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UNIVERSIDAD PONTIFICIA

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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

Especialidad de Organización Industrial

TRABAJO FIN DE GRADO

ANALYSIS IN BOXSIZER IMPLEMENTATION TO REDUCE THE NUMBER OF POSSIBLE BOX SIZES

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Madrid

Julio de 2019

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ANÁLISIS EN LA IMPLEMENTACIÓN DE EQUIPAMIENTO BOXSIZER PARA REDUCIR LOS POSIBLES TAMAÑOS DE CAJA

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Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

RESUMEN DEL PROYECTO

1. Introducción

Los centros de distribución (CD) son lugares donde la eficiencia de los procesos de empaquetamiento y envío pueden tener un alto impacto en los costes y operaciones de una empresa. Por lo tanto, la optimización de estos procedimientos puede significar no sólo ahorros sustanciales sino también un mejor rendimiento de la instalación.

Este proyecto fue realizado como *Senior Design Project* en la Universidad de Florida en colaboración con un equipo compuesto por Gabriela Buraglia, Bianca Gallina, Pablo Barros de Lis, Kelsey Lecker, Kevin Ramos y Connor Richardson. El patrocinador de este proyecto es una empresa de moda estadounidense, en adelante referida como la Compañía[1]. Se especializa en accesorios y ropa de lujo, con venta en tiendas en propiedad y outlets en Norteamérica, Asia y Europa, y unos ingresos anuales de 4.220 millones de dólares.

El problema presentado en este proyecto tiene lugar en un centro de distribución de la Compañía situado al Noreste de Florida, que abastece a todas las tiendas y puntos de venta de la Compañía en Norteamérica, Hawaii y otras islas, así como directamente a los clientes.

1.1. Planteamiento del Problema

Actualmente, el Centro de Distribución utiliza 13 tamaños de caja diferentes para todos sus envíos. El proceso en el que se preparan los pedidos tiene dos defectos principales: en primer lugar, debido a que la lógica del WMS (Warehouse Management System) no es completamente precisa, esta solo da una estimación de la caja más apropiada para cada pedido. Por otro lado, los trabajadores apenas tienen tiempo para reorganizar los artículos de manera que todo el pedido se ajuste al tamaño de caja dado, por lo que muchas veces añaden una caja adicional para poder colocar todos los productos.

En otras palabras, no siempre se utiliza el tamaño de caja óptima en cada pedido, lo que da lugar a que se envíen grandes volúmenes de espacio vacío produciendo costes innecesarios en transporte y material [BBdLL+19].

Para afrontar estos problemas, la firma subcontrató un análisis de un tercero (UPS) con el principal objetivo de revelar las oportunidades de mejora de su sistema y encontrar posibles soluciones [UPS17]. El informe de dicha evaluación sugería reducir el número de cajas de 13 a un máximo de 5, junto con la compra de maquinaria BoxSizer, un sistema automatizado que ajusta el tamaño del paquete a la altura de los productos que contiene, eliminando así el espacio vacío que habría quedado encima de ellos [Wesb]. El proceso seguido por el BoxSizer se ilustra en la Figura 1 [Lin].

[1] Por motivos de confidencialidad, la Compañía prefiere mantenerse anónima.

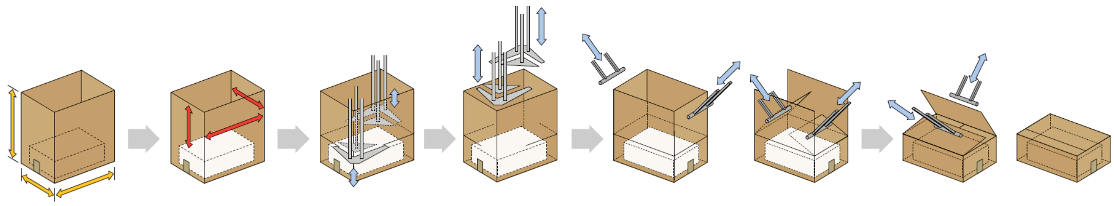


Figura 1. Proceso de Eliminación del Espacio Vacío con un BoxSizer

Para complementar al BoxSizer, la sugerencia incluía también la compra de máquinas montadoras de cajas, que automatizarían el proceso de construcción de las cajas. Es decir, recibiendo el lote de cajas planas (que es como llegan al CD), una a una les da forma volumétrica.

Con el fin de preparar la implementación del equipo, se deben determinar las dimensiones del nuevo grupo de hasta 5 cajas que se usarán con el BoxSizer. Esto ha de hacerse de manera que el impacto y los beneficios de la inversión en el equipamiento sean máximos [BBdLL^{+}19]. La Compañía ya había propuesto un conjunto de 5 dimensiones, determinadas sin un análisis sólido que justificara la elección, por lo que deberán ser mejoradas.

Junto con la búsqueda de las dimensiones óptimas, se estudiará y validará la viabilidad económica y operativa del proyecto.

1.2. Estado del arte

Como cabe esperar, muchas otras empresas también han explorado soluciones al problema presentado. Los siguientes ejemplos pueden ser útiles para ilustrar algunos de los caminos que un centro de distribución puede tomar.

Staples utilizó una solución llamada empaquetamiento “smart-size”. Con él, los empleados personalizaban el tamaño de las cajas de manera que se ajustaban exactamente a los de sus productos [Clo12]. De esta forma, hallaron que la solución resultaba en una mayor eficiencia operativa y en una reducción de los gastos de transporte, ya que les permitía realizar más envíos por camión.

Mason Companies también desarrolló una solución para un problema similar en el que se centraron en la diferencia entre pagar por el envío basado en el peso dimensional (o peso volumétrico) frente al peso real. Su solución fue implementar un tamaño de caja que se ajustara exactamente al producto, lo cual resultó en una diminución en los gastos. [Moh17].

Además de estos casos de gestión de almacenes, también es importante explorar pasadas investigaciones sobre la optimización de las dimensiones de las cajas en un CD. En un documento muy instructivo de Jan Brinker e Ibrahim Gunduz Halil, se considera un problema de la p-mediana para encontrar un número específico de tamaños de caja óptimos, dado el conjunto de pedidos y el conjunto de tamaños de caja [BG16]. Se trata de un problema de optimización muy similar al presentado en el presente proyecto y no sólo cubre la minimización del vacío en las cajas, sino que también incluye en su algoritmo una gama de 12 estrategias básicas de empaquetamiento diferentes, ofreciendo un enfoque tremendamente interesante al problema.

1.3. Objetivo del proyecto

La Compañía solicitó un conjunto de hasta 5 dimensiones de caja que fuesen óptimas para la actividad del CD, de cara a la implementación del BoxSizer. Junto con la búsqueda de nuevas dimensiones óptimas para las cajas, la Compañía espera recibir un análisis de la implementación de los nuevos equipos, incluyendo una investigación sobre el impacto en el transporte, una justificación económica del proyecto y todo tipo de recomendaciones pertinentes. El análisis se dividirá en tres secciones diferentes, que son las siguientes:

- **Estudio de las nuevas dimensiones de caja.** En primer lugar, se determinarán las nuevas dimensiones de las cajas. La importancia de esta búsqueda deriva del hecho de que, si las dimensiones de las cajas no son eficientes, el espacio vacío que acabará habiendo en ellas provocará mayores costes de transporte y un peor rendimiento en las instalaciones.

- **Análisis del impacto en el transporte.** Este análisis ha sido solicitado por la Compañía. El departamento de transporte del CD es una de las áreas que más experimentará los efectos del nuevo equipamiento y de la reducción del número de cajas. El ahorro en el que debería resultar la inversión inicial tendrá lugar en su mayor parte allí. Por lo tanto, una vez encontradas las dimensiones óptimas, se estudiarán sus efectos en el transporte.

- **Análisis de costes.** Finalmente, en un análisis de costes, se tendrán en cuenta todos los efectos de la implementación. Por lo tanto, será la prueba decisiva para justificar la inversión para la Compañía. Para realizar el análisis se utilizarán los resultados de los dos apartados anteriores, junto con datos anteriores de la empresa.

2. Metodología

Durante el transcurso del proyecto, la Compañía proporcionó todos los datos que consideró relevantes, así como los que fueron solicitados. Además de estos datos, y de los que se obtuvieron de otras fuentes, se tuvieron en cuenta todas las observaciones y conclusiones de las visitas al CD, las recomendaciones de los gestores del mismo y consideraciones no cuantificables. A continuación, se resumen los principales conjuntos de datos utilizados en este proyecto:

- **Historial de Pedidos.** La Compañía proporcionó un historial con 224.243 pedidos de un período de tiempo reciente.

