization models generated that explore the modification of case and pallet dimensions. We experimented with the same decision variables in this analysis procedure as per our 4-count model experimentation, modifying the presence of space gaps, case directions on a pallet, automation constraints, and total product *weight* in generating the twenty-eight models in this analysis procedure. We explored the modification of case and pallet dimensions. As mentioned, not all modifications performed were implemented in our final recommendations.

**Figure 6**

*TOPS Carton and Pallet Visualizations (18-Count, Models C and B)*

**Model C:**



**Model B:**

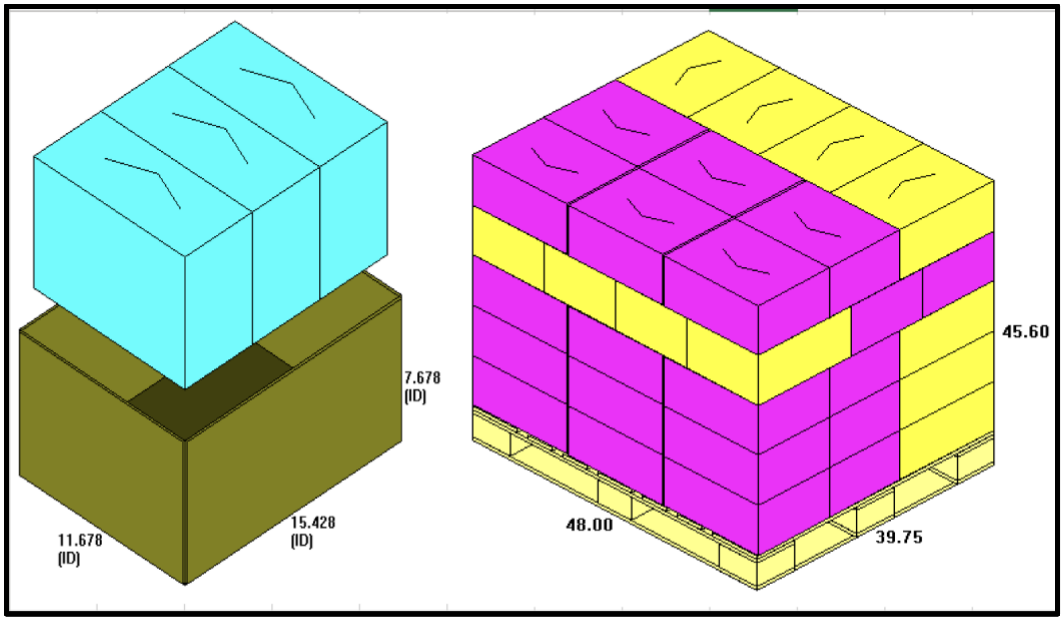



Figure 6 shows 18-count models C and B, two 18-count optimization models that were derived from our sensitivity analysis procedure and displayed in our interviews.

Table B1 in Appendix B summarizes all 18-count optimization models that explore the modification of case and pallet dimensions. We experimented with the same decision variables as previously mentioned, modifying the presence of space gaps, case directions on a pallet, automation constraints, and total product $weight$ in generating the thirty-five models in this analysis procedure. We explored the modification of case and pallet dimensions. As mentioned, not all modifications performed were implemented in our final recommendations.

Our dimension adaptations explored for 151 generated models enabled us to arrive at 15 optimal models. Tables 4, 5, and 6 summarize our optimal 4-count, 10-count and 18-count models respectively. All model numbering corresponds to the numbering for the models displayed in Tables B4-B6 in Appendix B for each product type.

**Table 4**

*4-Count TOPS Models*

| TOPS Dimensions | Model A | Model B | Model C | Model D | Model E |
|---|---|---|---|---|---|
| Carton Length | 7.219” | 7.219” | 7.219” | 7.219” | 7.219” |
| Carton Width | 4.875” | 4.875” | 4.875” | 4.875” | 4.875” |
| Carton Height | 2.518” | 2.518” | 2.518” | 2.518” | 2.518” |
| Case Length | 7.740” | 7.678” | 5.428” | 7.74” | 7.74” |
| Case Width | 15.553” | 10.553” | 15.366” | 5.803” | 5.803” |
| Case Height | 5.731” | 13.293” | 13.293” | 13.293” | 13.293” |
| Pallet Length | 48.38” | 48.00” | 47.06” | 49.00” | 49.00” |
| Pallet Width | 40.06” | 40.62” | 38.69” | 40.62” | 40.31” |
| Pallet Height | 43.85” | 47.41” | 47.41” | 47.41” | 47.41” |
| Current Carton-to-pallet count | 528 | | | | |
| Carton-to-pallet count | 540 | 660 | 600 | 600 | 600 |
| Count increase | 12 | 132 | 72 | 72 | 72 |
| Ship output increase % | 2.27 | 25.00 | 13.64 | 13.64 | 13.64 |

| | | | | | |
|---|---|---|---|---|---|
| Carton volume % change (If any, otherwise N/A) | N/A | N/A | N/A | N/A | N/A |
| Case volume % change (If any, otherwise N/A) | 30.28 | 8.84 | 13.50 | 39.66 | 39.66 |
| Pallet volume % change (If any, otherwise N/A) | 11.29 | 21.06 | 13.05 | 23.58 | 22.64 |
| Pallet weight (lbs, per pallet) | 453.20 | 513.80 | 472.70 | 508.70 | 508.70 |
| Estimated trailer weight (lbs, assuming 60 pallet-per-trailer count) | 27,192 | 30,828 | 28,362 | 30,522 | 30,522 |

**Table 5**

*10-Count TOPS Models*

| TOPS Dimensions | Model A | Model B | Model C | Model D | Model E |
|---|---|---|---|---|---|
| Carton Length | 7.25” | 7.25” | 6.75” | 7.25” | 7.25” |
| Carton Width | 4.7” | 4.7” | 4.45” | 4.7” | 4.7” |
| Carton Height | 5.89” | 5.89” | 5.64” | 5.89” | 5.89” |
| Case Length | 9.928” | 7.803” | 9.428” | 6.428” | 6.428” |
| Case Width | 15.428” | 15.053” | 14.428” | 15.428” | 19.74” |
| Case Height | 12.481” | 12.481” | 11.981” | 19.544” | 15.231” |

| | | | | | |
|---|---|---|---|---|---|
| Pallet Length | 47.25” | 46.12” | 48.75” | 47.25” | 47.62” |
| Pallet Width | 41.00” | 40.62” | 39.25” | 40.38” | 40.12” |
| Pallet Height | 44.97” | 44.97” | 43.47” | 46.10” | 46.10” |
| Current Carton-to-pallet count | 252 | | | | |
| Carton-to-pallet count | 288 | 270 | 312 | 288 | 288 |
| Count increase | 36 | 18 | 60 | 36 | 36 |
| Ship output increase % | 14.29 | 7.14 | 23.81 | 14.29 | 14.29 |
| Carton volume % change (If any, otherwise N/A) | N/A | N/A | 15.59 | N/A | N/A |
| Case volume % change (If any, otherwise N/A) | 18.73 | 8.95 | 1.21 | 20.37 | 20.03 |
| Pallet volume % change (If any, otherwise N/A) | 1.47 | 1.88 | 3.12 | 2.45 | 2.58 |
| Pallet weight (lbs, per pallet) | 518.70 | 498.70 | 556.80 | 518.70 | 518.70 |
| Estimated trailer weight (lbs, assuming 60 pallet-per-trailer count) | 31,122 | 29,922 | 33,408 | 31,122 | 31,122 |

**Table 6**

*18-Count TOPS Models*

| TOPS Dimensions | Model A | Model B | Model C | Model D | Model E |
|---|---|---|---|---|---|
| Carton Length | 11.13” | 11.13” | 11.13” | 11.13” | 11.13” |
| Carton Width | 4.94” | 4.94” | 4.94” | 4.94” | 4.94” |
| Carton Height | 7.25” | 7.25” | 6.50” | 6.50” | 7.25” |
| Case Length | 15.366” | 11.678” | 11.678” | 15.366” | 7.803” |
| Case Width | 22.865” | 15.428” | 15.428” | 22.865” | 11.741” |
| Case Height | 7.678” | 7.678” | 13.428” | 13.428” | 20.178” |
| Pallet Length | 47.06” | 48.00” | 48.00” | 47.06” | 48.75” |
| Pallet Width | 38.88” | 39.75” | 39.75” | 38.88” | 40.38” |
| Pallet Height | 45.60” | 45.60” | 46.85” | 46.85” | 46.60” |
| Current Carton-to-pallet count | 120 | | | | |
| Carton-to-pallet count | 150 | 150 | 180 | 180 | 160 |
| Count increase | 30 | 30 | 60 | 60 | 60 |
| Ship output increase % | 25.00 | 25.00 | 50.00 | 50.00 | 33.33 |

| | | | | | |
|---|---|---|---|---|---|
| Carton volume % change (If any, otherwise N/A) | N/A | N/A | 10.34 | 10.34 | N/A |
| Case volume % change (If any, otherwise N/A) | 18.73 | 8.95 | 1.21 | 20.37 | 66.77 |
| Pallet volume % change (If any, otherwise N/A) | 1.47 | 1.88 | 3.12 | 2.45 | 30.00 |
| Pallet weight (lbs, per pallet) | 650.20 | 691.20 | 767.90 | 743.30 | 711.30 |
| Estimated trailer weight (lbs, assuming 60 pallet-per-trailer count) | 39,012 | 41,472 | 46,074 | 44,598 | 42,678 |

There is a 13.64% average increase in total carton-to-pallet counts for all 4-count models based on the ship output increases listed in Table 4, a 14.76% average increase in total carton-to-pallet counts for all 10-count models based on the ship output increases listed in Table 5, and a 36.66% average increase in total carton-to-pallet counts for all 18-count models based on the ship output increases listed in Table 6. The average proposed case $volume$ change across all models with altered case dimensions is 29.59%. The average proposed pallet $volume$ change across all models with altered pallet dimensions is 14.64%. The average proposed carton $volume$ change across all models with altered carton dimensions is 12.09%. Our freight load reduction analysis, which is summarized in greater detail in chapter 4.4, confirms that the load reduction opportunities for 4-count models A-E are 2.247%, 19.985%, 12.085%, 12.085%, and 12.085%. The load reduction opportunities for 10-count models A-E are 12.411%, 6.577%, 19.119%, 12.411%, and 12.411%. The load reduction opportunities for 18-count models A-E are 20.089%, 20.089%, 33.338%, 33.338%, and 25.040%. We further review load reduction and cost savings opportunities in chapter 4.4.

In this paragraph, we summarize critical learnings from our optimization modeling process based on steps previously defined in our methodology. We learned that once models are presented with strong ship output improvements, product stability becomes a greater priority. We also learned, in the process of performing carton testing, that additional physical validation to maximize modeling feasibility is sometimes necessary. Modeling feasibility is driven from the ability to maximize one key objective without compromising performance on other factors. There is no perfect solution, but perfection in reality is driven through the ability to minimize as many potential risks as possible while still maximizing firm benefit. We had to utilize creativity in order to identify the specific changes that would drive great ship output increases while aligning to key stakeholder values. We had to ask the right questions to receive the right answers to deeply understand the impact of our solutions. Compromises in one factor had to be made to ensure maximal performance against an additional factor. Our analysis enabled us to accomplish this objective amongst other objectives.

In chapters 4.2 and 4.3, we summarize interview feedback for all fifteen optimal models, leading to the top two models for each product type, summarized at the end of chapter 4.3.

**4.2: Informational Interview Results**

Chapters 4.2.1-4.2.5 summarize our interview results by model assessment category: marketing effectiveness, manufacturing efficiency, transportation, packaging, and sustainability.

**4.2.1: Interview Results - Marketing Effectiveness**

We gained feedback on our options in terms of marketing effectiveness. We spoke with a brand commercialization stakeholder at Smucker. This stakeholder mentioned that pallets with significant pallet overhang increase the risk of retail space overhang, driving increased product fitting challenges for club retailers, who sometimes sell products on pallets directly. She also mentioned that pallets with significant overhang create door closure challenges, particularly in freezer environments, where there is finite space between doors, both for club and standard retailers. Additionally, given the challenges in storing frozen products in freezer environments during the holidays due to limited shelf space, Smucker cannot assume that more product at the retailer is always a benefit. She lastly mentioned that any models adapting carton dimensions increase the risk of manufacturing equipment failure requiring significant machinery re-investment costs that would create net financial losses for Smucker due to high equipment replacement costs. This is a greater risk under the assumption that the dimensional tolerance on existing equipment is low, requiring high precision accuracy. She was most supportive of models that did not have significant pallet overhang and did not modify carton dimensions. Select marketing statistics that supported our conversation are included in Tables B9-B11 in Appendix B.

#### 4.2.2: Interview Results - Manufacturing Efficiency

We evaluated these same options against manufacturing efficiency. We had a discussion with a manufacturing expert at Smucker. For our 4-count models, the individual mentioned that the narrowness of design options for model C could create constraints related to product bowing and tipping. If the case is too narrow in one direction, it will have a high center of gravity, creating a less stable pallet. He also claimed that 4-count model E was unacceptable due to high risk of column stack collapsing prior to execution of stretch wrapping processes. He felt that the 4-count model D option would drive instability in product conveying tasks due to the tower shape, deeming it unacceptable. These two models would also drive challenges in pallets not being highly shippable. He claimed that pallet overhang, as long as it is less than 1”, does not pose a great concern for all product types.

Our representative mentioned that models C and D for the 18-count product and model C for the 10-count product would create many constraints. Modifying carton dimensions is a challenging endeavor. Modifying carton dimensions leads to equipment failure driving new equipment purchase that can be a costly investment. The 10-count product is the most popular SKU and is run on many lines, indicating that changes to carton dimensions for this product type would incur very high installation and equipment replacement costs. Even though the 18-count product runs on fewer lines than the 10-count product, high investment costs would still be incurred. He confirmed that there is a broad range of potential costs that Smucker would incur to purchase new equipment, ranging between $50,000 and $500,000 for all product types. He anticipated that the 10-count total investment cost would be near $300,000, with a raw tooling investment cost between $50,000-$100,000 per production line. Case space changes based on carton size and packing patterns. He was significantly less supportive of model D for the 10-count product due to challenges in case forming, filling, and taping. He claimed the 10-count model E as unacceptable due to similar concerns, along with loading challenges due to required laying. He was less supportive of the 10-count model B option, given increased constraints modifying case dimensions in the listed form. He said that 18-count model E had an unstable design as well as difficulties removing cartons from cases.