- **Tarifas de envío de UPS.** Este conjunto de datos está organizado en hojas de cálculo, en las que hay una tarifa de envío para cada peso de los paquetes y zona de destino, y fue proporcionado por la empresa [UPS19]. Un factor clave en este conjunto de datos es la irregularidad y no linealidad con la que se establecen las tarifas. Además, la Compañía tiene algunos acuerdos específicos con el transportista que están incluidos en un documento aparte [TU].

- **Análisis previos.** Dos análisis realizados antes de este proyecto fueron de gran utilidad. En primer lugar, el UPS On-Site Assessment [UPS17], que es el informe del análisis realizado por UPS con el fin de encontrar posibles soluciones a los altos costes que tenía la Compañía. Muchos de los resultados que obtuvieron fueron de gran utilidad para el presente proyecto. En segundo lugar, el análisis de costes que la Compañía ya había realizado para las 5 dimensiones que propuso, fue usado como base para el estudio económico de este proyecto.

2.1. Análisis de las Dimensiones Óptimas de Caja

Lo primero que había que definir era la estrategia de optimización que se escogería para realizar el modelo. Se consideraron dos posibilidades: maximizar el aprovechamiento del espacio en las cajas y minimizar los costes de transporte. Debido a la complejidad de la forma en que se definen las tarifas de envío, se decidió optimizar en torno a la minimización de los espacios vacíos en las cajas. Sin embargo, se recomienda que la Compañía investigue en el futuro el enfoque alternativo propuesto.

El paso previo a crear el modelo de optimización consistió en la organización de los datos y el cálculo de la fracción de vacío en cada pedido. Para realizar el análisis, se proporcionó un conjunto de 224.243 pedidos con los siguientes detalles: Número de caja, Pick-ticket, Volumen del producto, Unidades embaladas, Tamaño de la caja, Volumen de la caja, Peso real, Código postal y Forma de envío. Dado que la información no estaba agrupada por pedidos, sino por tipo de producto enviado, fue necesario utilizar Microsoft Access para ordenarla. Para ello, los datos de Microsoft Excel fueron exportados a Access y se diseñó una consulta para seleccionar las categorías de interés, agrupar en pedidos y calcular el "Volumen de pedido", determinado por la expresión en la Ecuación 1:

$$Volumen\,del\,Pedido = \sum (Volumen\,del\,Producto \times Unidades) \tag{1}$$

Esto permitió obtener un volumen total para cada pedido, que es lo que realmente sería útil. Una vez que los datos volvieron a estar en Excel, los pedidos se ordenaron al azar.

Tras disponer de los datos necesarios para la optimización, se construyó un modelo basado en la minimización de los espacios vacíos en las cajas. El modelo final utilizado en el proyecto fue un programa lineal que, para un conjunto de pedidos $i \in O$ que pueden ser empaquetados en cajas $j \in B$, toma su porcentaje de espacio vacío c_{ij} y lo minimiza de forma que selecciona un único tamaño de caja para cada pedido dando un valor binario a x_{ij}, que representa el tamaño de caja utilizado para ese pedido. Todo con una restricción del posible número de cajas usado, s.

El modelo se describe en la Figura 2 [BBdLL+19] en términos algebraicos:

Objetivo:

Minimizar la cantidad total de espacio vacío	$min \quad \sum_{i \epsilon O} \sum_{j \epsilon B} cij * xij$	

Sujeto a:

Todos los pedidos se empaquetan en una sola caja	$\sum_{j \epsilon B} xij = 1$	$\forall i \epsilon O$
Un máximo de s cajas es seleccionado (4 ó 5)	$\sum_{j \epsilon B} yj = s$	
Una caja no seleccionada (y_j=0) no puede coger pedidos	$\sum_{i \epsilon O} xij \leq Myj$	$\forall j \epsilon B$
Las variables x_{ij} e y_j son binarias	$xij, yj \in \{0,1\}$	

Figura 2. Modelo de Optimización en Forma Algebraica

Dónde:

- O es el conjunto de todos los pedidos considerados.
- B es el conjunto de todos los tamaños de caja considerados.
- El elemento c_{ij} es la cantidad de espacio vacío en la caja j cuando se asigna al pedido i.
- s es el número de posibles tamaños de caja que pueden ser seleccionados.
- M es una constante arbitraria de gran tamaño.

La ecuación usada para calcular el espacio vacío en cada caja se incluye en la Ecuación 2.

$$c_{ij} = 1 - \frac{Volumen\ de\ Pedido\ i}{Volumen\ de\ Caja\ j} \tag{2}$$

Mediante el uso de Excel, Visual Basic (VBA) se utilizó para calcular la fracción de vacío c_{ij} que cada pedido tendría en cada uno de los tamaños de caja probados. El código de Visual Basic utilizado para calcular los c_{ij} está incluido en el Apéndice. Una muestra de c_{ij} tal y como fueron introducidos al modelo se ilustra en la Tabla 1, con los pedidos en las filas y el conjunto de cajas siendo analizado en las columnas. En los casos en los que un pedido no cupiese en una caja, se introdujo un valor de 5 para penalizar el valor objetivo en caso de ser seleccionadas.

	Cij 1	Cij 2	Cij 3	Cij 4	Cij 5	Cij 6	Cij 7	Cij 8	Cij 9	Cij 10	Cij 11	Cij 12	Cij 13
Order 54278	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.042	0.129
Order 54279	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.333	0.351	0.472	0.583	0.681	0.710
Order 54280	0.992	0.996	0.997	0.998	0.998	0.998	0.999	0.999	0.999	0.999	1.000	1.000	1.000
Order 54281	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.042	0.129
Order 54282	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.166	0.362	0.419
Order 54283	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.304	0.323	0.449	0.565	0.667	0.697
Order 54284	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.123	0.306	0.469	0.517
Order 54285	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.076	0.159
Order 54286	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.167	0.243
Order 54287	5.000	5.000	5.000	5.000	5.000	5.000	0.099	0.430	0.446	0.549	0.644	0.727	0.752
Order 54288	0.636	0.809	0.841	0.890	0.917	0.928	0.943	0.964	0.965	0.972	0.978	0.983	0.984
Order 54289	5.000	5.000	5.000	5.000	5.000	5.000	0.099	0.430	0.446	0.549	0.644	0.727	0.752

Tabla 1. Muestra de los c_{ij} Calculados con VBA

El modelo fue introducido en Excel *Solver* y en GAMS, pero no tuvieron capacidad suficiente para el ejecutar el modelo con una muestra razonable. Finalmente, se utilizó un software de optimización numérica online llamado NEOS. Este tomaba el código en lenguaje de GAMS, y un archivo de entrada (la tabla con los c_{ij}) en formato .gdx (GAMS Data eXchange). GAMS fue nuevamente utilizado para generar dicho archivo. El código usado en NEOS también está incluido en el Apéndice, Subsección A.1.3.

Debido a que NEOS tiene un límite de tamaño de 16 MB para el archivo de entrada, una calculadora de tamaño de muestra fue utilizada para determinar cuántos pedidos se necesitaban para generar un intervalo de confianza considerable. De los 224.243 pedidos, una muestra de 64.000 tomados de períodos relevantes generó un intervalo de confianza del 99 % $\pm$ 0,431054 %. De esta forma se compuso una muestra representativa que el software admitía para la ejecución.

Debido a la limitación del tamaño del archivo de entrada, se comprendió que no sería suficiente con una sola optimización que resultase en las dimensiones óptimas. Esto habría sido posible si se hubiesen podido introducir tantos tamaños de caja como se deseasen. El tamaño máximo de archivo permitía introducir unas 16 cajas. Por ello, se decidió utilizar un proceso iterativo, en el que el algoritmo encontraría las mejores dimensiones de cada conjunto insertado como entrada, y el proceso se repetiría para varios conjuntos de dimensiones diferentes, hasta que convergiera en una conclusión sólida.

El proceso iterativo seguido, es descrito a continuación:

1. **Iteración 1**. Selección de las mejores 5 de las 13 originales. Recomendación: *28*, *39*, *43*, *60*, *64*.
2. **Iteración 2**. Mejores 5 de la selección elegida en la Iteración 1 más las 5 cajas propuestas inicialmente por la Compañía. Recomendación: *28*, *39*, *43*, *60*, *64*.
3. **Iteración 3**. Mejores 5 de la selección elegida en la Iteración 2 más 10 tamaños de cajas populares en la industria. Recomendación: *b*, *39*, *43*, *60*, *64*.

4. **Iteración 4**. Mejores 5 de la selección elegida en la Iteración 3 más 10 nuevos tamaños que eran variaciones de los actuales 5 mejores (uno más grande y uno más pequeño que cada tamaño). Recomendación: *b*, *39*, *43*, *60*, *64b*.

5. **Iteración 5**. Repetición de la Iteración 4 sin la caja *64b*, ya que a la Empresa no le convencía un tamaño de caja tan grande. Recomendación: *b*, *39*, *43*, *60*, *64*.

2.2. Análisis del Impacto en el Transporte

Como se ha explicado previamente, se realizó un análisis del impacto que tendría sobre el área de transporte la implementación del BoxSizer y la reducción del número de tamaños de caja. Esto tendría en cuenta tanto los costes de envío de las cajas como su rendimiento y aprovechamiento.

Los costes de transporte utilizados en el análisis se determinaron a partir de los aproximadamente 20.000 pedidos de la muestra de 64.000 que habían sido enviados por servicios varios de UPS en Estados Unidos. El coste de envío para cada pedido se determinó mediante las tablas de tarifas para los diversos métodos de envío [UPS19], así como incluyendo los acuerdos específicos entre el transportista y la Compañía.

El coste de envío de cualquier pedido se determina en una tabla de tarifas de envío por dos factores: la zona de destino del pedido, y el máximo entre el peso de la caja y el *peso dimensional* (o peso volumétrico), que es un peso virtual del pedido. El peso dimensional, se calcula con la fórmula que se indica en la Ecuación 3 a continuación. El factor dimensional es fijado por los transportistas según el método de envío (también puede ser acordado) y tiene un efecto importante en el coste de envío [Pal16].

$$Peso\,Volumétrico \approx \frac{Volumen\ de\ Caja}{Factor\ Dimensional} \qquad (3)$$

A continuación, se resume el proceso seguido con VBA para los cálculos de este análisis. El código puede ser examinado en el Apéndice, Sección A.2.

1. En primer lugar, se halló el “código de envío” a partir del historial de pedidos. Este código hace referencia a un estado/zona y a un método de envío de UPS (next day air, next day air early, next day air saver, second day air, second day air AM, three day select y ground). A cada pedido se le asignó un número del 1 al 7 según el método que su código indicase.

2. A continuación, teniendo el código postal y el método de envío de cada pedido, mediante una tabla, se halló la “zona de envío”, que agrupa los códigos postales para cada método. Teniendo la zona de envío de cada pedido, el precio de su envío fue fácilmente hallado en las tablas, que asignan una tarifa para cada precio y zona de envío.

3. En el siguiente paso, para cada conjunto de cajas se asignó una caja a cada pedido, escogiendo la que menos espacio vacío dejase. Con ello, el peso volumétrico y el factor dimensional fueron calculados.

4. Con esto, solo quedaba hallar el coste total y promedio en cada uno de los escenarios (conjunto de cajas usadas), de forma que la situación inicial de 13 cajas pudiera compararse con la solución propuesta.

3. Resultados

3.1. Resultados de la Optimización

Como se ha explicado, lo que se estaba introduciendo como input en la optimización era el volumen de la caja (a través del c_{ij}). Por lo tanto, los resultados finales del algoritmo fueron volúmenes de caja, pero no sus dimensiones (largo, ancho y altura). Esto es de gran importancia, ya que una vez conocidos esos volúmenes óptimos, había que definir las dimensiones. Esto se hizo atendiendo a factores cualitativos que fueron discutidos con los gerentes del Centro de Distribución. Tras una proposición de 5 cajas con sus respectivas dimensiones, los gerentes de la Compañía hicieron algunas modificaciones a las mismas que las harían más factibles para el Centro de Distribución. Estos factores podían ser, por ejemplo, la estabilidad de la caja o experiencias negativas con ciertos tamaños, como era con los más pequeños.

La Compañía mandó hacer los tamaños de caja finalmente seleccionados, y en una última visita al CD se analizó su desempeño con pedidos reales con el fin de comprobar su validez y observar cualquier tipo de defecto o desventaja. Finalmente se decidió utilizar un set final de 4 dimensiones de caja, que incluía cajas de la optimización realizada y también de las modificaciones propuestas por los gerentes.

Estos últimos 4 tamaños propuestos eliminaban una de las cajas debido a que se concluyó con los gerentes del CD que sería redundante al ser utilizada junto a las otras. Los 4 tamaños finales eran *b4*, *3*, *4* y *64_2*. La situación final se detalla en la Tabla 2.

	Tamaño	Largo	Ancho	Altura	BoxSizer H	Volumen [in3]
Optimización	b	12.5	9	6.48	10.98	729
	39	15.13	15.13	8.25	15.82	1889
	43	21.88	17.13	11.6	20.20	4348
	60	24	20.25	18.75	19.75	9113
	64	24	20	20.88	21.88	10022
Propuesta Final	b4	14	11	12.5	13.5	1925
	3	17	15	11	18.5	2805
	4	24	20	12	13	5760
	64	24	20	21	22	10080

Tabla 2. Medidas de las Cajas Resultantes de la Optimización y de la Proposición Final

En consecuencia, la recomendación final terminó siendo un conjunto de 4 cajas con un trasfondo de análisis tanto analítico como empírico, por lo que se cree que la solución es de una fiabilidad considerable.

3.2. Resultados del análisis de transporte

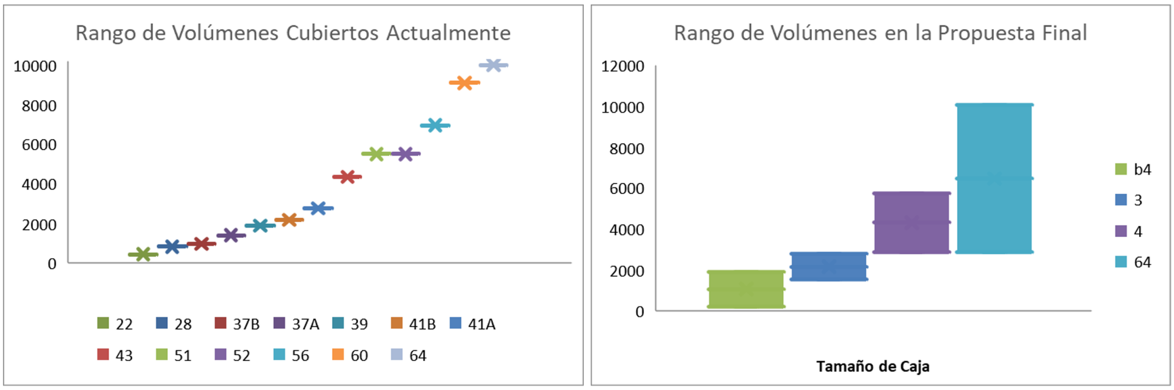
El análisis se llevó a cabo con los 20.000 pedidos de la muestra de 64.000 que habían sido enviados con UPS. Se analizaron tres conjuntos de cajas, el original con 13 cajas, el resultado de la optimización y la propuesta final.

Con el conjunto final propuesto, se determinó que el Centro de Distribución ahorraría aproximadamente $2,35 por pedido. Estas importantes mejoras se ven en la Figura 3.

(a) Reducción en el Peso Volumétrico Medio **(b)** Reducción en el Coste Medio por Pedido

Figura 3. KPIs de la Propuesta Final

La significación de la solución final se hace aún más notable cuando se representa el rango de volúmenes que cubre cada caja, que se ilustra en la Figura 4. Estas gráficas muestran que teóricamente el vacío se eliminará completamente de cada pedido enviado [BBdLL^{+}19]. En cambio, en el primer caso, cualquier espacio entre los volúmenes de dos tamaños de caja consecutivos indica que existirá vacío en la caja cuando sea llenada con productos, lo que significa que el envío de la caja costará más de lo que debería.



(a) Set Original de 13 Cajas **(b)** Proposición Final de Cuatro Cajas

Figura 4. Comparativa del Rango de Volúmenes Cubiertos

Se puede entender con la Figura 4b que la solución final es un logro notable ya que no sólo cubre todos los rangos de volúmenes, sino que además elimina una caja del sistema, con todos los beneficios operativos y económicos que conlleva.

Es importante señalar que el conjunto final de cajas es una combinación del trabajo analítico del equipo y de las recomendaciones del Centro de Distribución, derivadas de su experiencia. Esto hace que la solución sea aún más sólida, pero debido a su naturaleza no debería ser una solución óptima en términos cuantitativos, lo cual es el sacrificio en que se incurre en pos de obtener beneficios operativos en el Centro de Distribución.

3.3. Estudio Económico

El análisis económico del proyecto tenía como propósito comprobar si, aparte de los beneficios operativos que se iban a obtener, económicamente era viable. Los costes y ahorros se dividieron en tres áreas principales: mano de obra, material y transporte. A continuación, se resumen las principales partes del análisis:

- **Ahorro en mano de obra.** Representa la reducción en el número de empleados que resultaría de la implementación del BoxSizer. La compra de las montadoras de cajas tendría un efecto importante en esta área. Con la opinión de los gerentes del Centro de Distribución, se concluyó que la mano de obra encargada de la construcción de las cajas podría disminuir en 3 trabajadores, mientras que la mano de obra encargada de precintar las cajas se reduciría a uno o dos trabajadores. En conjunto, estos cambios significarían casi $400.000 en ahorros anuales.