**4.2.3: Interview Results - Transportation**

We further evaluated our options against transportation risks. We spoke with two representatives within warehouse operations to gain feedback on our top five options by product type against transportation risks. One evident tradeoff that was evaluated in our interviews with these personnel was the desire to maximize ship output and trailer product $weight$ while minimizing pallet overhang. Warehouse operations representatives were highly satisfied with the models that maximized transportation savings through increased ship output. They also were highly satisfied with the models that minimized pallet overhang and underhang. They communicated that double-stacked pallet $heights$ cannot exceed 96" at most major distribution centers, which is greater than the provided double-stacked pallet $height$ constraint of 95" (47.5" per pallet) that was considered in model development. The higher the total product $volume$ on existing trailers, the greater the ability to fulfill orders of large size with fewer assets, driving transportation savings through trailer cost avoidance. Additionally, increased total product $volume$ enables fewer pallets to be prepared for trailer loading, driving additional cost savings through avoided pallet handling and storage fees within distribution centers. We verified that the benchmark cost to be used for handling and storage of an individual pallet is $30 per pallet. Additionally, these stakeholders looked to minimize on-hand inventory as much as possible due to cash availability concerns. Models driving an increase in total loaded product $volume$ per trailer enable more received inventory to be shipped quickly assuming demand is present, driving lower on-hand inventory levels enabling increased cash availability. These individuals felt that the maximization of ship output would also maximize total product $weight$ on trailers which was an additional valued priority. Previously case $weight$ was not directly calculated for the new models, but upon the request of these individuals it was added, and it was discovered that Model C-E for 18-count cartons had a risk of exceeding the truck limit for $weight$ if including 60 pallets per truckload, while all other models were well within the weight constraints outlined. They lastly valued the specific models that minimized pallet overhang and underhang to maximize product stability and reduce pallet damage risk. Based on this feedback, we knew that the models that maximized ship output without violating trailer or product $weight$ constraints with the lowest amount of overhang/underhang were more satisfactory than other options.

**4.2.4: Interview Results - Packaging**

We gained an understanding of how each option ranks against packaging risks. We spoke with an individual in Smucker's packaging team to gain relevant feedback. One of the most relevant risks that was reviewed during our interview was the risk of product tipping on a conveyor belt particularly for cases that are 'skinny', with a low $base\ area$ ($length$ * $width$). The individual was also not supportive of any pallets with significant overhang due to increased pallet damage risk. They lastly mentioned the risk of packaging bowing that can occur when total carton $volume$ within cases is abnormally high. The risk of packaging bowing increases amidst higher physical touching and increased movement activity. For those reasons, the interviewee was most supportive of specific models with a higher case $base\ area$ and minimal pallet overhang. Minimal physical touching and handling of specific products will minimize the risk of packaging bowing.

**4.2.5: Interview Results - Sustainability**

We understood how each option ranks against sustainability risks. We spoke with one representative in sustainability at Smucker. The first immediate impact that was highlighted was the minimal increase in total required packaging material use driven by an increase in total item sizes. The individual confirmed, on average, that the increase in packaging material required to support a much larger increase in total product ship output upon increasing the size of items is very small. On average, a 5% increase in total packaging material use is required to support a large increase in total loaded product $volume$ (25%-50% increase) driven by size increases. She confirmed that the sustainability impact based on increased packaging material use is minor unless major size changes are made, which were not made through the model development process. She did confirm that solutions with minimal pallet overhang and maximized ship output best align to current sustainability priorities. Pallets with significant overhang require increased packaging material use if pallets are damaged. Re-wrapping of particular pallets in the event of pallet damage also delays the trailer loading process. This could drive increased idle truck runtime if assets are running throughout the trailer loading process. She also evaluated the difference in $weight$ relative to the increase in ship output for each model, identifying the models with the lowest $weight - to - output$ ratio as the most optimal. A low ratio indicates that the increase in total product $weight$ is small in comparison to the increase in total ship output. She confirmed that pallets with high total loaded product $volume$ enable fewer trucks to be utilized to execute customer orders, enabling significant reductions in total carbon emissions. Additionally, idle truck runtime risk increases as the total number of trucks required to fulfill customer orders increases, an additional benefit of using fewer trucks to fulfill orders. Fuel consumption is higher for reefer trailers than standard trailers, driving potential worsened environmental outcomes if idle runtime is high due to a high number of used reefer assets. Based on these points, our representative was most supportive of models that maximize ship output, minimize pallet overhang, and drive a low $weight - to - output$ ratio. In chapter 4.4, we summarize the carbon emissions reductions driven from our primary and secondary recommendations.

**4.3: Summary of Informational Interviews**

The most consistent priorities across all interviews were the desire to minimize risk of equipment replacement, minimize pallet overhang/underhang, maximize ship output, maximize case $base\ area$, maximize efficiency across case forming, case filling, and case conveying processes, and achieve a low $weight - to - output$ ratio.

We solicited specific feedback from each stakeholder, asking them to rank each specific model seen in Tables 4-6 in chapter 4.1 on a scale of best to worst (1 to 5 respectively), and to let us know if any model was unacceptable from their perspective. Upon receiving this feedback, we were able to identify three top solutions. All stated models yield varying degrees of implementation feasibility. We deem all models viable options that Smucker should consider implementing.

The 4-count stakeholder rankings are summarized in Table 7, the 10-count Table 8, and the 18-count in Table 9. After summarizing the ranking results, we go into greater depth on our top two models for each product type. It is important to note that all models with an unacceptable label were not considered for selection upon identifying our primary options. All primary options were chosen by identifying the model with lowest combined score after excluding all unacceptable models. Our secondary options considered unacceptable models for selection. We identified our secondary options by identifying the lowest combined score among all models not part of our primary recommendations. There was one exception to this rule: a tie in total score.

10-count models A and D had the same combined score when evaluating them as the primary recommendation, after excluding 10-count models C and E. 10-count models C and E had the same combined score when evaluating them as a secondary option, since they were deemed unacceptable by manufacturing. In the event of a tie, we first determined whether the two models had any scores of 5. If at least one 5 was found in one of the two or both models and no scores of one were given, the model with the fewest number of 5's was selected. If no scores of 5 were given and scores of one were given, the model with the highest number of one scores was selected.

**Table 7**

*4-Count Stakeholder Ranking Summary*

| Stakeholder Ranking Summary (4-Count) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **Marketing** | **Manufacturing** | **Packaging** | **Warehouse Operations 1** | **Warehouse Operations 2** | **Sustainability** | **Total Score** | **Rank** |
| **Model A** | 2 | 3 | Not given | 5 | 5 | 5 | 20 | 5 |
| **Model B** | 3 | 2 | 2 | 1 | 1 | 2 | 11 | 1 |
| **Model C** | 1 | 5 | 1 | 2 | 2 | 1 | 12 | 2 |
| **Model D** | 5 | Unacceptable | Not given | 4 | 4 | 3 | 16 | 4 |
| **Model E** | 4 | Unacceptable | Not given | 3 | 3 | 4 | 14 | 3 |

**Table 8**

*10-Count Stakeholder Ranking Summary*

| Stakeholder Ranking Summary (10-Count) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **Marketing** | **Manufacturing** | **Packaging** | **Warehouse Operations 1** | **Warehouse Operations 2** | **Sustainability** | **Total Score** | **Rank** |
| **Model A** | 2 | 2 | Not given | 4 | 4 | 3 | 15 | 1 |
| **Model B** | 3 | 5 | 1 | 5 | 5 | 5 | 24 | 5 |
| **Model C** | 3 | Unacceptable | Not given | 1 | 1 | 4 | 9 | 2 |
| **Model D** | 2 | 5 | Not given | 3 | 3 | 2 | 15 | 4 |
| **Model E** | 4 | Unacceptable | Not given | 2 | 2 | 1 | 9 | 3 |

**Table 9**

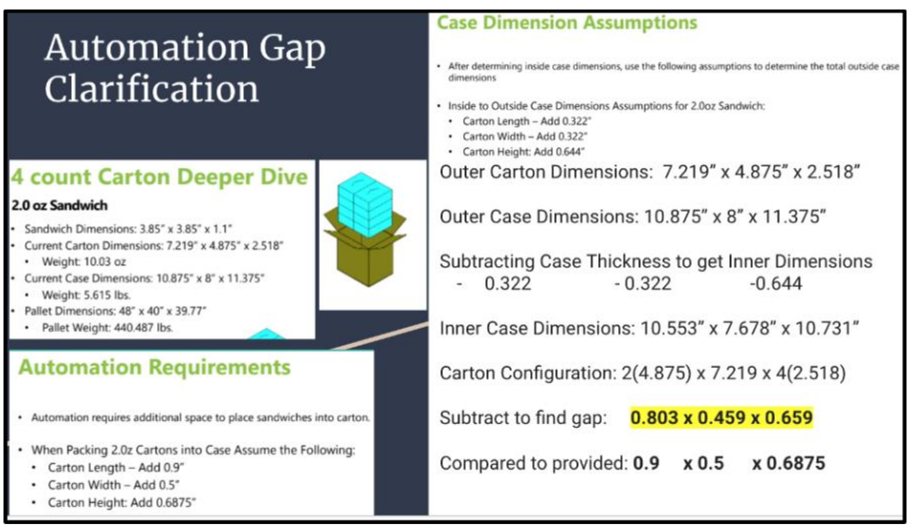
*18-Count Stakeholder Ranking Summary*

| Stakeholder Ranking Summary (18-Count) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model** | **Marketing** | **Manufacturing** | **Packaging** | **Warehouse Operations 1** | **Warehouse Operations 2** | **Sustainability** | **Total Score** | **Rank** |
| **Model A** | 1 | 3 | Not given | 4 | 4 | 3 | 15 | 1 |
| **Model B** | 1 | 4 | Not given | 5 | 5 | 5 | 20 | 5 |
| **Model C** | 1 | Unacceptable | Not given | 1 | 1 | 2 | 5 | 3 |
| **Model D** | 1 | Unacceptable | Not given | 1 | 1 | 1 | 4 | 2 |
| **Model E** | 2 | 5 | Not given | 3 | 3 | 4 | 17 | 4 |

The 4-count model with the most positive feedback was model B, as seen in Table 4 in chapter 4.1. This model has more but still small degrees of overhang relative to model A. This model has a relatively strong case *base area* driving low product toppling risk. It has maximal ship output driving significant transportation cost savings and carbon emission reductions. This model has the second lowest $weight - to - output$ ratio. This model was ranked highly by our packaging representative. During our manufacturing interview, our representative validated that this model was more acceptable than model C and had an acceptable manufacturing design. Model B also considered varying automation gaps that were calculated compared to the values provided as constraints. The calculated gap values were used by taking the outer case dimensions for the 4-count carton, subtracting case thickness and calculating the difference between those dimensions and the dimensions of taking the outer carton dimensions and orienting the cartons to the existing packaging. The calculations can be seen in Figure 7: the calculated gap was smaller than the provided gap in all three dimensions, therefore potentially reducing one of the constraints by requiring smaller gaps than originally hypothesized. However, this would need to be further tested by Smucker to confirm its accuracy, as this is outside the scope of this capstone project.

**Figure 7**

*Automation Gap Analysis for 4-Count Packaging*




The 10-count model that had the most positive feedback was model A. This is seen in Table 5 in chapter 4.1. While model A has the second-highest total combined ship output relative to other models, it has the lowest $weight - to - output$ ratio and yields a strong reduction in carbon emissions, both values of our sustainability stakeholder. It has a high case $base\ area$, minimizing the risk of product toppling. This model was the second-best model ranked by all warehouse representatives due to a high ship output and high pallet $weight$. This model also has less pallet underhang than model B and minimal pallet overhang on $width$. Our manufacturing representative confirmed that the carton dimensions for 10-count model C creates incremental challenges, due to reasons mentioned in chapter 4.2.2. Model A drives fewer challenges related to equipment changes and direct customers compared to model C based on manufacturing feedback.

The 18-count model that had the most positive feedback was model A. This is seen in Table 6 in chapter 4.1. Similar to our 10-count optimal solution, model A has the third-highest computed total ship output and third-lowest $weight - to - output$ ratio. This solution has no pallet overhang and minor pallet underhang. It has a relatively strong case $base\ area$ that reduces the risk of product toppling. From a manufacturing perspective, our stakeholder reinforced that modifications to any carton dimensions are incredibly challenging, deeming models C and D as unacceptable. Our manufacturing stakeholder mentioned that equipment changes driven through adopting these two models would be costly and time-consuming, driving large constraints. Model B was ranked less favorably by warehouse operations and sustainability stakeholders than model A.

It is evident, from Tables 7-9, that fantastic secondary options are the 4-count model C, 10-count model C, and 18-count model D options. If Smucker faces challenges implementing our primary recommendations and/or can absorb the cost of new equipment investment quickly, these secondary options serve as great alternatives.

**4.4: Load Reduction Analysis Results**

In this chapter, we summarize the findings from a load reduction analysis performed to highlight load reduction opportunities. We first summarize the load reduction opportunities for all fifteen models included in Tables 4-6 in chapter 4.1. We then summarize the average load reduction opportunities for TOPS primary and secondary recommendations. We lastly highlight cost savings and carbon emission reduction opportunities based on the load reduction opportunities for our TOPS primary and secondary recommendations.

**Table 10**

*Load Reduction Analysis, 4-count models*

| 4-Count | |
|---|---|
| **Model** | **Average percent reduction in required shipments** |
| Model A | 2.247% |
| Model B | 19.985% |
| Model C | 12.085% |
| Model D | 12.085% |
| Model E | 12.085% |

Table 10 confirms that Smucker could experience total semiannual load reductions of 2.247%, 19.985%, 12.085%, 12.085%, and 12.085% if 4-count models A-E are selected.