- **Ahorro en material de caja.** Sorprendentemente, el análisis del material de las cajas determinó que con la solución propuesta de cuatro cajas habría más gastos en material de caja. Esto puede explicarse por el hecho de que los tamaños de caja finalmente propuestos eran proporcionalmente más caros que los 13 conjuntos originales. El resultado fue un coste adicional de casi $9.000 en la muestra de 64.000 pedidos, lo que supone unos $200.000 anuales.

- **Ahorro en relleno de las cajas** También se analizó la reducción de la cantidad de relleno necesaria (es decir, las almohadas de aire colocadas en las cajas para que se terminen de llenar haciendo la caja más rígida y consistente). Para estimar el ahorro en el relleno, se comparó el porcentaje actual de espacio vacío por caja (18,8 %) con el que se esperaba con el BoxSizer, que era de 0 %. Como esto asumía volúmenes líquidos de los productos, para ser realistas, se usó un factor del 10 % que tuviese en cuenta el vacío en cada caja. Con todo ello, el vacío por caja bajaría al 8,8 %, lo que se tradujo en un ahorro en relleno de unos $120.000.

  La Figura 5 muestra la relación entre costes y ahorros en cada una de las áreas de operaciones de la preparación de las cajas, para una muestra de 64.000 pedidos.

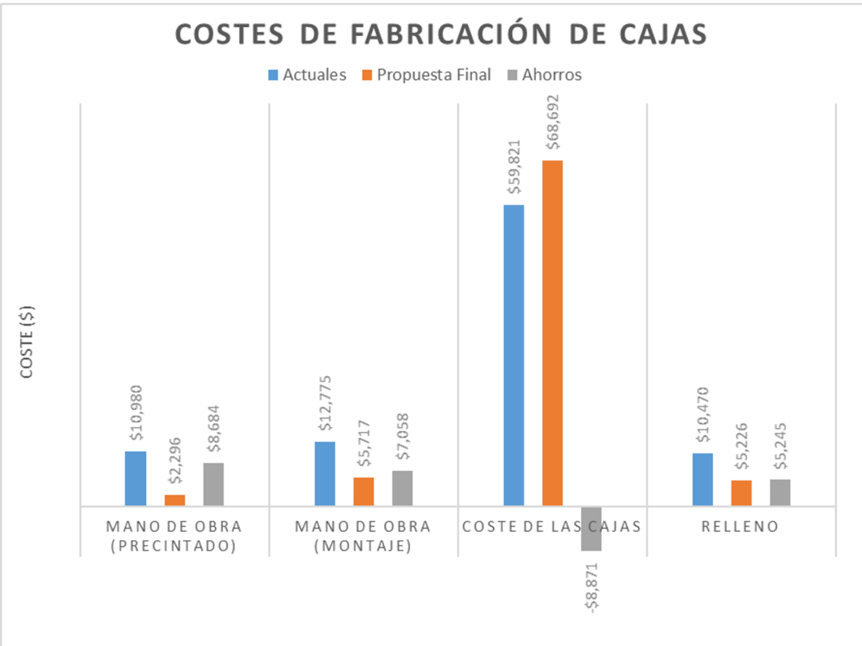


Figura 5. Reducción de Costes en las Operaciones de Preparación de las Cajas

- **Ahorro en transporte.** Estos fueron hallados en el Análisis del Impacto en el Transporte y fueron de $2.35 de ahorro por pedido. Para el resto de los pedidos se asumió un ahorro de $0,5, lo que en total supuso un ahorro anual de casi $170.000.

Los resultados se extrapolaron a un periodo de tiempo de un año a partir del número anual de pedidos, 1.571.124, y se consideró que un factor de 0,8 debía ser aplicado a todos los ahorros para hacerlos más conservadores. Los resultados del análisis de costes son sintetizados en dos ratios tradicionalmente usados en este tipo de proyectos [Jul01], que se exponen en la Tabla 3.

Inversión	
4 máquinas montadoras	$318,000
2 BoxSizers	$1,145,000
Contingencia (30%)	$500,000
Total	$1,963,000

Ahorro Anual	
Mano de Obra (Precintado)	$170,552
Mano de Obra (Montaje)	$138,609
Coste de Cajas	-$217,771
Relleno	$102,997
Transporte	$1,349,717
Total	$1,544,105

PayBack (años)	1.27
Retorno de la Inversión	79%

Tabla 3. Resultados Finales del Estudio Económico

Como se puede observar, el ahorro anual sería de aproximadamente 1,5 millones de dólares y el retorno de la inversión (ROI) del 79 %. Además, a través del cálculo del Payback, se halló que el dinero invertido se recuperaría en casi 1 año y 3 meses.

4. Conclusiones

Se puede afirmar con seguridad que la solución expuesta al problema y la implementación del nuevo equipo tendrán efectos operativos, económicos y ambientales positivos. El BoxSizer agilizará considerablemente el proceso final de preparado de los pedidos, eliminando así un posible cuello de botella, lo cual mejorará la fluidez en todo el Centro de Distribución y acabará afectando positivamente a todas las áreas del CD.

También resultará en importantes beneficios ambientales. Se espera que cualquier reducción del vacío dentro de las cajas se traduzca directamente en una reducción de los residuos generados. Tras la implementación del BoxSizer, las almohadas de aire utilizadas para rellenar los huecos vacíos en las cajas ya no serán necesarias. Esto no sólo supondrá un ahorro de costes, sino también un importante impacto medioambiental debido a la reducción del uso de plástico. Las tiendas minoristas ya no tendrán que deshacerse de un enorme número de almohadas de aire que, en última instancia, terminan en los vertederos de residuos [BBdLL+19].

La metodología utilizada a lo largo de este proyecto tiene un importante componente analítico, pero siempre estuvo presente la consideración de factores que no podían ser incluidos en un modelo de optimización por su naturaleza no cuantitativa. Además, la colaboración con los patrocinadores de la empresa fue muy productiva y, junto con los esfuerzos del equipo, permitió alcanzar el objetivo del proyecto superando las expectativas.

Los resultados de las tres secciones del proyecto se consideran realmente valiosos. La optimización condujo a la selección de 4 tamaños de cajas, lo que supuso una mejora del objetivo inicial, que era seleccionar 5. Además, la optimización pasó por un proceso iterativo y luego fue reforzada con la experiencia y el conocimiento empírico de los gerentes del Centro de Distribución para hacerla más realista y conveniente. El análisis del impacto en el transporte mostró que la implementación del BoxSizer junto con la reducción de cajas tendría efectos excepcionales tanto económica como operacionalmente. Se hallaron una gran cantidad de ahorros en el transporte de los pedidos, además de importantes resultados sobre los volúmenes cubiertos por cada conjunto de tamaños de caja. Finalmente, en el estudio económico, las dos cifras obtenidas, un retorno de la inversión (ROI) del 79 % y un Payback de 1,27 años, son indicadores de que la inversión es altamente recomendable.

Se considera que el equipo ha dado valiosas recomendaciones e ideas a la Compañía y a los gerentes de CD, a partir de todo lo que se observó, analizó y aprendió. Siempre fue una preocupación aconsejar a los gerentes sobre procedimientos con margen de mejora. La Compañía consideró todas las recomendaciones apropiadas y altamente constructivas.

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ANALYSIS IN BOXSIZER IMPLEMENTATION TO REDUCE THE NUMBER OF POSSIBLE BOX SIZES

PROJECT SUMMARY

1. Introduction

DISTRIBUTION centers (DC) are places where efficient packaging and shipping processes can have a high impact on a firm's costs and warehouse operations. Therefore, an effort to optimize these procedures can mean not only savings but also a better performance at the facility.

This project was a Senior Design Project at the University of Florida, done collaboratively by a team composed of Gabriela Buraglia, Bianca Gallina, Pablo Barros de Lis, Kelsey Lecker, Kevin Ramos, and Connor Richardson. The sponsor of this project is an American fashion company, hereafter referred to as the Company[1]. It is specialized in luxury accessories and apparel, with retail and outlet stores in North America, Asia, and Europe and annual revenues of $4.22B.

The problem presented in this project takes place in a distribution center of the Company, which supplies all the Company's stores and outlets in North America, Hawaii and other islands, as well as directly to customers. It will be referred to as Northeast Florida Distribution Center or NFDC.

1.1. Problem Statement

Currently, the Northeast Florida Distribution Center is using 13 different box sizes for its outbound shipments. The process in which they place the orders has 2 main problems: first, as the WMS logic is not completely precise, it only gives an estimation of the most appropriate box for an order. On the other hand, workers cannot afford to spend much time trying to rearrange items to ensure the entire order fits in the given size, so many times they will add an additional box in order to fit all the products. In other words, the optimal package sizes are not always used leading to large volumes of empty space being shipped and unnecessary shipping and material costs [BBdLL$^+$19].

To face this problem, the firm outsourced an analysis from a third-party (UPS) with the main objective of revealing the opportunities to improve their system and finding possible solutions [UPS17]. The assessment report suggested reducing the number of boxes from 13 to a maximum of 5, together with the purchase of a BoxSizer, an automated carton system equipment that adjusts the size of a package to the height of the products inside, removing the empty space that would have been on top of it [Wesb]. The process followed by the BoxSizer is illustrated in Figure 1 [Lin].

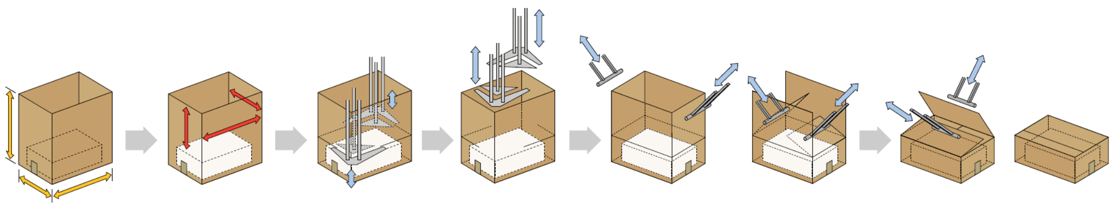


Figure 1. Void Eliminating Process with a BoxSizer

[1]For confidentiality reasons, the Company prefers to remain anonymous.

To complement the BoxSizer, the suggestion included also the purchase of case erectors, which would automate the process of building the box, that is, taking in the flat carton as it is received and putting it in a box shape.

In order to prepare for the implementation of the equipment, the dimensions of the new boxes that the BoxSizer will take in should be determined so that its impact is maximized and costs are reduced as much as possible [BBdLL+19]. The Company had already proposed a set of 5 dimensions, determined by making several assumptions, without a solid analysis supporting the election, and they are needed to be improved.

Together with the search for the optimal dimensions, the project will aim to support the implementation, through the study of its economic and operational feasibility.

1.2. State of the Art

As can be expected, many other companies have also explored solutions to the issue presented. The examples that follow can be useful to illustrate some of the paths that a distribution center can take.

Staples explored a solution, by implementing "smart-size packaging", in which employees customized the box sizes for its shipments [Clo12]. They found this solution resulted in increased operational efficiency and a reduction in transportation costs by enabling them to fit more shipments per truck.

Mason Companies also developed a solution for a similar problem where they focused on the difference between paying for shipping based on dimensional weight (DIM) versus actual weight [Moh17]. Their solution was to implement box sizing that would fit the product exactly and they were able to see cost savings [BBdLL+19].

In addition to these warehouse management cases, it is also of relevance to examine the research done on the optimization of box dimensions. In a very instructive paper by Jan Brinker and Ibrahim Gunduz Halil, a p-median approach is applied to find a specified number of optimal, demand-related packaging sizes, given the set of orders and the set of packaging sizes [BG16]. It is a very similar optimization problem to the one presented in the present project and it not only covers the minimization of void in the boxes that are being filled, but it also includes a range of 12 different basic packing strategies in its algorithm in a tremendously interesting approach to the problem.

1.3. Project Objective

The Company asked for a set of 5 (or less) package dimensions that would be optimal for the DC activity. Together with the search for optimal new box dimensions, the Company expects to receive an analysis of the implementation of the new equipment, including research on the impact on the transportation side, an economic justification of the project and all sort of pertinent recommendations. The analysis will be split into three different sections that will be carried out, which are the following:

- **Study on the dimensions of the new boxes.** First of all, the new dimensions of the boxes have to be determined. The importance of this search derives from the fact that if the package sizing is not efficient, the void space in the packages will lead to higher costs in transportation and a worse performance overall.

- **Analysis on transportation impact.** This analysis was also asked by the sponsor. The transportation department of the DC is the area that will experience the most all the changes that will be taking place. The savings in which the investment should eventually result, will mostly take place there. Therefore, once the optimal dimensions are found, a deep analysis will be conducted on the transportation side.
- **Cost analysis.** Finally, in a cost analysis, all the effects of the implementation will be taken into consideration. Hence, it will be the decisive test to justify the project for the Company. To perform the analysis, the results from the two previous sections will be the used, together with past data from the company.

2. Methodology

Over the course of the project, the Company provided all the data sets they considered relevant as well as the ones that were requested. In addition to these documents and the ones coming from other sources, all the insights from the visits to the DC, managers' recommendations and non-measurable considerations will be regarded. The main data sets used throughout this project are summarized below:

- **Order history.** The Company provided a data set with 224,243 orders from a recent period of time.
- **UPS shipping rates.** This data set is organized in spreadsheets, in which there is a shipping fee for every package weight (lbs.) and zone of destination, and it was provided by the Company [UPS19]. A key factor in this data set is its irregularity and non-linearity. In addition, the Company has a few specific agreements with the carrier that are included in a separate document [TU].
- **Previous analysis.** Two analysis performed prior to this project were of great use. First, the UPS On-Site Assessment [UPS17], which is the report from the analysis conducted by UPS in order to find possible solutions to the high costs that the Company had. Many of the results they obtain in the process were very valuable for the present project. Also, the Company had already performed the cost analysis for the 5 dimensions they proposed, and it was the foundation for the economic study in this project.

2.1. Optimal Box Dimensions Analysis

The first thing to define was the optimization strategy that would be chosen to proceed with the analysis. It was considered both to maximize box utilization or minimize shipping costs. Due to the complexity of the way shipping rates are defined, it was decided to optimize around minimizing void spaces in the boxes. However, it is recommended that the Company looks into these aspects in the future.

The first step in creating the optimization model included organizing the data and calculating the fraction of void in each order. In order to perform the analysis, a set of 224,243 orders was provided with the following details: Carton Number, Pick-ticket, Unit Volume, Packed Units, Carton Size, Carton Volume, Actual Weight, Zip, and Ship Via. Since the orders were not grouped together, it was necessary to use Microsoft Access to sort neatly the information. After the data was imported from Microsoft Excel into Access, a select query was designed to pick: Carton Number, Pick-ticket, "Order Volume", Carton Size, Carton Volume, Actual Weight, Zip, and Ship Via. The "Order Volume" was determined by the expression in Equation 1:

$$Order\,Volume = \sum(Unit\,Volume \times Packed\,Units) \tag{1}$$

This allowed to get a realized volume for each order, which is what would actually be useful. Once the data was in Excel again, the orders were sorted randomly.

After having the data necessary for the optimization, a model was built based on the minimization of the empty spaces in the boxes. The final model used in the project was a linear program which, for a set of orders $i \in O$ that can be packed in boxes $j \in B$, takes their percentage of empty space c_{ij} and minimizes it so that it selects only one box size for each order by giving a binary value to x_{ij}, that represents the box size j used for order i. This has to be done with a restriction on the number of box sizes that can be used, s.

The model is outlined in Figure 2 [BBdLL+19] in algebraic terms:

<u>Objective</u>:

Minimize total void in the orders	$min \quad \sum_{i \epsilon O} \sum_{j \epsilon B} cij * xij$	

<u>Subject to</u>:

All orders are placed in exactly one box	$\sum_{j \epsilon B} xij = 1$	$\forall i \epsilon O$
At most s boxes are selected (4 or 5)	$\sum_{j \epsilon B} yj = s$	
A box that is not selected (y_j=0) cannot take orders	$\sum_{i \epsilon O} xij \leq Myj$	$\forall j \epsilon B$
All x_{ij} and y_j variables are binary	$xij, yj \, \epsilon \, \{0,1\}$	

Figure 2. Optimization Model in Algebraic Form

Where:

- O is the set of all orders considered.
- B is the set of all potential box sizes.
- c_{ij} is the amount of empty space in box j when allocated with order i.
- s is the fixed number of boxes.
- M is an arbitrary large constant.

The equation used to find the empty space in each box is included in Equation 2.

$$c_{ij} = 1 - \frac{volume\, of\, order\, i}{volume\, of\, box\, j} \tag{2}$$

Within Excel, VBA was utilized to calculate the fraction of void c_{ij} that every order would have in each of the box sizes tested whichever they were. The Visual Basic code used to calculate the c_{ij}'s is included in the Appendix, subsection A.1.1. A sample of c_{ij}'s is shown in Table 1, with the orders on the rows and the void spaces of the boxes under examination on the columns. A value of 5 was given to the orders that cannot fit in a box in order to penalize the objective value in case of being selected.