**Table 11**

*Load Reduction Analysis, 10-count models*

| 10-Count | |
|---|---|
| **Model** | **Average percent reduction in required shipments** |
| Model A | 12.411% |
| Model B | 6.577% |
| Model C | 19.119% |
| Model D | 12.411% |
| Model E | 12.411% |

Table 11 confirms that Smucker could experience total semiannual load reductions of 12.411%, 6.577%, 19.119%, 12.411%, and 12.411% if 10-count models A-E are adopted.

**Table 12**

*Load Reduction Analysis, 18-count models*

| 18-Count | |
|---|---|
| **Model** | **Average percent reduction in required shipments** |
| Model A | 20.089% |
| Model B | 20.089% |
| Model C | 33.338% |
| Model D | 33.338% |
| Model E | 25.040% |

Table 12 confirms that Smucker could experience total quarterly load reductions of 20.089%, 20.089%, 33.338%, 33.338%, and 25.040% if 18-count models A-E are adopted.

**Figure 8**

*Load Reduction Summary, TOPS Primary Recommendations*

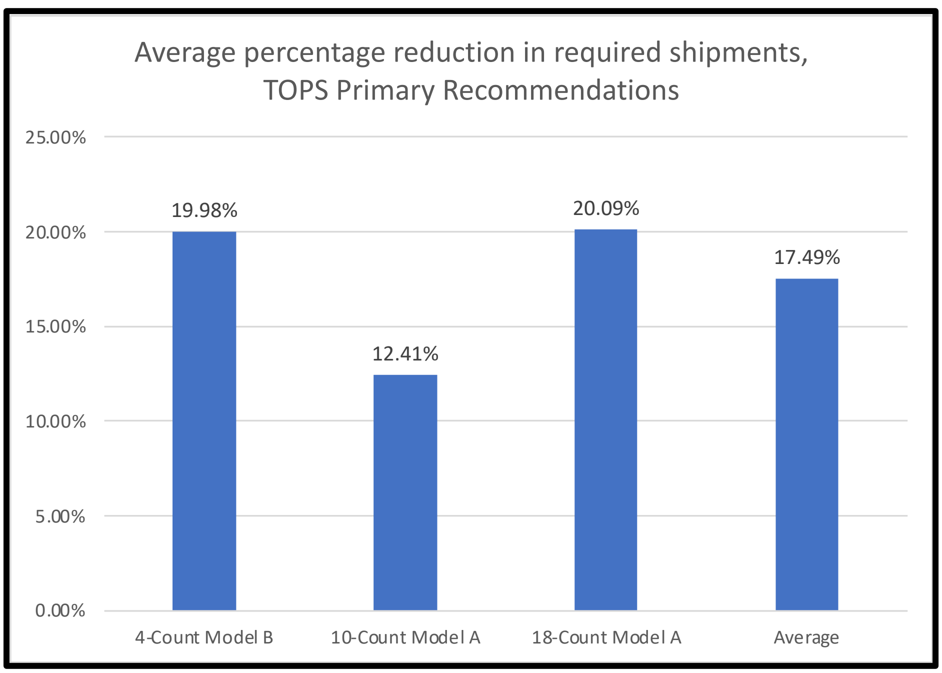


Figure 8 confirms that the total semiannual average load reduction across all TOPS primary recommendations is 17.49%, emphasizing that the noticeable increase in ship output is driving significant reductions in required shipments at each shipping point.

**Figure 9**

*Load Reduction Summary, TOPS Secondary Recommendations*

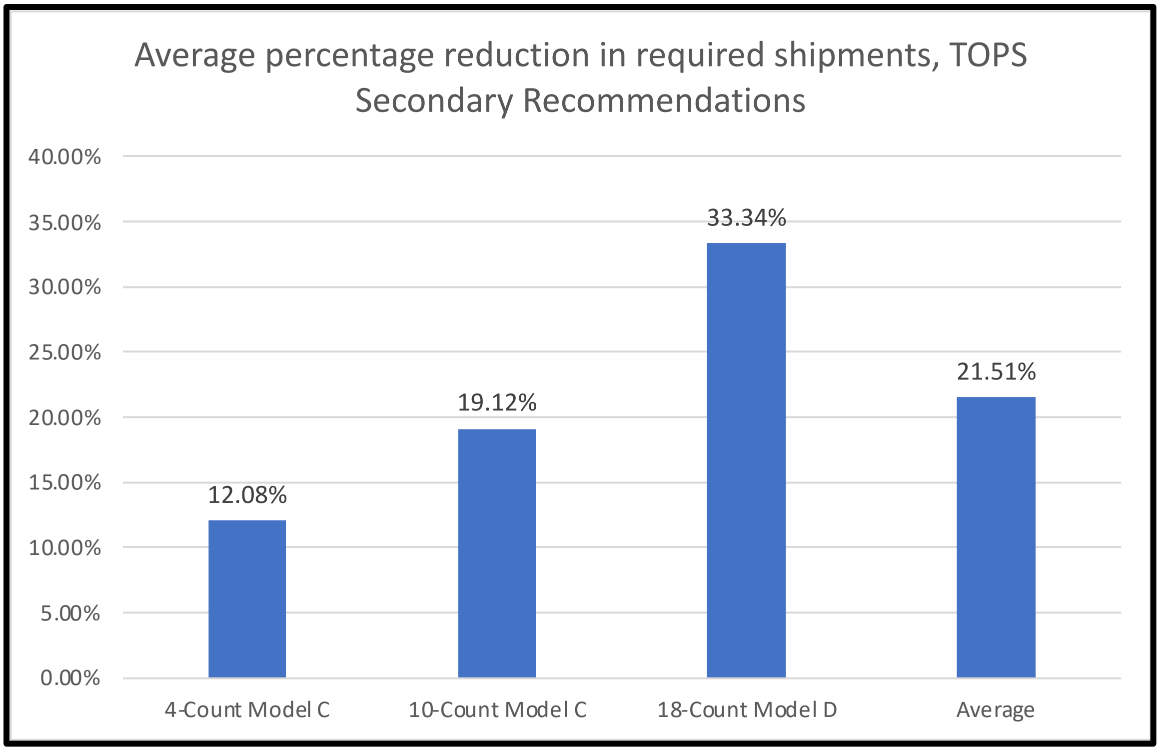



Figure 9 confirms that the total semiannual average load reduction across all TOPS secondary recommendations is 21.51%, emphasizing that the noticeable increase in ship output is driving significant reductions in required shipments at each shipping point.

Based on the sample $volume$ and benchmark costs, the total estimated semiannual cost savings for our TOPS primary and secondary recommendations are $7,934,060.85 and $9,805,620.06 respectively. The total estimated annual cost savings for our TOPS primary and secondary recommendations are $15,868,121.70 and $19,611,240.11 respectively. The total estimated annual reduction in carbon emissions for our TOPS primary and secondary recommendations is 1,377 tons of *CO2* and 1,717 tons of *CO2* respectively. The cost savings calculations include pallet handling and storage fees in addition to trailer transportation savings. The carbon emission calculation procedure is listed in Table B15 in Appendix B. The cost savings calculation procedure is listed in Table B16 in Appendix B.

## Ch 5: RECOMMENDATIONS

Our primary recommendations focus on select optimal optimization models. We have presented secondary recommendations supporting the configuration, sustainability, marketing, manufacturing, transportation, and packaging research from our literature review. The dimension and orientation recommendations resolve our key objective of maximizing total frozen product ship output. Our secondary recommendations support additional key capstone objectives to ensure Smucker's continued business success by aligning on stakeholder values.

From a dimension perspective, Smucker should adopt model B for 4-count, model A for 10-count products and model A for 18-count products if feasible before other options. All model solutions listed in Tables 4-6 in chapter 4.1 drive strengths and weaknesses that Smucker can evaluate in greater detail prior to implementation. Our goal to identify the solutions that yielded strong interview performance feedback and high satisfaction from our direct representatives was achieved.

Our secondary recommendations are summarized below.

From a configuration perspective, Smucker should ensure products are present at extreme-point coordinates to promote increased product stability after the product loading process is complete. They should minimize the residual space between cases on a pallet by rotating cases to an alternative dimension using the brick-laying approach, increasing the case-per-pallet count by a minimum of one case. Smucker should sort based on area-height and/or height-area techniques if they choose to sort products. Smucker should load pallets towards the front of the trailer first and along the same equivalent wall or side where the product has already been loaded before in other locations. These tasks will reduce product damage risk. These recommendations stem directly from the research included in Appendix C.

From a sustainability perspective, Smucker should deliver pallets to trailer dock doors efficiently to minimize idle truck runtime. They should ensure that products have a healthy shelf life to prevent additional material waste. They should refrain from shipping products in under-utilized trucks and minimize use of unnecessary assets to reduce total carbon emissions.

From a marketing perspective, our informational interviews validate that our primary recommendations minimize the risk of retail space or door overhang concerns that create potential retailer and customer dissatisfaction. The minimization of retail space and door overhang was achieved by recommending models that have minimal to no pallet overhang.

Smucker should ensure that price changes are fairly aligned with product size changes such that consumers do not feel overcharged at the store. Smucker should incorporate horizontal positioning in most retail stores to encourage varied product selection. Smucker should refrain from over shipping products in trailers to also reduce the risk of base damage and merchant rejection. Smucker should ensure that pallets do not violate any retailer ship requirements based on communicated requirements.

From a manufacturing perspective, Smucker should ensure that product drawings with new dimensions align with manufacturing capabilities, requirements, and set regulations. Smucker, across the same frozen product type, should ensure consistency across size, shape, packaging, and $weight$ metrics to minimize the risk of robotic failure. The design should enable Smucker to produce products with high dimensional tolerance, enabling current equipment to be used without requiring machinery re-purchase. This will minimize total manufacturing costs without driving large increases in production error margins. Smucker should understand the retail impact of producing per new product dimensions before purchasing specialized manufacturing equipment if low dimensional tolerance is required. If retail sales are not expected to grow based on selling products with revised product dimensions, the cost of purchasing new machinery will outweigh retail sales increases under new product dimensions, driving net financial losses for Smucker.

From a transportation perspective, Smucker should confirm that pallet storage locations minimize the amount of time required to pick, pack, and fulfill shipment orders and are located close to the point of usage. Pallet dimensions should enable safe storage in racked locations or on warehouse floors. Smucker should ensure that pallet dimensions do not violate OSHA regulations and do not generate more overhang than the amount approved through our recommendations. Smucker should reduce excess packaging material to prevent pallet damage. Lastly, Smucker should refrain from using two-way pallet bases when forming pallets to improve forklift accessibility and reduce merchant rejection risk.

Smucker should ensure that conveyor belts are properly programmed to reduce product toppling risk for our best solutions that maximize case $base\ area$. They should ensure that barcode labels are highly discernable. Smucker should ensure that packaging materials fit products well to reduce costs and damage risk.

By adopting the recommendations listed in this chapter, Smucker will be able to increase total frozen product ship output, experiencing annual transportation cost savings of $15,868,121.70 through reduced required shipments. They will be able to reduce carbon emissions annually by 1,377 tons. They will also be able to ensure business success on other fronts.

## Ch 6: CONCLUSION

In terms of potential next steps, Smucker should adopt all our recommendations. They should explore implementing models B, A, and A for 4, 10, and 18-count products respectively if feasible before other models listed in Tables 4-6 in chapter 4.1. The research performed also provides insight into potential future capstone projects. For example, Smucker can explore dimension adaptations to alternative products to support increased load efficiency if demand growth is expected. Smucker can also explore opportunities to reduce total carbon emissions by adapting activities relevant to warehouse operations processes.

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## APPENDICES

### Appendix A: Methodology Extension - Figures

Figures A1-A3 summarize the top five and current 4, 10, and 18-count TOPS models displayed in our interviews. Figures A4-A6 summarize visuals relevant to the extreme-point heuristics research. Figure A7 summarizes dimension changes based on the Excel optimization model. Figures A8-A10 summarize the 4, 10, and 18-count top two TOPS models included in Tables 4-6 in chapter 4.1.