	Cij 1	Cij 2	Cij 3	Cij 4	Cij 5	Cij 6	Cij 7	Cij 8	Cij 9	Cij 10	Cij 11	Cij 12	Cij 13
Order 54278	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.042	0.129
Order 54279	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.333	0.351	0.472	0.583	0.681	0.710
Order 54280	0.992	0.996	0.997	0.998	0.998	0.998	0.999	0.999	0.999	0.999	1.000	1.000	1.000
Order 54281	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.042	0.129
Order 54282	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.166	0.362	0.419
Order 54283	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.304	0.323	0.449	0.565	0.667	0.697
Order 54284	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.123	0.306	0.469	0.517
Order 54285	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.076	0.159
Order 54286	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.167	0.243
Order 54287	5.000	5.000	5.000	5.000	5.000	5.000	0.099	0.430	0.446	0.549	0.644	0.727	0.752
Order 54288	0.636	0.809	0.841	0.890	0.917	0.928	0.943	0.964	0.965	0.972	0.978	0.983	0.984
Order 54289	5.000	5.000	5.000	5.000	5.000	5.000	0.099	0.430	0.446	0.549	0.644	0.727	0.752

Table 1. Sample VBA Output of c_{ij}'s Calculation

After trying other optimization programs and having some trouble with the model size, a free online numerical optimization solver called NEOS was used. NEOS took in a GAMS code, and an input file (the table with the c_{ij}'s) in .gdx format (GAMS Data eXchange). GAMS was used to generate this file. The code used in NEOS is also included in the Appendix, subsection A.1.3. Also, the CPLEX solver was selected to be used after some research.

Since NEOS had a size limitation of 16 MB, a sample size calculator was used to determine how many orders were needed to generate a high confidence interval. From the 224,243 orders, a sample 64,000 of these orders taken from relevant periods were enough to generate a confidence interval of $99\% \pm 0.431054\%$. This reduction of the amount of data was important since big sample sizes made input files too big. Still, the size limitation supposed, apart from a limitation on the number of orders, also one on the number of box sizes tested in the optimization (the ideal would be as many as possible). The way to work around this was to make use of an iterative approach. That is to say, the algorithm would find the best dimensions from the set inserted as input, and the process would be repeated for many different sets of dimensions, until it resulted in a solid conclusion.

The iterative process that was followed is explained below:

1. **Iteration 1**. Selects the best 5 from the original 13. Recommendation: *28*, *39*, *43*, *60*, *64*.
2. **Iteration 2**. Best 5 from the selection of Iteration 1 plus the 5 boxes initially proposed by the Company. Recommendation: *28*, *39*, *43*, *60*, *64*.
3. **Iteration 3**. Best 5 from the selection of Iteration 2 plus 10 sizes that encompassed popular box sizes in the industry. Recommendation: *b*, *39*, *43*, *60*, *64*.
4. **Iteration 4**. Best 5 from the selection of Iteration 3 plus 10 new sizes that were variations of the current 5 best (one larger and one smaller than each size). Recommendation: *b*, *39*, *43*, *60*, *64b*.
5. **Iteration 5**. Repetition of Iteration 4 without box *64b*, as the Company did not consider convenient a box that large. Recommendation: *b*, *39*, *43*, *60*, *64*.

2.2. Transportation Impact Analysis

Complementing the work done finding the optimal box dimensions, an analysis on the impact of the implementation of the BoxSizer and the reduction of box sizes was performed. This would take into account both the costs of shipping the boxes as well as their performance and utilization.

The transportation costs used in the analysis were determined from the approximately 20,000 orders in the sample that were shipped by various UPS services in the continental United States.

The shipping cost for each order was determined by using the shipping rate tables for all of the shipping methods [UPS19] as well as including the specific agreements between the carrier and the Company.

The cost to ship any order is determined in a shipping rate table by two factors: the destination zone of the order, and the maximum between the weight of the box and the *dimensional weight* (DIM weight), which is a virtual weight of the order. The dimensional weight, also called DIM weight, is calculated with the formula listed in Equation 3 below. The DIM factor is determined by the shipping method. It has an important effect on the shipping cost, and it is set by the major freight carriers, although it can be agreed by the company and the carrier [Pal16].

$$DimWeight \approx \frac{BoxVolume}{DimFactor} \tag{3}$$

The process followed with VBA for the calculations in this analysis is summarized below. The code can be examined in the Appendix, section A.2.

1. First, the shipping code was determined from the order data. This shipping code refers to a specific state or area, and a shipping method: next day air, next day air early, next day air saver, second day air, second day air AM, three day select or ground. Each order was given a number from 1 to 7 meaning the method that its shipping code stated.
2. Then, the shipping "zone" was determined from a table that related the zip codes to the shipping methods. Having the shipping zones, the shipping price was easily found in the tables, where for each zone and each weight there is a fee.
3. In the next step, after having defined the box set in question (13 original ones, optimized set, or final proposed one), the code would make each order go into the box in which it would have the least void space, and the DIM weight and factor were calculated.
4. Having that, the results could be obtained by finding the total and average cost in each of the scenarios, so that the initial situation of 13 boxes could be compared to the solution proposed.

3. Results

3.1. Results From Optimization

As it has been explained, what was being introduced as an input was the box volume (in the form of a c_{ij}). Therefore, the final outputs from the algorithm were box volumes, but not their dimensions. This is of great importance, since once those optimal volumes were known, the dimensions *lwh* had to be defined. This was done attending to qualitative factors which were discussed with the NFDC managers. After a proposal of 5 boxes was made with their respective dimensions, the managers of the Company made some modifications to them according to qualitative factors, which would make them more feasible for the Distribution Center. These factors could be, for example, the stability of the box or negative experiences with certain sizes, as it was with the smaller ones.

The Company had the final selection of box sizes constructed, and in a last visit to the CD their performance was analyzed with real orders in order to check their validity and observe any type of defect or disadvantage. Finally, it was decided to use a set of 4 box dimensions, which included boxes from the optimization performed and also from the modifications proposed by the managers.

These last 4 proposed sizes eliminated one of the boxes because it was concluded with the CD managers that it would be redundant when used with the other 4. The 4 final sizes were *b4*, *3*, *4* and *64_2*. The final situation is detailed in Table 2.

	Size	L	W	H	BoxSizer H	Volume [in3]
Optimized	b	12.5	9	6.48	10.98	729
	39	15.13	15.13	8.25	15.82	1889
	43	21.88	17.13	11.6	20.20	4348
	60	24	20.25	18.75	19.75	9113
	64	24	20	20.88	21.88	10022
Recommendation	b4	14	11	12.5	13.5	1925
	3	17	15	11	18.5	2805
	4	24	20	12	13	5760
	64	24	20	21	22	10080

Table 2. Measures of the Optimized and the Final Set of Boxes Proposed

In consequence, the final recommendation ended up being a set of four boxes that had a background of both analytical and also empirical analysis, for what it is believed that the solution has a high reliability.

3.2. Results From Transportation Analysis

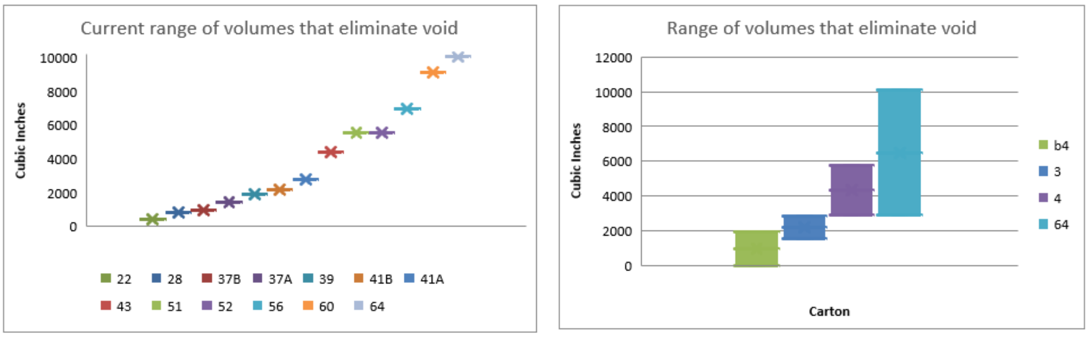
The analysis was carried upon the nearly 20,000 orders that had been shipped with UPS from the 64,000 sample. Three box sets were analyzed, the original one with 13 boxes, the result from the optimization, and the final proposal.

With the final set proposed, it was determined that the Northeast Florida Distribution Center would save approximately $2.35 per order. These important improvements are seen in Figure 3.

(a) Reduction in Average Dimensional Weight **(b)** Reduction in Average Cost per Order

Figure 3. Key Performance Indicators for Final Proposal

The significance of the final solution becomes even more apparent when the range of volumes that each box covers is graphed, which is depicted in Figure 4. These illustrations show that the void will be theoretically removed from every single order that is shipped, meaning they will always ship the minimum volume possible for every order [BBdLL+19]. In the first case, any gaps between the volumes of two consecutive box sizes indicate void in the box when it is shipped, meaning the box will potentially cost more to ship than it has to.



(a) Original 13 Boxes by Volume

(b) Final Four Proposed Sizes by Volume

Figure 4. Comparison of Ranges of Volumes Covered

It is easily understood by looking at Figure 4b, that the final solution is a notable achievement since, not only does it cover all ranges of volumes, but it also eliminates one box from the system, with all the operational and economic benefits that it bears.

It is important to note that the final set of boxes is a combination of the analytic efforts of the team and the recommendations from the NFDC, driven by their experience. This makes the solution even more solid, but due to its nature it should not be an optimal solution in quantitative terms, which is the sacrifice made in order to have operational benefits at the DC.

3.3. Cost Analysis

The economic analysis of the whole project had the purpose of putting it through a final test to see if, apart from the operational benefits that were going to take place, some major profits would be made. The costs and savings were split in three main areas: transportation, labor, and material. The savings for an annual timespan were obtained from a linear extrapolation to the annual number of orders: 1,571,124. The main parts of the analysis are summarized below:

- **Labor savings.** They represent the reduction in the number of employees that would result from the implementation of the BoxSizer. The purchase of the case erectors would have an important effect here. After discussing it with the NFDC managers, it was concluded that the labor in charge of box erecting could decrease by 3 workers, whereas the labor in charge of sealing the boxes would be reduced to one or two workers. Altogether, these changes would mean nearly \$400,000 in annual savings.

- **Box material savings.** Though it may seem surprising, the box material analysis determined that with the proposed solution of four boxes there would be more expenses on material. This can be explained by the fact that the finally proposed box sizes were proportionally more expensive than the original 13 set. The result was an additional cost of nearly \$9,000 in the sample of 64,000 orders, meaning around \$200,000 annually.

- **Void filling savings.** The reduction in the amount of dunnage needed (that is, the air pillows put in the boxes that are not entirely full to make them more rigid, consistent) was also analyzed. In order to estimate the savings in void filling, the current percentage of void per box (18.8%) was compared with the one that was expected with the BoxSizer which was 0%. As this assumed liquid volumes, in order to be realistic, a factor of 10% was created to account for void in each box. With that considered, the void per box would go down to 8.8%, which resulted in savings of around \$120,000.

  Figure 5 shows the relation between costs and savings in each of the box making operations areas, for an order amount of 64,000.

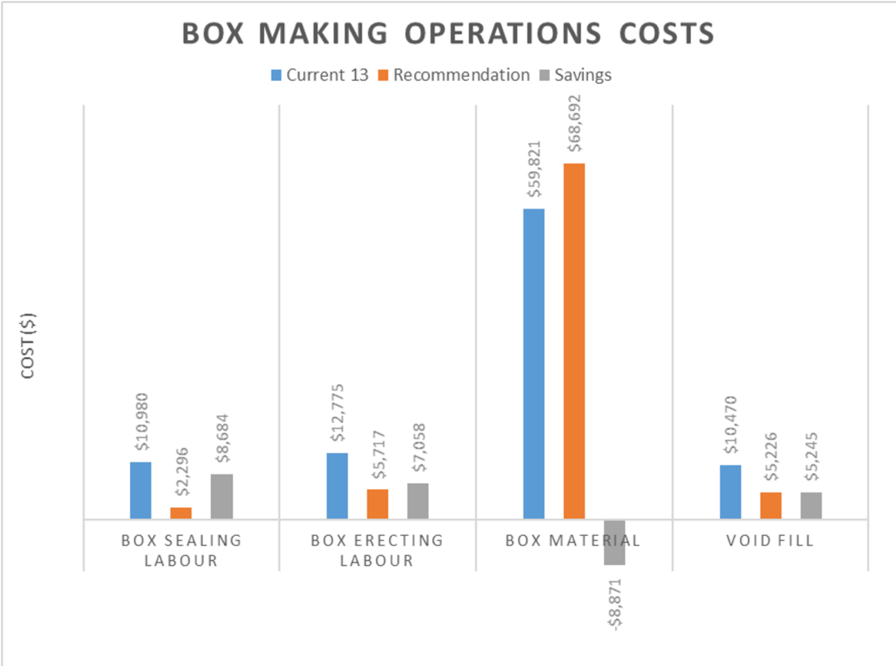


Figure 5. Cost Analysis of Box Making Operations

- **Transportation savings.** These were found in the Transportation Analysis and were $2.35 per order. For the rest of the orders, savings of $0.5 were assumed, meaning annual savings of nearly $170,000.

The results were put into an annual timespan, and a factor of 0.8 was applied to all the savings in order to be conservative. The results of the cost analysis, that is concluded with two figures relevant in these kind of projects [Jul01], are exposed in Table 3.

Investment	
4 case erectors	$318,000
2 BoxSizers	$1,145,000
Contingency (30%)	$500,000
Total	$1,963,000

Annual Savings	
Box Sealing Labour	$170,552
Box Erecting Labour	$138,609
Box Material	-$217,771
Void Fill	$102,997
Transportation	$1,349,717
Total	$1,544,105

PayBack (yr.)	1.27
ROI	79%

Table 3. Final Results From Economic Analysis

The annual savings were determined to be approximately $1.5 million and the Return On Investment, 79% [Mar16]. The Payback for the project is also calculated to find that the money invested would be recovered in nearly 1 year and 3 months.

4. Conclusions

It can be confidently affirmed that the exposed solution to the box dimension problem will have positive operational, economic and environmental effects. The BoxSizer will considerably speed up the final part of the order preparation process, thus eliminating a potential bottleneck, which will improve fluidity throughout the Distribution Center and end up positively affecting all areas of the DC.

The solution also has recognizable environmental benefits. It is hoped that any reduction in void within the boxes will translate directly to a reduction in waste. Currently, the distribution center uses air pillows to account for wasted space in the box, but after the BoxSizer is implemented, the air pillows will no longer be necessary. Not only will this result in cost savings, but also major environmental impacts from the reduction in use of plastic. The retail stores will no longer have to dispose of countless numbers of air pillows which ultimately end up in landfills [BBdLL+19].

The methodology used throughout this project has a major analytic component, but the consideration of factors that could not be put into an optimization model for their non-quantitative nature was always present. Also, the cooperation with the sponsors from the Company was highly productive, and together with the team's efforts, it made possible to complete the scope of the project exceeding the expectations.

The results of the 3 sections of the project are considered to be truly valuable. The optimization led to picking 4 box sizes which was an improvement of the initial objective which was to select 5. Furthermore, the optimization went through an iteration process and was later reinforced with the experience and empiric knowledge from the NFDC managers to make it more suitable for a DC and realistic. The transportation impact analysis showed that the implementation of the BoxSizer together with the reduction of boxes would have exceptional effects both economically and operationally. It found both an incredible amount of savings on the transportation side, but also important insights on the volumes covered by each box sizes set. Finally, for the cost analysis, the two figures obtained, a ROI of 79% and a Payback of 1.27 years are indicators of the investment being commendable.

It is believed that the team has given valuable recommendations and insights to the Company and the DC managers, from everything that was observed, analyzed and learned. It was always a concern to advice the managers on procedures with room for improvement. The Company found all the recommendations appropriate and highly constructive.

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PART I

PROJECT REPORT

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Acronyms

ICAI	Instituto Católico de Artes e Industrias
WMS	Warehouse Management Systems
SKU	Stock Keeping Unit
DIM	Dimensional Weight
JIT	Just-In-Time
DC	Distribution Center
NFDC	Northeast Florida Distribution Center
PTL	Put-To-Light
DTC	Direct-To-Consumer
RSC	Regular Slotted Carton
ROI	Return on Investment

Chapter 1

Introduction

DISTRIBUTION centers (DC) are places where efficient packaging and shipping processes can have a high impact on a firm's costs and warehouse operations. Therefore, an effort to optimize these procedures can mean not only savings but also a better performance at the facility.

This project was a Senior Design Project at the University of Florida, done collaboratively by a team composed of Gabriela Buraglia, Bianca Gallina, Pablo Barros de Lis, Kelsey Lecker, Kevin Ramos, and Connor Richardson. The sponsor of this project is an American fashion company, hereafter referred to as the Company[1]. It is specialized in luxury accessories and apparel, with retail and outlet stores in North America, Asia, and Europe. Some relevant figures can give an idea of its place in the business:

- Annual revenue of $4.22B
- 987 directly operated stores
- 13,500 employees

The problem presented in this project takes place in a distribution center of the Company, which supplies all the Company's stores and outlets in North America, Hawaii and other islands, as well as directly to customers. It will be referred to as Northeast Florida Distribution Center or NFDC.