**Figure A1**

*4-count TOPS Top Five and Current Images*

| Current Count: | 528 | | | Bolded values indicate pallet overhang (48" x 40") | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model #** | **Carton Layout** | **Carton Dimensions** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Cartons/pallet** | **Ship Output % Increase (Current State of 528)** | **Cartons in Case** | **Cases on Pallet** |
| Current Dimensions | | 7.219 x 4.875 x 2.518 | 10.875 x 8 x 11.375 | 48 x 40 x 39.77 | 528 | 0 | | |
| Model A | 3 x 2 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 5.731 | **48.38** x **40.06** x 43.85 | 540 | 2.27% | | |
| Model B | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.678 x 10.553 x 13.293 | 48 x **40.62** x 47.41* | 660* | 25.00% | | |
| Model C | 2 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 15.566 x 13.293 | 47.06 x 38.69 x 47.41 | 600 | 13.64% | | |
| Model D | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 13.293 | **49** x **40.62** x 47.41 | 600 | 13.64% | | |
| Model E | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 13.293 | **49** x **40.31** x 47.41 | 600 | 13.64% | | |

***All other dimensions are assuming the provided 0.9 x 0.5 x 0.6875 gap dimensions between cartons & cases. This configuration assumes gaps of 0.803 x 0.459 x 0.659 based on current configuration**

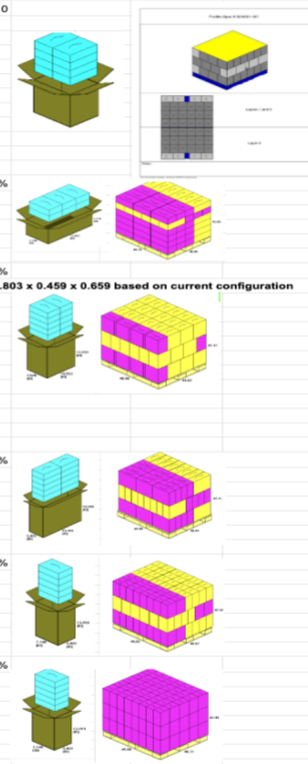


**Figure A2**

*10-count TOPS Top Five and Current Images*

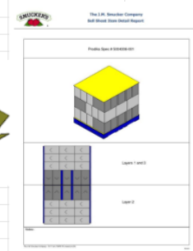
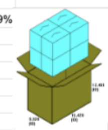
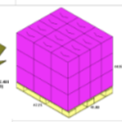
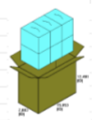
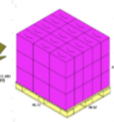
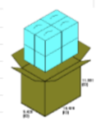
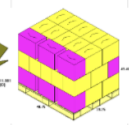
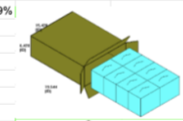
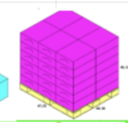
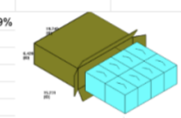
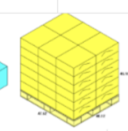
| Current Count: | 252 | | | **Bolded values indicate pallet overhang (48" x 40")** | | | | |
|---|---|---|---|---|---|---|---|---|
| **Model #** | **Carton Layout** | **Carton Dimensions** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Cartons/pallet** | **Ship Output % Increase (Current State of 252)** | **Cartons in Case** | **Cases on Pallet** |
| Current Dimensions | | 7.25 x 4.7 x 5.89 | 15.322 x 8.072 x 13.019 | 48 x 40 x 44.717 | 252 | 0.00% |  |  |
| Model A | 4 x 2 | 7.25 x 4.7 x 5.89 | 9.928 x 15.428 x 12.481 | 47.25 x **41** x 44.97 | 288 | 14.29% |  |  |
| Model B | 3 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 15.053 x 12.481 | 46.12 x **40.62** x 44.97 | 270 | 7.14% |  |  |
| Model C | 2 x 2 x 2 | **6.75** x **4.45** x **5.64** | 9.428 x 14.428 x 11.981 | **48.75** x 39.25 x 43.47 | 312 | 23.81% |  |  |
| Model D | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 15.428 x 19.544 | 47.25 x **40.38** x 46.10 | 288 | 14.29% |  |  |
| *** Indicates model has case openings not facing upward** | | | | | | | | |
| **Model D has case openings facing sideways on pallet, not upward** | | | | | | | | |
| Model E | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 19.74 x 15.231 | 47.62 x **40.12** x 46.10 | 288 | 14.29% |  |  |
| *** Indicates model has case openings not facing upward** | | | | | | | | |
| **Model E has case openings facing sideways on pallet, not upward** | | | | | | | | |

**Figure A3**

*18-count TOPS Top Five and Current Images*

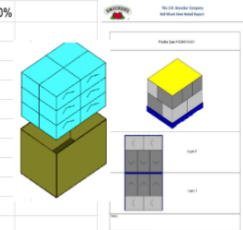
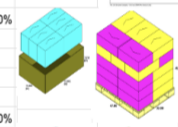
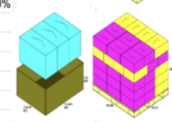
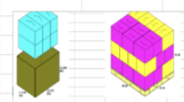
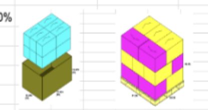
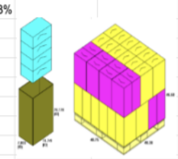
| Current Count: | 120 | | | Bolded values indicate pallet overhang (48" x 40") | | | | |
|---|---|---|---|---|---|---|---|---|
| Model # | Carton Layout | Carton Dimensions | Case Dimensions (ID) | Pallet Dimensions | Cartons/pallet | Ship Output % Increase (Current State of 120) | Cartons in Case | Cases on Pallet |
| Current Dimensions | | 11.13 x 4.94 x 7.25 | 23.25 x 15.375 x 15.5625 | 48 x 40 x 36.75 | 120 | 0.00% |  | |
| Model A | 3 x 2 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 22.865 x 7.678 | 47.06 x 38.88 x 45.6 | 150 | 25.00% |  | |
| Model B | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 11.678 x 15.428 x 7.678 | 48 x 39.75 x 45.6 | 150 | 25.00% |  | |
| Model C | | 11.13 x 4.94 x **6.50** | 11.678 x 15.428 x 13.428 | 48.00 x 39.75 x 46.85 | 180 | 50.00% |  | |
| Model D | | 11.13 x 4.94 x **6.50** | 15.366 x 22.865 x 13.428 | 47.06 x 38.88 x 46.85 | 180 | 50.00% |  | |
| Model E** | 1 x 4 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 11.741 x 20.178 | **48.75** x **40.38** x 46.6 | 160 | 33.33% |  | |
| ** Indicates model has carton openings not facing upward | | | | | | | | |
| Model E has carton openings facing sideways in case, not upward | | | | | | | | |

**Figure A4**

*Definition of Extreme-Points in 3D and 2D Packings*

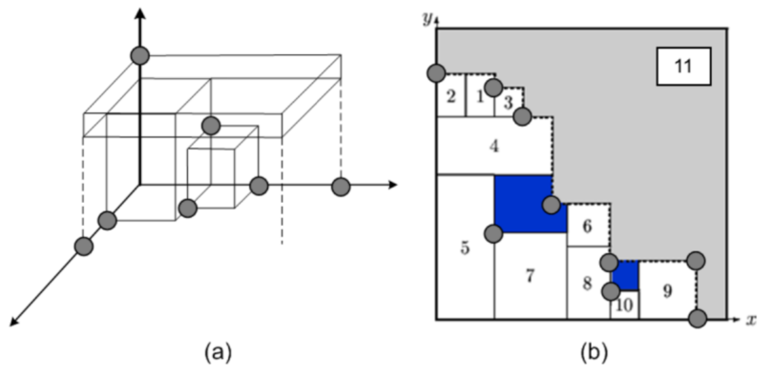



Figure 4: Example of Definition of Extreme Points in 3D and 2D Packings

**Figure A5**

*EP's defined by an item*

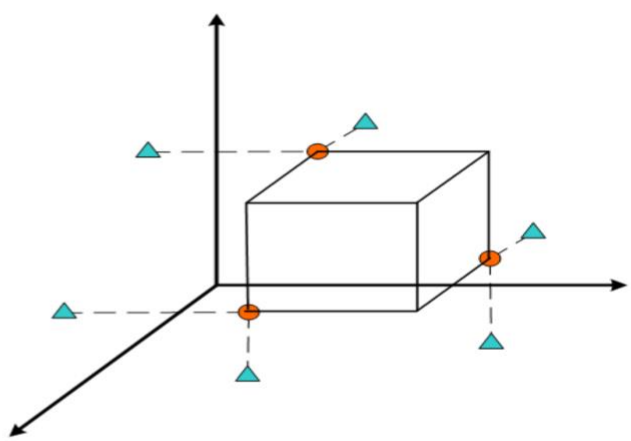


Figure 5: $EP$s defined by an item (the $EP$ are the triangles)

**Figure A6**

*Zhang, Guo, Zhu, Oon, Lin Algorithm Adjustments*

**Algorithm 2** Extreme Point Insertion with Space Defragmentation

```
EP-INSERT-SD(I, B)
for each item i ∈ I
    placed = FALSE
    for each bin b ∈ B
        if volume of i is less than remaining space in b
            for each point p ∈ b.EP-list
                if i can be placed at p after PUSH-OUT
                    placed = TRUE
                    PUSH-OUT(b, p)
                    place item i at p
                    NORMALIZE(b)
                    update extreme points b.EP-list
                    update x̄_i^r, ȳ_i^r, z̄_i^r for all items in b
                    break and try to load the next item
    if placed == FALSE
        for each bin b ∈ B
            for each item j ∈ b
                if INFLATE-REPLACE(b, i, j) == TRUE
                    placed = TRUE
                    NORMALIZE(b)
                    update extreme points b.EP-list
                    update x̄_i^r, ȳ_i^r, z̄_i^r for all items in b
                    insert j to the front of I
                    break and try to load the next item
    if placed == FALSE
        add an empty bin b′ to the end of B
        place item i into b′ at (0, 0, 0)
        append new extreme points to b′.EP-list
```

**Figure A7**

*Recommended Dimension Modifications 53' Trailer Optimization Model*

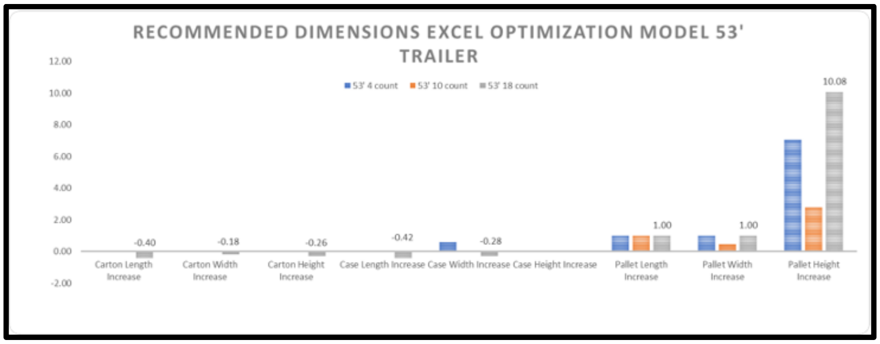
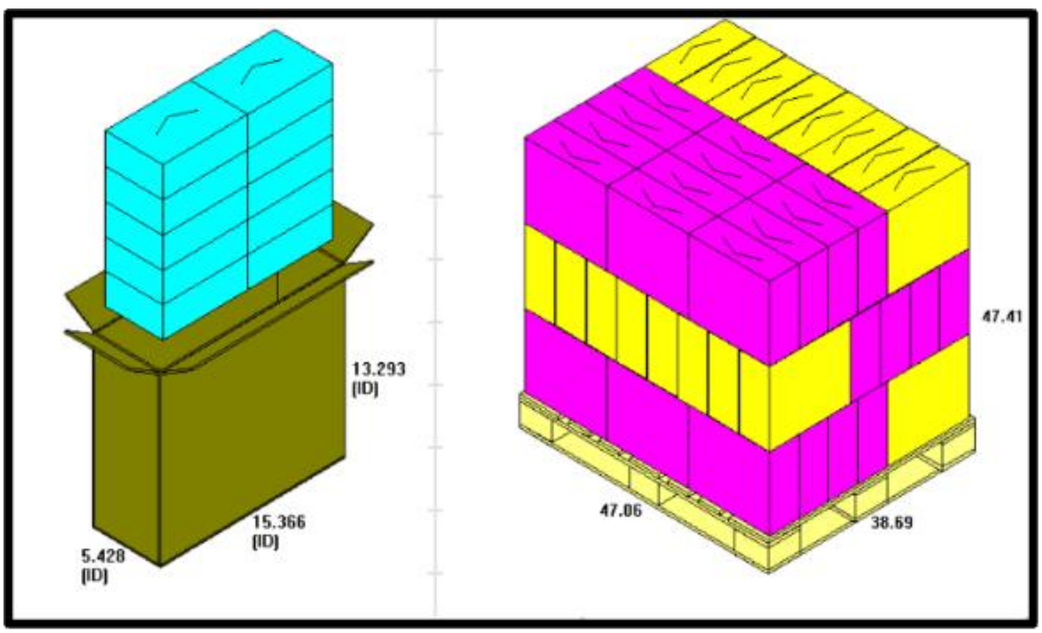



**Figure A8**

*4-count TOPS Case and Pallet Visualizations (Models C and B)*

**Model C:**



**Model B:**

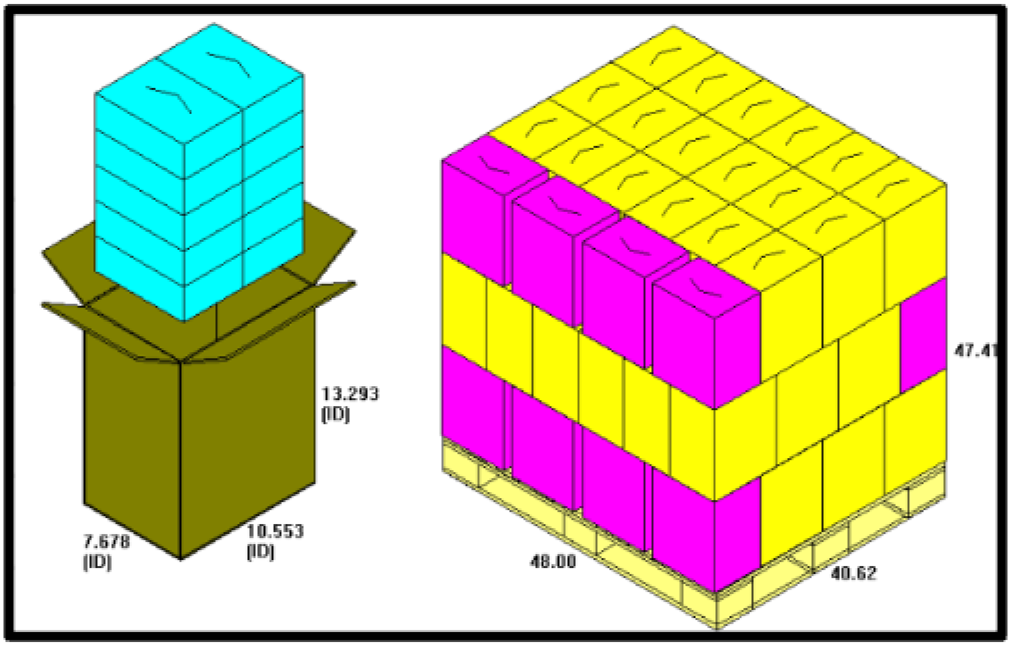
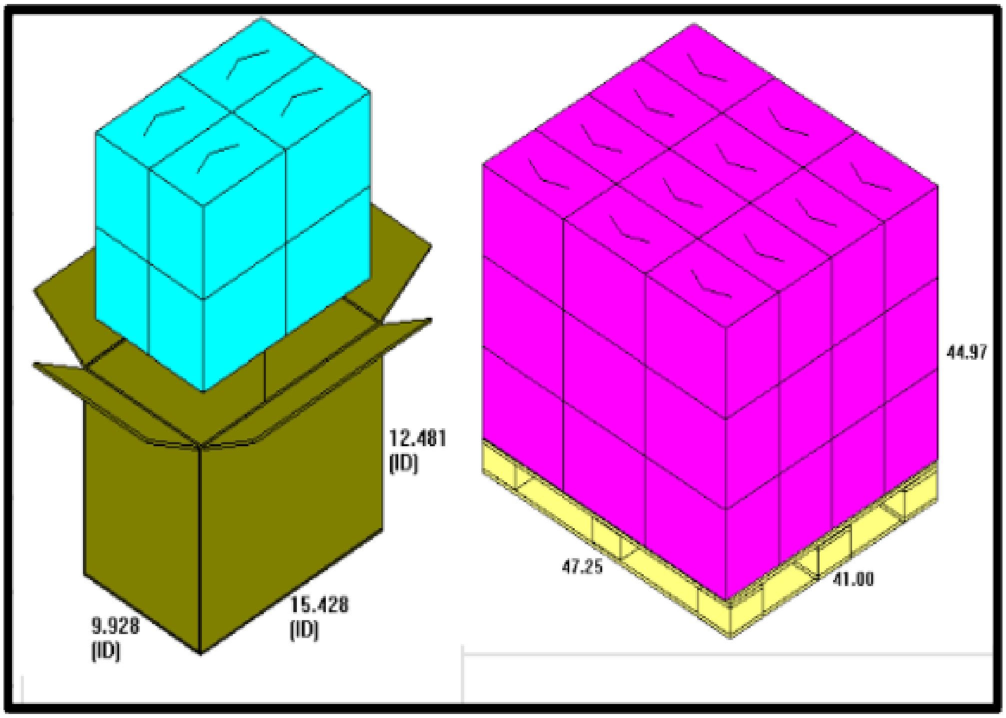


**Figure A9**

*10-count TOPS Case and Pallet Visualizations (Models A and C)*

**Model A:**



**Model C:**

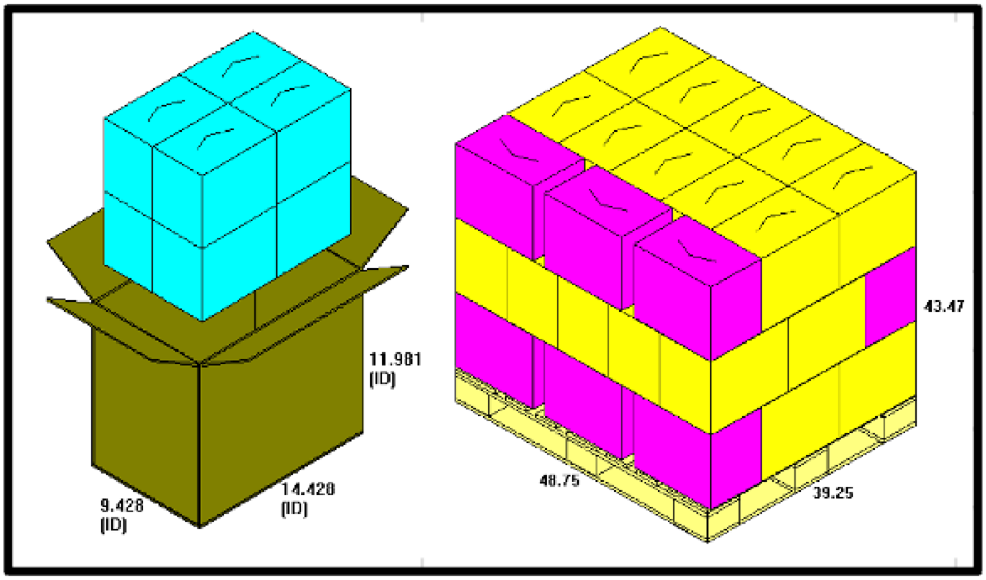
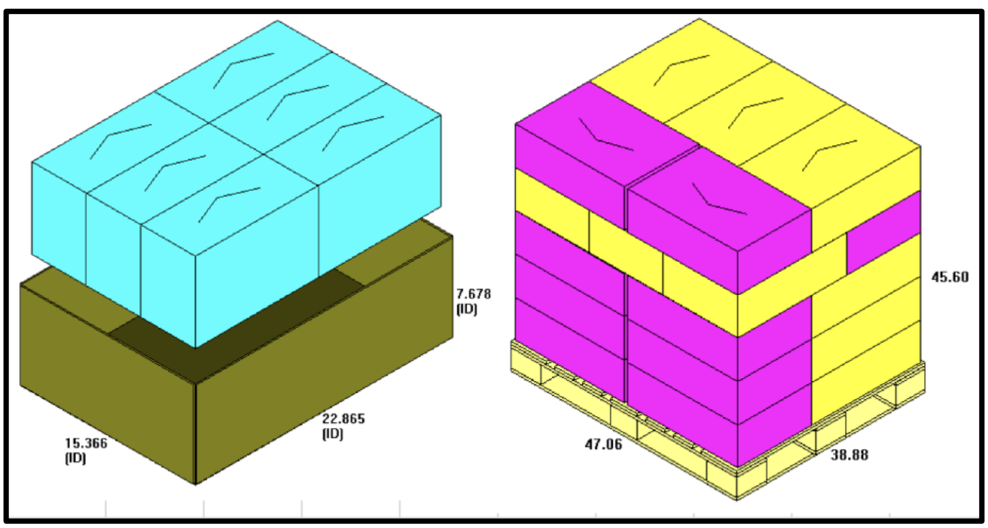


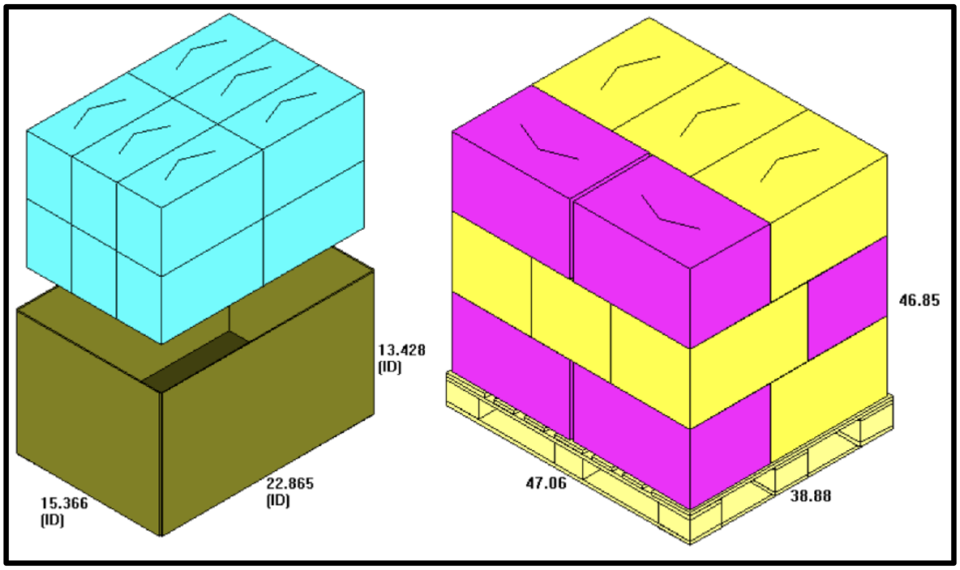

**Figure A10**

*18-count TOPS Case and Pallet Visualizations (Models A and D)*

**Model A:**



**Model D:**



## Appendix B: Methodology Extension - Tables

Tables B1-B8 summarize our complete TOPS sensitivity analyses, the top five TOPS sensitivity analysis options, and the carton-modified models used throughout the capstone process. Tables B9-B11 summarize critical marketing statistics. Tables B12-B14 summarize select TOPS optimization model constraints. Tables B15-B16 summarize the carbon emissions calculation procedure and cost savings calculation procedure.

**Table B1**

*TOPS Sensitivity Analysis (18-Count)*

| CAPSTONE 18-Count | | | | | | 120 | | |
|---|---|---|---|---|---|---|---|---|
| **Shipcase ID** | **Unitload** | **Carton Layout** | **Carton Dimensions (ID)** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Total cartons/pallet** | **Patterns** | **Gaps?** |
| 1 | 1 | 1 x 8 x 1 | 11.13 x 4.94 x 7.25 | 40.053 x 11.741 x 7.678 | 48.25 x 40.38 x 45.60 | 160 | 1 | N |
| 2 | 1 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 11.741 x 7.678 | 48.25 x 39.81 x 45.60 | 150 | 2 | Y |
| 6 | 1 | 1 x 3 x 2 | 11.13 x 4.94 x 7.25 | 15.366 x 11.741 x 14.928 | 48.25 x 39.81 x 36.10 | 120 | 2 | Y |
| 1 | 1 | 2 x 3 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 22.865 x 7.678 | 47.06 x 38.88 x 45.60 | 150 | 2 | Y |
| 2 | 1 | 3 x 1 x 1 | 11.13 x 4.94 x 7.25 | 11.678 x 15.428 x 7.678 | 48 x 39.75 x 45.60 | 150 | 2 | Y |
| 3 | 1 | 3 x 2 x 1 | 11.13 x 4.94 x 7.25 | 22.803 x 15.428 x 7.678 | 47.25 x 38.88 x 45.60 | 150 | 2 | Y |
| 4 | 1 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 11.741 x 7.678 | 47.06 x 39.81 x 45.60 | 135 | 2 | Y |
| 2 | 1 | 1 x 4 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 11.741 x 20.178 | 48.75 x 40.38 x 46.6 | 160 | 2 | Y |
| 2 | 2 | 1 x 4 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 11.741 x 20.178 | 48.25 x 40.62 x 46.6 | 160 | 1 | N |
| 2 | 8 | 1 x 4 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 11.741 x 20.178 | 48.50 x 40.62 x 46.6 | 152 | 2 | Y |
| 3 | 1 | 2 x 4 x 1 | 11.13 x 4.94 x 7.25 | 15.053 x 11.741 x 20.178 | 48.25 x 39.5 x 46.6 | 160 | 2 | Y |
| 4 | 1 | 2 x 1 x 4 | 11.13 x 4.94 x 7.25 | 7.803 x 22.865 x 20.178 | 48.75 x 39.44 x 46.6 | 160 | 2 | Y |
| 4 | 2 | 2 x 1 x 4 | 11.13 x 4.94 x 7.25 | 7.803 x 22.865 x 20.178 | 46.38 x 40.62 x 46.6 | 160 | 1 | N |
| 5 | 1 | 1 x 1 x 4 | 11.13 x 4.94 x 7.25 | 11.678 x 7.865 x 20.178 | 48 x 40.94 x 46.6 | 160 | 1 | N |
| 5 | 4 | 1 x 1 x 4 | 11.13 x 4.94 x 7.25 | 11.678 x 7.865 x 20.178 | 48.56 x 40.94 x 46.6 | 152 | 2 | Y |
| 6 | 1 | 2 x 1 x 4 | 11.13 x 4.94 x 7.25 | 22.803 x 7.865 x 20.178 | 46.25 x 40.94 x 46.6 | 160 | 1 | N |
| 6 | 4 | 2 x 1 x 4 | 11.13 x 4.94 x 7.25 | 22.803 x 7.865 x 20.178 | 46.25 x 39.5 x 46.6 | 144 | 2 | Y |
| 7 | 1 | 1 x 2 x 4 | 11.13 x 4.94 x 7.25 | 11.678 x 15.116 x 20.178 | 48 x 39.44 x 46.6 | 160 | 2 | Y |
| 8 | 1 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 11.741 x 7.678 | 48.25 x 39.81 x 45.6 | 150 | 2 | Y |
| 9 | 1 | 3 x 2 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 22.865 x 7.678 | 47.06 x 38.88 x 45.6 | 150 | 2 | Y |
| 10 | 1 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 11.678 x 15.428 x 7.678 | 48 x 39.75 x 45.6 | 150 | 2 | Y |
| 11 | 1 | 3 x 2 x 1 | 11.13 x 4.94 x 7.25 | 22.803 x 15.428 x 7.678 | 47.25 x 38.88 x 45.6 | 150 | 2 | Y |
| 12 | 1 | 1 x 2 x 1 | 11.13 x 4.94 x 7.25 | 15.053 x 11.741 x 5.365 | 48.25 x 39.5 x 45.41 | 140 | 2 | Y |
| 13 | 1 | 2 x 1 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 22.865 x 5.365 | 48.75 x 39.44 x 45.41 | 140 | 2 | Y |
| 13 | 2 | 2 x 1 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 22.865 x 5.365 | 46.38 x 40.62 x 45.41 | 140 | 1 | N |
| 14 | 1 | 2 x 2 x 1 | 11.13 x 4.94 x 7.25 | 15.053 x 22.865 x 5.365 | 46.38 x 38.56 x 45.41 | 140 | 2 | Y |
| 15 | 1 | 1 x 2 x 1 | 11.13 x 4.94 x 7.25 | 22.803 x 7.865 x 5.365 | 46.25 x 40.94 x 45.41 | 140 | 1 | N |
| 16 | 1 | 1 x 2 x 1 | 11.13 x 4.94 x 7.25 | 11.678 x 15.116 x 5.365 | 48 x 39.44 x 45.41 | 140 | 2 | Y |
| 17 | 1 | 2 x 2 x 1 | 11.13 x 4.94 x 7.25 | 22.803 x 15.116 x 5.365 | 46.31 x 38.56 x 45.41 | 140 | 2 | Y |
| 19 | 1 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 15.428 x 11.553 | 48.75 x 40.12 x 41.22 | 135 | 2 | Y |
| 19 | 2 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 15.428 x 11.553 | 48.75 x 39.62 x 41.22 | 135 | 2 | Y |
| 19 | 3 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 7.803 x 15.428 x 11.553 | 47.25 x 40.62 x 41.22 | 135 | 1 | N |
| 20 | 1 | 3 x 3 x 1 | 11.13 x 4.94 x 7.25 | 22.303 x 15.428 x 11.553 | 47.25 x 38.38 x 41.22 | 135 | 2 | Y |
| 21 | 1 | 1 x 3 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 7.865 x 11.553 | 47.06 x 40.94 x 41.22 | 135 | 1 | N |
| 23 | 1 | 3 x 3 x 1 | 11.13 x 4.94 x 7.25 | 15.366 x 22.365 x 11.553 | 47.06 x 38.38 x 41.22 | 135 | 2 | Y |

**Table B2**

*TOPS Sensitivity Analysis (4-Count)*

| CAPSTONE 4-COUNT REQ 1_15 | | | | | | 528 | | |
|---|---|---|---|---|---|---|---|---|
| Shipcase ID | Unitload | Carton Layout | Carton Dimensions (ID) | Case Dimensions (ID) | Pallet Dimensions | Total cartons/pallet | Patterns | Gaps? |
| 8 | 1 | 3 x 2 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 5.731 | 48.38 x 40.06 x 43.85 | 540 | 2 | Y |
| 8 | 2 | 3 x 2 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 5.731 | 48.38 x 39.81 x 43.85 | 540 | 2 | Y |
| 8 | 2 | 3 x 2 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 5.731 | 47.62 x 40.31 x 43.85 | 540 | 1 | N |
| 9 | 1 | 3 x 3 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 8.293 | 48.38 x 40.06 x 41.35 | 540 | 2 | Y |
| 9 | 2 | 3 x 3 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 8.293 | 48.38 x 39.81 x 41.35 | 540 | 2 | Y |
| 9 | 3 | 3 x 3 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 8.293 | 47.62 x 40.31 x 41.35 | 540 | 1 | N |
| 10 | 1 | 3 x 4 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 10.793 | 48.38 x 40.06 x 39.91 | 540 | 2 | Y |
| 10 | 2 | 3 x 4 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 10.793 | 48.38 x 39.81 x 39.91 | 540 | 2 | Y |
| 10 | 3 | 3 x 4 | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 10.793 | 47.62 x 40.31 x 39.91 | 540 | 1 | N |
| 4 | 5 | 1 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 8.178 x 13.293 | 46 x 40 x 47.41 | 540 | 2 | Y |
| 4 | 1 | 1 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 8.178 x 13.293 | 46 x 39.75 x 47.41 | 555 | 2 | Y |
| 7 | 1 | 1 x 7 | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 18.356 | 49 x 40.62 x 43.60 | 560 | 2 | Y |
| 7 | 2 | 1 x 7 | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 18.356 | 49 x 40.31 x 43.60 | 560 | 1 | N |
| 1 | 9 | 2 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 15.566 x 13.293 | 47.06 x 38.69 x 47.41 | 600 | 2 | Y |
| 3 | 1 | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 13.293 | 49 x 40.62 x 47.41 | 600 | 2 | Y |
| 3 | 2 | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 13.293 | 49 x 40.31 x 47.41 | 600 | 1 | N |
| 1 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 15.566 x 13.293 | 47.06 x 38.69 x 47.41 | 600 | 2 | Y |
| 1 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 15.566 x 13.293 | 47.06 x 40.25 x 47.41 | 630 | 1 | N |
| 3 | 10 | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.678 x 5.678 x 13.293 | 50 x 42 x 47.41 | 630 | 2 | Y |
| 3 | 11 | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.678 x 5.678 x 13.293 | 48 x 42 x 47.41 | 630 | 2 | N |
| 3 | 12 | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.678 x 5.678 x 13.293 | 48 x 42 x 47.41 | 630 | 1 | N |
| 3 | 1 | 1 x 5 | 7.219 x 4.875 x 2.518 | 7.678 x 5.678 x 13.293 | 50 x 42 x 47.41 | 645 | 2 | Y |
| 2 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.678 x 10.553 x 13.293 | 48 x 40.62 x 47.41 | 660 | 2 | Y |
| 2 | 1 | 2 x 4 | 7.219 x 4.875 x 2.518 | 5.428 x 13.491 x 15.168 | 47.44 x 40.25 x 47.04 | 630 | 1 | N |
| 2 | 9 | 2 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 13.491 x 15.168 | 47.44 x 38.81 x 47.04 | 600 | 2 | Y |
| 3 | 3 | 2 x 4 | 7.219 x 4.875 x 2.518 | 5.553 x 20.428 x 7.918 | 47 x 40.12 x 47.10 | 592 | 2 | Y |
| 3 | 13 | 2 x 4 | 7.219 x 4.875 x 2.518 | 5.553 x 20.428 x 7.918 | 47 x 40.62 x 47.10 | 576 | 2 | Y |
| 8 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 5.803 x 13.116 x 15.168 | 49 x 40.31 x 45.91 | 600 | 2 | Y |
| 9 | 1 | 4 x 3 | 7.219 x 4.875 x 2.518 | 7.74 x 15.553 x 10.793 | 47.62 x 38.75 x 45.91 | 600 | 2 | Y |
| 10 | 1 | 4 x 3 | 7.219 x 4.875 x 2.518 | 7.74 x 10.991 x 15.356 | 48 x 38.62 x 45.91 | 600 | 2 | Y |
| 11 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.74 x 13.491 x 10.481 | 48.38 x 38.38 x 47.04 | 600 | 2 | Y |
| 13 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.74 x 5.99 x 20.231 | 47.69 x 40.31 x 47.35 | 592 | 2 | Y |
| 13 | 2 | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.74 x 5.99 x 20.231 | 48.38 x 39.62 x 47.35 | 592 | 2 | Y |
| 14 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.74 x 20.428 x 5.731 | 48 x 40.31 x 47.1 | 592 | 2 | Y |
| 14 | 2 | 2 x 5 | 7.219 x 4.875 x 2.518 | 7.74 x 20.428 x 5.731 | 48.38 x 39.94 x 47.1 | 592 | 2 | Y |
| 16 | 1 | 3 x 3 | 7.219 x 4.875 x 2.518 | 15.553 x 7.74 x 8.293 | 47.62 x 40.69 x 45.91 | 585 | 2 | Y |
| 18 | 1 | 1 x 5 | 7.219 x 4.875 x 2.518 | 5.428 x 13.491 x 7.918 | 48.56 x 40.25 x 47.04 | 585 | 2 | Y |
| 22 | 1 | 2 x 5 | 7.219 x 4.875 x 2.518 | 15.366 x 13.116 x 5.606 | 47.06 x 40.69 x 45.91 | 570 | 2 | Y |

**Table B3**

*TOPS Sensitivity Analysis (10-Count)*

| CAPSTONE 10-Count | | | | | | 252 | | |
|---|---|---|---|---|---|---|---|---|
| **Shipcase ID** | **Unitload** | **Carton Layout** | **Carton Dimensions (ID)** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Total cartons/pallet** | **Patterns** | **Gaps?** |
| 1 | 1 | 4 x 2 | 7.25 x 4.7 x 5.89 | 9.928 x 15.428 x 12.481 | 47.25 x 41 x 44.97 | 288 | 1 | N |
| 2 | 1 | 4 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 19.74 x 12.481 | 48.25 x 40.62 x 44.97 | 288 | 2 | Y |
| 2 | 2 | 4 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 19.74 x 12.481 | 48.75 x 40.12 x 44.97 | 288 | 1 | N |
| 4 | 1 | 3 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 15.053 x 12.481 | 48.75 x 39.75 x 44.97 | 270 | 2 | Y |
| 4 | 1 | 3 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 15.053 x 12.481 | 48.75 x 38.88 x 44.97 | 270 | 2 | Y |
| 4 | 1 | 3 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 15.053 x 12.481 | 46.12 x 40.62 x 44.97 | 270 | 1 | N |
| 5 | 1 | 2 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 10.303 x 12.481 | 48.75 x 40 x 44.97 | 264 | 2 | Y |
| 5 | 7 | 2 x 2 | 7.25 x 4.7 x 5.89 | 7.803 x 10.303 x 12.481 | 48.12 x 40.62 x 44.97 | 252 | 2 | Y |
| 6 | 1 | 2 x 3 | 7.25 x 4.7 x 5.89 | 7.803 x 10.303 x 18.419 | 48.75 x 40 x 43.72 | 264 | 2 | Y |
| 6 | 7 | 2 x 3 | 7.25 x 4.7 x 5.89 | 7.803 x 10.303 x 18.419 | 48.12 x 40.62 x 43.72 | 252 | 2 | Y |
| 7 | 1 | 2 x 2 | 7.25 x 4.7 x 5.89 | 5.240 x 15.428 x 12.481 | 47.25 x 38.94 x 44.97 | 252 | 1 | N |
| 3 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 15.428 x 19.544 | 47.25 x 40.5 x 45.97 | 288 | 1 | N |
| 3 | 2 | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 15.428 x 19.544 | 47.25 x 38.25 x 45.97 | 272 | 2 | N |
| 4 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 7.803 x 12.741 x 19.544 | 47.31 x 40.62 x 45.97 | 288 | 2 | Y |
| 4 | 2 | 2 x 4 | 7.25 x 4.7 x 5.89 | 7.803 x 12.741 x 19.544 | 48.75 x 39.19 x 45.97 | 288 | 1 | N |
| 5 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 15.428 x 19.544 | 47.25 x 40.38 x 46.10 | 288 | 1 | N |
| 6 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 19.74 x 15.231 | 47.62 x 40.12 x 46.10 | 288 | 1 | N |
| 7 | 1 | 2 x 2 | 7.25 x 4.7 x 5.89 | 15.428 x 9.928 x 12.481 | 47.25 x 39.38 x 46.6 | 288 | 1 | N |
| 8 | 1 | 2 x 2 | 7.25 x 4.7 x 5.89 | 12.741 x 9.928 x 15.231 | 47.62 x 39.19 x 46.6 | 288 | 1 | N |
| 9 | 1 | 1 x 4 | 7.25 x 4.7 x 5.89 | 7.803 x 12.741 x 19.544 | 48.5 x 40.62 x 44.79 | 288 | 2 | Y |
| 9 | 2 | 1 x 4 | 7.25 x 4.7 x 5.89 | 7.803 x 12.741 x 19.544 | 48.75 x 40.38 x 44.79 | 288 | 1 | N |
| 10 | 1 | 2 x 2 | 7.25 x 4.7 x 5.89 | 9.928 x 12.741 x 15.231 | 47.62 x 41 x 44.79 | 288 | 1 | N |
| 11 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 7.803 x 19.74 x 12.481 | 47.5 x 40.62 x 45.72 | 288 | 2 | Y |
| 11 | 2 | 2 x 4 | 7.25 x 4.7 x 5.89 | 7.803 x 19.74 x 12.481 | 48.75 x 39.38 x 45.72 | 288 | 1 | N |
| 12 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 19.74 x 15.231 | 47.62 x 40.5 x 45.72 | 288 | 1 | N |
| 12 | 2 | 2 x 4 | 7.25 x 4.7 x 5.89 | 6.428 x 19.74 x 15.231 | 47.62 x 38.5 x 45.72 | 272 | 2 | Y |
| 13 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 19.74 x 7.803 x 12.481 | 46.31 x 40.12 x 46.22 | 280 | 2 | Y |
| 14 | 1 | 2 x 4 | 7.25 x 4.7 x 5.89 | 12.741 x 7.803 x 19.544 | 46.31 x 40.38 x 46.22 | 280 | 2 | Y |

**Table B4**

*18-count TOPS Sensitivity Analysis Models (Top Five)*

| 18-Count Product | | | | | | | Current weight from slides: | 527.053 | |
|---|---|---|---|---|---|---|---|---|---|
| **Model Number** | **Carton Dimensions** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Carton-to-pallet count** | **Ship Output % Increase (Current State of 120)** | **Case wgt (lbs)** | **Case wgt * Cases/Pallet** | **UL wgt** | **Weight % Increase from Current** |
| Current Dimensions | 11.13 x 4.94 x 7.25 | 23.25 x 15.375 x 15.5625 | 48 x 40 x 36.75 | 120 | 0% | 45.44 | 454.4 | 516.1 | 0.00% |
| Model A | 11.13 x 4.94 x 7.25 | 15.366 x 22.865 x 7.678 | 47.06 x 38.88 x 45.6 | 150 | 25.00% | 23.54 | 588.5 | 650.2 | 25.98% |
| Model B | 11.13 x 4.94 x 7.25 | 11.678 x 15.428 x 7.678 | 48 x 39.75 x 45.6 | 150 | 25.00% | 12.59 | 629.5 | 691.2 | 33.93% |
| Model C | 11.13 x 4.94 x **6.50** | 11.678 x 15.428 x 13.428 | 48.00 x 39.75 x 46.85 | 180 | 50.00% | 23.54 | 706.2 | 767.9 | 48.79% |
| Model D | 11.13 x 4.94 x **6.50** | 15.366 x 22.865 x 13.428 | 47.06 x 38.88 x 46.85 | 180 | 50.00% | 45.44 | 681.6 | 743.3 | 44.02% |
| Model E* | 11.13 x 4.94 x 7.25 | 7.803 x 11.741 x 20.178 | **48.75** x **40.38** x 46.6 | 160 | 33.33% | 16.24 | 649.6 | 711.3 | 37.82% |
| **Model E has carton openings facing sideways in case, not upward** | | | | | | | | | |

**Table B5**

*10-count TOPS Sensitivity Analysis Models (Top Five)*

| 10-Count Product | | | | | | | Current weight from slides: | 477.717 | |
|---|---|---|---|---|---|---|---|---|---|
| **Model Number** | **Carton Dimensions** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Carton-to-pallet count** | **Ship Output % Increase (Current State of 252)** | **Case wgt (lbs)** | **Case wgt * Cases/Pallet** | **UL wgt** | **Weight % Increase from Current** |
| Current Dimensions | 7.25 x 4.7 x 5.89 | 15.322 x 8.072 x 13.019 | 48 x 40 x 44.717 | 252 | 0% | 9.711 | 407.862 | 469.6 | 0.00% |
| Model A | 7.25 x 4.7 x 5.89 | 9.928 x 15.428 x 12.481 | 47.25 x **41** x 44.97 | 288 | 14.29% | 12.693 | 456.948 | 518.7 | 10.46% |
| Model B | 7.25 x 4.7 x 5.89 | 7.803 x 15.053 x 12.481 | 46.12 x **40.62** x 44.97 | 270 | 7.14% | 9.711 | 436.995 | 498.7 | 6.20% |
| Model C | **6.75** x **4.45** x **5.64** | 9.428 x 14.428 x 11.981 | **48.75** x 39.25 x 43.47 | 312 | 23.81% | 12.693 | 495.027 | 556.8 | 18.57% |
| Model D* | 7.25 x 4.7 x 5.89 | 6.428 x 15.428 x 19.544 | 47.25 x **40.38** x 46.10 | 288 | 14.29% | 12.693 | 456.948 | 518.7 | 10.46% |
| Model E* | 7.25 x 4.7 x 5.89 | 6.428 x 19.74 x 15.231 | 47.62 x **40.12** x 46.10 | 288 | 14.29% | 12.693 | 456.948 | 518.7 | 10.46% |
| **Model D & E have case openings facing sideways on pallet, not upward** | | | | | | | | | |

**Table B6**

*4-count TOPS Sensitivity Analysis Models (Top Five)*

| All dimensions are in inches | **Bolded values indicate modified carton dimensions** | | **Bolded values indicate pallet overhang (48" x 40")** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4-Count Product | | | | | | | Current weight from slides: | 440.487 | |
| **Model Number** | **Carton Dimensions** | **Case Dimensions (ID)** | **Pallet Dimensions** | **Carton-to-pallet count** | **Ship Output % Increase (Current State of 528)** | **Case wgt (lbs)** | **Case wgt * Cases/Pallet** | **UL wgt (lbs)** | **Weight % Increase from Current** |
| Current Dimensions | 7.219 x 4.875 x 2.518 | 10.875 x 8 x 11.375 | 48 x 40 x 39.77 | 528 | 0% | 5.6 | 369.6 | 431.3 | 0.00% |
| Model A | 7.219 x 4.875 x 2.518 | 7.740 x 15.553 x 5.731 | **48.38** x **40.06** x 43.85 | 540 | 2.27% | 4.35 | 391.5 | 453.2 | 5.08% |
| Model B | 7.219 x 4.875 x 2.518 | 7.678 x 10.553 x 13.293 | 48 x **40.62** x 47.41 | 660* | 25.00% | 6.85 | 452.1 | 513.8 | 19.13% |
| Model C | 7.219 x 4.875 x 2.518 | 5.428 x 15.566 x 13.293 | 47.06 x 38.69 x 47.41 | 600 | 13.64% | 6.85 | 411 | 472.7 | 9.60% |
| Model D | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 13.293 | **49** x **40.62** x 47.41 | 600 | 13.64% | 3.725 | 447 | 508.7 | 17.95% |
| Model E | 7.219 x 4.875 x 2.518 | 7.740 x 5.803 x 13.293 | **49** x **40.31** x 47.41 | 600 | 13.64% | 3.725 | 447 | 508.7 | 17.95% |
| ***All other dimensions are assuming the provided 0.9 x 0.5 x 0.6875 gap dimensions between cartons & cases. This configuration assumes gaps of 0.803 x 0.459 x 0.659 based on current configuration (additional clarification provided on PowerPoint shared)** | | | | | | | | | |

**Table B7**

*10-count TOPS Carton-Modified Models*

| 10-COUNT REQ CM 2_21 | Length | Width | Height | Volume | % Change | Current State | % Change | Best Output | % Change | 2nd Best Output | % Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Current Dimensions | 7.25 | 4.7 | 5.89 | 201 | 0.00% | 252 | 14.29% | 288 | 0.00% | 270 | 0.00% |
| Length - 0.25 | 7 | 4.7 | 5.89 | 194 | -3.45% | 252 | 14.29% | 288 | 0.00% | 270 | 0.00% |
| Length - 0.5 | 6.75 | 4.7 | 5.89 | 187 | -6.90% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| Length - 0.75 | 6.5 | 4.7 | 5.89 | 180 | -10.34% | 252 | 19.05% | 300 | 4.17% | 300 | 11.11% |
| Length - 1 | 6.25 | 4.7 | 5.89 | 173 | -13.79% | 252 | 23.81% | 312 | 8.33% | 306 | 13.33% |
| Width - 0.25 | 7.25 | 4.45 | 5.89 | 190 | -5.32% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| Width - 0.5 | 7.25 | 4.2 | 5.89 | 179 | -10.64% | 252 | 23.81% | 312 | 8.33% | 300 | 11.11% |
| Width - 0.75 | 7.25 | 3.95 | 5.89 | 169 | -15.96% | 252 | 28.57% | 324 | 12.50% | 312 | 15.56% |
| Width - 1 | 7.25 | 3.7 | 5.89 | 158 | -21.28% | 252 | 42.86% | 360 | 25.00% | 324 | 20.00% |
| Height - 0.25 | 7.25 | 4.7 | 5.64 | 192 | -4.24% | 252 | 14.29% | 288 | 0.00% | 270 | 0.00% |
| Height - 0.5 | 7.25 | 4.7 | 5.39 | 184 | -8.49% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| Height - 0.75 | 7.25 | 4.7 | 5.14 | 175 | -12.73% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| Height - 1 | 7.25 | 4.7 | 4.89 | 167 | -16.98% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| L & W - 0.25 | 7 | 4.45 | 5.89 | 183 | -8.58% | 252 | 23.81% | 312 | 8.33% | 288 | 6.67% |
| W & H - 0.25 | 7.25 | 4.45 | 5.64 | 182 | -9.34% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| L & H - 0.25 | 7 | 4.7 | 5.64 | 186 | -7.55% | 252 | 14.29% | 288 | 0.00% | 270 | 0.00% |
| L, W & H - 0.25 | 7 | 4.45 | 5.64 | 176 | -12.46% | 252 | 23.81% | 312 | 8.33% | 288 | 6.67% |
| L - 0.25, W - 0.5 | 7 | 4.2 | 5.89 | 173 | -13.72% | 252 | 23.81% | 312 | 8.33% | 300 | 11.11% |
| L - 0.5, W - 0.25 | 6.75 | 4.45 | 5.89 | 177 | -11.85% | 252 | 23.81% | 312 | 8.33% | 300 | 11.11% |
| W - 0.25, H - 0.5 | 7.25 | 4.45 | 5.39 | 174 | -13.36% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| W - 0.5, H - 0.25 | 7.25 | 4.2 | 5.64 | 172 | -14.43% | 252 | 23.81% | 312 | 8.33% | 300 | 11.11% |
| L - 0.25, H - 0.5 | 7 | 4.7 | 5.39 | 177 | -11.64% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| L - 0.5, H - 0.25 | 6.75 | 4.7 | 5.64 | 179 | -10.85% | 252 | 14.29% | 288 | 0.00% | 288 | 6.67% |
| L-.25, W-.5, H-.25 | 7 | 4.2 | 5.64 | 166 | -17.38% | 252 | 23.81% | 312 | 8.33% | 300 | 11.11% |
| L-.5, W-.25, H-.25 | 6.75 | 4.45 | 5.64 | 169 | -15.59% | 252 | 23.81% | 312 | 8.33% | 300 | 11.11% |
| L-.25, W-.25, H-.5 | 7 | 4.45 | 5.39 | 168 | -16.34% | 252 | 23.81% | 312 | 8.33% | 288 | 6.67% |

**Table B8**

*18-count TOPS Carton-Modified Models*

| 18-COUNT REQ CM 2_21 | Length | Width | Height | Volume | % Change | Current State | % Change | Best Output | % Change | 2nd Best Output | % Change |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Current | 11.13 | 4.94 | 7.25 | 399 | 0.00% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| Length - 0.25 | 10.88 | 4.94 | 7.25 | 390 | -2.25% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| Length - 0.5 | 10.63 | 4.94 | 7.25 | 381 | -4.49% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| Length - 0.75 | 10.38 | 4.94 | 7.25 | 372 | -6.74% | 120 | 25.00% | 150 | -6.25% | 150 | 0.00% |
| Length - 1 | 10.13 | 4.94 | 7.25 | 363 | -8.98% | 120 | 16.67% | 140 | -12.50% | 140 | -6.67% |
| Width - 0.25 | 11.13 | 4.69 | 7.25 | 378 | -5.06% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| Width - 0.5 | 11.13 | 4.44 | 7.25 | 358 | -10.12% | 120 | 50.00% | 180 | 12.50% | 165 | 10.00% |
| Width - 0.75 | 11.13 | 4.19 | 7.25 | 338 | -15.18% | 120 | 50.00% | 180 | 12.50% | 180 | 20.00% |
| Width - 1 | 11.13 | 3.94 | 7.25 | 318 | -20.24% | 120 | 66.67% | 200 | 25.00% | 180 | 20.00% |
| Height - 0.25 | 11.13 | 4.94 | 7 | 385 | -3.45% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| Height - 0.5 | 11.13 | 4.94 | 6.75 | 371 | -6.90% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| Height - 0.75 | 11.13 | 4.94 | 6.5 | 357 | -10.34% | 120 | 50.00% | 180 | 12.50% | 180 | 20.00% |
| Height - 1 | 11.13 | 4.94 | 6.25 | 344 | -13.79% | 120 | 50.00% | 180 | 12.50% | 180 | 20.00% |
| L & W - 0.25 | 10.88 | 4.69 | 7.25 | 370 | -7.19% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| W & H - 0.25 | 11.13 | 4.69 | 7 | 365 | -8.33% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| L & H - 0.25 | 10.88 | 4.94 | 7 | 376 | -5.62% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| L, W & H - 0.25 | 10.88 | 4.69 | 7 | 357 | -10.39% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| L - 0.25, W - 0.5 | 10.88 | 4.44 | 7.25 | 350 | -12.14% | 120 | 50.00% | 180 | 12.50% | 165 | 10.00% |
| L - 0.5, W - 0.25 | 10.63 | 4.69 | 7.25 | 361 | -9.33% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| W - 0.25, H - 0.5 | 11.13 | 4.69 | 6.75 | 352 | -11.61% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| W - 0.5, H - 0.25 | 11.13 | 4.44 | 7 | 346 | -13.22% | 120 | 50.00% | 180 | 12.50% | 165 | 10.00% |
| L - 0.25, H - 0.5 | 10.88 | 4.94 | 6.75 | 363 | -8.99% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| L - 0.5, H - 0.25 | 10.63 | 4.94 | 7 | 368 | -7.79% | 120 | 33.33% | 160 | 0.00% | 150 | 0.00% |
| L-.25, W-.5, H-.25 | 10.88 | 4.44 | 7 | 338 | -15.17% | 120 | 50.00% | 180 | 12.50% | 165 | 10.00% |
| L-.5, W-.25, H-.25 | 10.63 | 4.69 | 7 | 349 | -12.45% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |
| L-.25, W-.25, H-.5 | 10.88 | 4.69 | 6.75 | 344 | -13.59% | 120 | 33.33% | 160 | 0.00% | 160 | 6.67% |

**Table B9**

*Wal-Mart Marketing Statistics*

| **Metric** | **Value** |
|---|---|
| Standard Shelf Width | 30" |
| Wasted Shelf Space (Based on Sample PW) | 4.875" |
| Sample Product Width | 5.025" |
| Optimal Product Width | 5" |
| Optimal number of products/shelf | 6 |
| Standard Shelf Depth | 18" |
| Sample Unit Depth | 4.5" |

| | |
|---|---|
| Ideal Unit Depth | 4.4" |
| Optimal number of products/shelf to fully utilize shelf depth | 5 |
| Vendor Pack/Shelf Facing Ratio | 1.5 to 1 |
| Depth of Vendor Pack | 22" |

**Table B10**

*Target Marketing Statistics*

| **Metric** | **Value** |
|---|---|
| Standard Shelf Width | 30" |
| Ideal number of facings/shelf | 4 per shelf |
| Current product merchandising approach | Horizontal |

**Table B11**

*Meijer Marketing Statistics*

| **Metric** | **Value** |
|---|---|
| Average Shelf Height Minimum | 9" |
| Average Shelf Height Maximum | 11" |
| Average Shelf Depth Minimum | 25" |
| Average Shelf Depth Maximum | 27" |
| Ideal number of 4-count facings/shelf | 6 per shelf |
| Ideal number of 10-count facings/shelf | 5 per shelf |
| Current 4-Count merchandising approach | Vertical |
| Current 10-Count merchandising approach | Vertical |

| | |
|---|---|
| Empty Shelf Space 4-Count Maximum | 0.50” |
| Empty Shelf Space 10-Count Maximum | 0.50” |

**Table B12**

*Constraint Summary*

| List of Constraints | Constraint Maximum Limit |
|---|---|
| 4-count carton-to-case constraint | 12 |
| 10-count carton-to-case constraint | 8 |
| 18-count case weight constraint (lbs) | 55 |
| Pallet Length Constraint | 49” length maximum (1” overhang maximum), 46” length minimum (2” underhang minimum) |
| Pallet Width Constraint | 41” width maximum (1” overhang maximum), 38” width minimum (2” underhang minimum) |
| Pallet height constraint (including CHEP pallet base height of 5.66”) | 47.5” |
| Automation constraints | See Tables B13 and B14 |
| Maximum pallets-in-trailer constraint | 60 |
| Trailer total weight constraint (lbs) | 45,000 |

| | |
|---|---|
| Trailer total product weight constraint (lbs) | 42,000 |

**Table B13**

*Automation Constraints (4-Count and 10-Count)*

| Variable | Packing product-in-carton | Packing carton-in-case |
|---|---|---|
| Carton Length | 0.23” | 0.9” |
| Carton Width | 1” | 0.5” |
| Carton Height | 0.32” | 0.6875” |

**Table B14**

*Automation Constraints (18-Count)*

| Variable | Packing product-in-carton | Packing carton-in-case |
|---|---|---|
| Carton Length | 0.328” | 0.5625” |
| Carton Width | 1” | 0.5” |
| Carton Height | 0.23” | 0.375” |

**Table B15**

*Carbon Emissions Calculation Procedure*

| **Formula** | **Detail** | **Citation** |
|---|---|---|
| [Miles travelled per shipment/Fuel consumption (mpg) (6 miles per gallon) ] (1) * Carbon per US gallon of diesel (2.77 kg) (1) | Carbon Footprint per Shipment (KG) | 1 - *Trucking carbon footprint: DSN Chemical Transportation*, (Stevens, 2016). |
| Carbon footprint per shipment * Total Semiannual Removed Loads (Models A-E) | Semiannual Carbon Footprint Reduction (KG) | N/A |
| Semiannual Carbon Footprint Reduction (Models A-E) * 2 | Annual Carbon Footprint Reduction (KG) | N/A |

**Table B16**

*Cost Savings Calculation Procedure*

| **Formula** | **Detail** |
|---|---|
| [Average cost per load (@ Shipping Point) * Total Semiannual Removed Loads (Models A-E)] * 2 | Annual Freight Transportation Cost Savings (Reduced Required Shipments) |
| Total Semiannual Removed Pallets (Models A-E) * 2 * Pallet handling fee | Annual Pallet Handling Cost Savings |
| Annual Freight Transportation Cost Savings | Annual Freight Transportation Cost Savings |

| | |
|---|---|
| (Reduced Required Shipments) + Annual Pallet Handling Cost Savings | |

**Appendix C: State of the Practice Extension - Extreme Point Heuristics**

In this appendix, we summarize key aspects of the Extreme-Point Heuristics algorithm. We then summarize optimal configuration approaches. We finally summarize optimal sorting approaches.

First, we can confirm the theory behind the extreme-point heuristics algorithm. The extreme-point (EP) heuristics algorithm is an algorithm "...exploits free space inside packing by the shapes of items already in the container" (Crainic et al., 2008, 8). Additionally, the basic idea of EP's is that "...when an $item\ k$ with sizes $wk, dk, and\ hk$ is added to a given packing and is placed with its left-back-down corner in position $(xk, yk, zk)$ , it generates a series of new potential points, the EP's, where additional items can be accommodated. The new EP's are generated by projecting the points with coordinates $(xk + wk, yk, zk), (xk, yk + dk, zk), and\ (xk, yk, zk + hk)$ on the orthogonal axes of the container" (Crainic et al., 2008, 6). Figures A4 and A5 in Appendix A show the location of the extreme-points in a sample box.

The extreme-point heuristics algorithm finds EP's that are required to be added to the list following the placement of an item in position $(xk, yk, zk)$ (Crainic et al., 2008). The algorithm follows the below steps:

- If a container is empty, an item is placed in position $(0,0,0)$ , generating three EP's in positions $(wk, 0,0), (0, dk, 0), and\ (0,0, hk)$.
- If a container is full, the item is placed in position $(xk, yk, zk)$ generating the below coordinate points:
  - Point $(xk + wk, yk, zk)$ on the $Y\ and\ Z$ axes.
  - Point $(xk, yk + dk, zk)$ on the $X\ and\ Z$ axes.
  - Point $(xk, yk, zk + hk)$ on the $X\ and\ Y$ axes.
- Each point is projected on items lying between $item\ k$ and the wall of the container.
- If there are multiple items on which points can be projected, the algorithm chooses the nearest one" (Crainic et al., 2008).

The selected algorithm updates an EP list every time an item is added. It can be used within constructive heuristics where items are placed in larger containers consecutively. The complexity of the extreme-point heuristics algorithm is that of linear time ($O(n)$ complexity) (Crainic et al., 2008). Complexity, in terms of mathematics, refers to the total resources required to solve a problem or complete a task. The time complexity equation listed above suggests that the amount of time it takes to strategically place items in a bin, or in our case, cartons into cases, cases on pallets, and pallets on trailers is ordered linearly. As the size of the item increases, the amount of time to properly configure and sort items in a bin increases. The correlation between product size and configuration task times can be correlated to our sensitivity analysis findings. When design complexity increases based on product size changes the total configuration time will increase. To summarize, we can highlight a few critical takeaways from the extreme-point heuristics research. First, the algorithm takes a locational approach by analyzing the relative size of items to be loaded into a bin relative to the size of items that theoretically can be placed into a bin based on the degree of empty space in a container and the shapes that can be formed out of that space. The algorithm always reverts towards loading items at the front of the container first at EP [(*0,0,0*)] before exploring the placement of items in other locations of the bin (Crainic et al., 2008). Lastly, the algorithm prioritizes the loading of new items on the same equivalent wall or side of the container assuming empty space is available where a prior item had already been loaded. This is done instead of placing items on alternative walls of the bin first where no items had been previously loaded. These actions promote the highest degree of product stability driving low damage risk. A critical objective of our capstone project was to maximize product stability and reduce product damage risk.

Second, before outlining alternative case, carton, and pallet configuration approaches, we must summarize the findings from derivative research that outlines ideal strategies that can be paired with the extreme-point heuristics algorithm concept to maximize configuration effectiveness. Zhang et al. (2011) summarizes the application of the 3D bin-packing problem in "...illustrating the concept of space defragmentation" (699). The team used critical EP objectives to de-segment space in the process of inserting objects at extreme-points based on the EP algorithm. Figure A6 located in Appendix A summarizes the adjustments made to the primary EP algorithm in a few main steps:

- "The algorithm, instead of checking if the current $item\ i$ can be placed at $p$ into the $bin\ b$ given at the current packing, checks if it can be placed at $p$, after the push-out procedure.
- $Xi, Yi, and\ Zi$ values are calculated for items in the bin using algorithm 1, which computes $Xi$ for each $item\ i$ in $bin\ b,$ and determines if the insertion at $point\ p$ is feasible.
- If the insertion is feasible, then $Push - Out\ (b, p)$ is performed, the item is loaded, and the bin is normalized (items pushed towards origin at [(*0,0,0*)] as much as possible)" (Zhang et al., 2011, 701).

Lastly, this article summarized a few key supporting strategies that can make the EP concept and theory more effective. The first strategy that was employed in the development of this modification is the first fit strategy, a strategy that focuses on loading items into the first container that can accommodate it at the first feasible extreme-point. The second key strategy that complements the extreme-point algorithm research is the bin shuffling strategy. This strategy employs the EP-INSERT-SD procedure as a subroutine (Zhang et al., 2011). This first fit strategy recommends that we load at the first feasible extreme-point, which when the bin is empty, takes the location of [(*0,0,0*)] on the orthogonal axes. It outlines each possible bin that has the space to place the item based on given dimensions (Zhang et al., 2011). By using this approach along with the EP algorithm concept, we increase the likelihood of maximum product utilization. Once the item placement process has been completed, the approach ensures that the highest possible number of items have been loaded carefully into a bin such that residual space is minimized. Minimizing residual space through $volume$ maximization was another critical tradeoff balanced throughout our methodology. Our recommended optimization models minimize residual space and maximize product $volume$ leading to increased ship output.

Table C1 summarizes critical configuration approaches from the empirical research.

**Table C1**

*Key Configuration Approaches*

| Key Configuration Approaches | Concept | Citation |
|---|---|---|
| **Gilmore and Gomory Model** | This focuses on "...generating pallet configuration patterns based on $length$ and $width$ in subsequent stages" (1).<br>This focuses on "...maximizing value of pieces cut or minimizing wastage used in a cutting pattern when segmenting product into bins" (2).<br><br>This focuses on "...maximizing total value of pieces where pieces must be aligned with their edges always parallel to the edges of the master surface (dimensions of bin or case) when segmenting product into bins" (3). | 1 - *Gilmore and Gomory model on two dimensional multiple stock size cutting stock problem*, (Octarina et al., 2019, 1).<br><br>2 - *ScienceDirect*, An exact algorithm for general, orthogonal, two-dimensional knapsack problems, (Baker et al., 2011, 1).<br><br>3 - *New Upper Bounds for the Two-Dimensional Orthogonal Cutting Stock Problem*, (Boschetti et al., 2002, 1). |

| | | |
|---|---|---|
| **Graph-Theoretical Approach** | Fekete and Schepers considered the positions of items in a feasible packing, defining a graph "...describing the item 'overlapping' according to the projection of items on each orthogonal axis" (1).<br><br>If we are loading to minimize storage or shelf space, we want to store items in a minimum number of bins. We want to "...assign each item to one bin, such that total $weight$ of the items in each bin does not exceed the $capacity\ C$ and the number of bins used for packing all items is minimized with empty space within each bin minimized" (2). | 1 - *Extreme-Point-Based Heuristics for Three-Dimensional Bin Packing*, (Crainic et al., 2008, 4).<br><br>2 - *A Graph Theoretic Approach for Minimizing Storage Space using Bin Packing Heuristics* (Sensarma & Sen Sarma, 2017, 1). |
| **Wall-Building Shelf Approach** | Given a rectangular-shaped container, rectangular-shaped boxes with different sizes are "...packed such that total loaded $volume$ is maximized. All boxes with the same origin-destination pair may be rotated in six orthogonal directions without load-related and positioning constraints" (1). | 1 - *A Modified Wall Building-Based Compound Approach for Container Loading Problem*, (Karoonsoontawong, 2013, 1). |
| **Martello and Toth Reduction algorithm** | This focuses on the "...partitioning of items within bins and exploring the implementation of items in a bin depending on if the items dominate versus over-dominate the available space. This research focuses on the addition of items into bins if they minimize empty | 1 - *Packing problems in one and more dimensions*, (Martello, 2018, 16). |

| | | |
|---|---|---|
| | space ensuring to not load in items that over-dominate space available” (1). | |
| **Branch/Bound algorithm** | This focuses on the “...sorting of items by non-increasing area where a search is performed based on a depth-first approach, where at each level an item is assigned to all active bins and to new bins. Unassigned items are assigned to a location in a bin based on the vertex in the bottom-left corner of the bin and to where they can't be moved leftward or downward. If no placement location is identified, no item can be assigned to a bin” (1). | 1 - *A lower bound for the non-oriented two-dimensional bin packing problem* (Dell’ Amico et al., 2002, 19-20). |
| **Height First, Area Second** | This focuses on “...packing items one at a time into layers or 3-D shelves, where the $height$ of the layer is equal to the $height$ of the tallest item packed into it. All items are packed with a basis on the floor of the layer” (1). | 1 - *Algorithms for Two-Dimensional Bin Packing and Assignment Problems* (Lodi, 1999, 65). |

To summarize the research strands highlighted in the table, we can categorize each of the above configuration strategies into a few key areas. The Gilmore and Gomory model takes a pattern formulation approach based on item $length$ and $width$ to configure optimally. The shelf wall-building approach focuses on the maximization of $volume$ to support optimal loading. The Martello and Toth reduction algorithm focuses on loading items that maximize product $volume$

without having products over-dominate available space in a bin due to large sizes. This could apply to cases being loaded on pallets or cartons being loaded into cases. The Branch and Bound algorithm focuses on the sorting of items by non-increasing area where items cannot be moved leftward and downward. The height-first and area-second algorithm focuses on the packing of items into layers to configure the product. While these various configuration approaches have been highlighted for reference, we used the extreme-point heuristics algorithm in our project. This algorithm generates the most effective insights that reduce product damage risk and maximize pallet stability.

Lastly, we summarize sorting strategies presented in the article by Crainic et al. (2008) that emphasizes how frozen products can be sorted optimally within cartons, cases, pallets, and trailers. Table C2 summarizes optimal sorting strategies for specific products complementing the research above. Each of these particular sorting strategies presents different options on how to sort items in cartons, cartons in cases, and cases on pallets. Smucker sought to be informed on optimal sorting approaches for products depending on pallet mixing. The sorting approaches that were proven to drive maximal product safety and stability through the research were the Area-Height and Height-Area sorting approaches.

**Table C2**

*Key Sorting Approaches*

| Key Sorting Approaches | Concept | Citation |
|---|---|---|
| **Volume-Height** | This is a theory where we sort based on "...non-increasing values of $volume$. Items with the same $volume$ are sorted based on increasing values of $height$ $(hi)$"(1). | 1 - *Extreme-Point-Based Heuristics for Three-Dimensional Bin Packing,* |
| **Height-Volume** | Items are sorted by "...non-increasing values of their $height$ $(hi)$. Items with the same $height$ are sorted by non-increasing values of their $volume$ $(wi * hi * di)$" (1). | |

| | | |
|---|---|---|
| | | (Crainic et al., 2008, 8). |
| **Area-Height** | Items are sorted by "...non-increasing values of their *base area* $(wi * di)$. Items with the same area are sorted by non-increasing values of their *height* $(hi)$"(1). | 1 - *Extreme-Point-Based Heuristics for Three-Dimensional Bin Packing*, (Crainic et al., 2008, 9). |
| **Clustered Area-Height** | Since two items have rarely the same *base area*, the second sorting criterion (*"Height"*) of the previous rule is not often used. "...In order to build more regular packings, in the clustered version of the Area-Height ordering rule, the bin area $(wi * di)$ is separated into clusters defined by the intervals per Equation 1: *Equation 1*: $[((j-1) * wi * di * \delta, j * wi * di * \delta)]$. *Wi* and *di* are the *width* and the *depth* of the bin, respectively where $\delta \in [1, 100]$. Items are then assigned to clusters according to their *base area* and clusters are ordered by decreasing values of $j$. Items assigned to the same cluster are sorted by non-increasing values of their *height* $(hi)$" (1). | |
| **Height-Area** | Items are sorted by "...non-increasing values of their *height* . Items having the same *height* are sorted by non-increasing values of their *base area* $(wi * di)$" (1). | |

| | | |
|---|---|---|
| **Clustered Height-Area** | This rule is a variant of the previous one where, given a value $\delta \in [1, 100]$, the $height$ ($hi$) of the bin is separated into clusters defined by the intervals per Equation 2: $$Equation\ 2: [((j - 1) * hi * \delta, j * hi * \delta)].$$ Items are then "...assigned to clusters according to their $height$ and clusters are ordered by decreasing values of $j$. Items assigned to the same cluster are sorted by non-increasing values of their $base\ area$ $(wi * di)$" (1). | |