1.1. Problem Statement

Currently, the Northeast Florida Distribution Center is using thirteen different box sizes for its outbound shipments. After the Warehouse Management System (WMS) determines what box size will suit each order, the packages are filled manually by the workers. Two main problems arise here; first, as the WMS logic is not completely precise, it only gives an estimation of the most appropriate box for an order. On the other hand, workers cannot afford to spend much time trying to rearrange items to ensure the entire order fits in the given size, so many times they will add an additional box in order to fit all the products. In other words, most orders are placed into boxes without considering space optimization and the optimal package sizes are not always used. As a result, large volumes of empty space are being shipped overall, meaning, as will be discussed later, unnecessary shipping and material costs [BBdLL+19].

[1]For confidentiality reasons, the Company prefers to remain anonymous.

To face this problem, the firm outsourced an analysis from a third-party (UPS) with the main objective of revealing the opportunities to improve their system and finding possible solutions [UPS17]. After examining the utilization of boxes and performing a cost analysis, they suggested reducing the number of boxes from 13 to a maximum of 5, together with the purchase of a BoxSizer, an automated carton system equipment that adjusts the size of a package to the height of the products inside, removing the empty space that would have been on top of it [Wesb]. A 3D model of the actual equipment in which the Company would invest is shown in Figure 1 [Wesa].

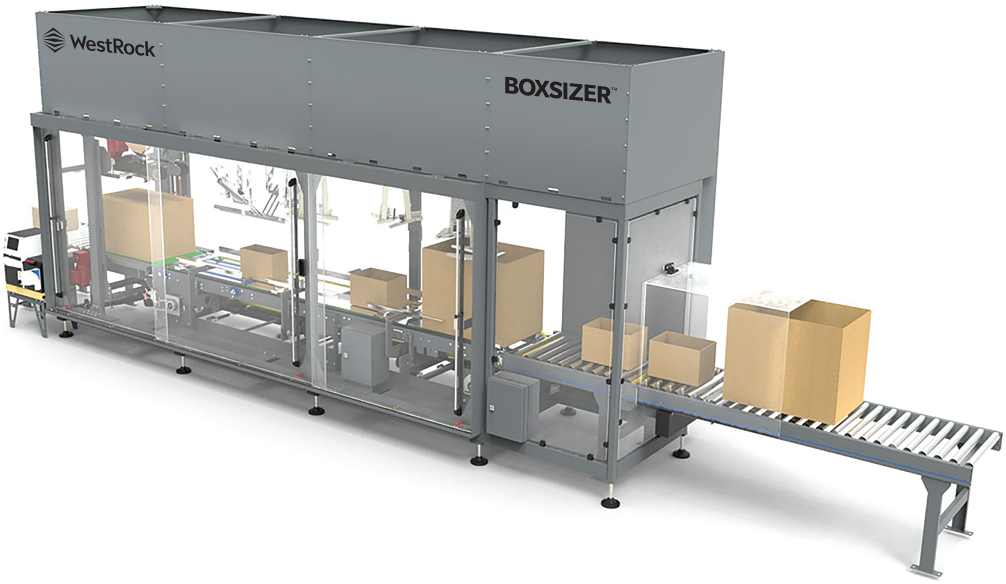


Figure 1. BoxSizer 3D Model

As for to comprehend its functioning, the process followed by the BoxSizer is illustrated in Figure 2 [Lin]. It is seen that it cuts down and closes the box introduced. Additionally, it seals the box as a last step.

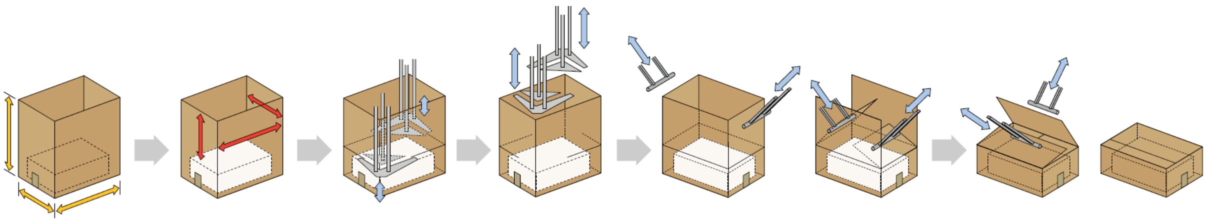


Figure 2. Void Eliminating Process With a BoxSizer

To complement the BoxSizer, the suggestion included also the purchase of case erectors, which would automate the process of building the box, that is, taking in the flat carton as it is received, and putting it in a box shape. It is also illustrated in Figure 3.

Figure 3. Case Erector Equipment

At a first look, this alternative would solve the stated problem, reducing both material and void spaces. However, the BoxSizer is limited to take in only 5 different box sizes in order to adapt their size. As, the DC is currently running 13, the dimensions of the new boxes should be determined, and it should be done in a way that the BoxSizer impact is maximized and costs are reduced as much as possible [BBdLL+19]. The Company has already proposed a set of 5 dimensions, but they were determined by making several assumptions, without a solid analysis supporting the election. Thus, in order to validate them, a holistic study will be carried with the objective of finding the optimal set of 5 or less box dimensions.

Together with the search for the optimal dimensions, the project will aim to support the implementation, through the study of its economic and operational feasibility. Due to the scope of the project, it will not only involve an analytical study, but also a physical side, as qualitative factors will be taken into consideration by using the insights from visiting the distribution center and also performing tests on-site.

1.2. The Northeast Florida Distribution Center (NFDC)

The Northeast Florida Distribution Center (NFDC) is where all the processes described in the project take place, and with a previous introduction, all the processes described later will be better understood. It is important to comprehend the basic functioning at the Distribution Center, and how most of the orders are prepared and shipped. The DC is provided with finished products that are ready to be shipped, that is, no fabrication takes place at the DC, only minor alterations to products or customizations.

Most of the orders at the NFDC are prepared at the put-to-light station, where the products are placed in the boxes. This is divided in two parts. On one side, a warehouse worker with a radio frequency scanner scans a carton coming from the warehouse supplier. Then, the warehouse management system (WMS) might direct the warehouse worker to place the different stock keeping units (a code that represents one, unique product line [Jam19], used to refer to specific products) in different cells. Each cell will end up being filled with one individual order. When the warehouse worker has selected the cartons/containers and confirms the selection via the radio frequency scanner or voice pick to the warehouse management system, the WMS will illuminate the light of the cell showing the order is ready to be placed in a box and the carton size that it should be put into. That is when the other side comes into play. The warehouse worker on the other side takes the products from the cell and places them in a box of the indicated size and confirms the put by pressing the button on the display [Pat08].

After the put-to-light stage, the boxes are sent through a conveyor to the shipping area, where they will be placed into trucks and finally distributed.

One last thing that will play an important roll is the way that the WMS decides what box size should be selected to take each order. This algorithm, called cartonization logic, checks the boxes from smaller to larger, to see which would be the smallest one in which the order would fit. There is a problem here. It uses the liquid volume of the order (composed by the sum of the volumes of the products), and the products are not at all liquid. Their shape and rigidity can vary in wide ranges. Thus, the box selected is not always suitable for the order, sometimes it is too small and 2 boxes are needed, others a big amount of empty space is left in the box.

A last factor in the process concerning the project discussion is the human factor, a crucial element in order picking in distribution centers, which is often disregarded [GGN15]. Not only is the WMS creating a non optimal situation, but also, the workers place the products in the boxes as quickly as possible. In a DC, time is gold and there is no time to think of a way to place the products in the box so that more can fit in, and they are placed without following any strategy. This results in another situation where more than one box has to take the products that were meant for only one.

Chapter 2

State of the Art

THE motivation behind this project stems from the trade-off between two different situations. The first one would be to have as many box sizes as needed so that there is a box size for every product, fitting them perfectly, thus minimizing material use, transportation costs and warehouse space, although operationally it would be unmanageable. On the other hand, having only one box size to take all products would minimize box inventory, handling, and purchasing costs [Wil65], but there would always be a large amount of empty space in the box. Both options represent opposite answers to the same problem and as in many other situations, the way to arrive to the optimal solution will be achieved by finding the correct balance. In this project, the optimal solution to the problem will ideally yield five or less optimal box sizes to be used for shipping purposes as it has previously been established by the company.

As can be expected, many other companies have also explored solutions to this issue. The examples that follow can be useful to illustrate some of the paths that a distribution center can take.

Corporate Express Ltd., one of the world's largest B2B suppliers of office equipment, experienced many orders that were smaller than their current box sizes. They introduced two new boxes that would fit the product dimensions closer and reduce wasted packaging space and unnecessary corrugate use [PR 08].

Staples explored a solution, by implementing "smart-size packaging", in which employees customized the box sizes for its shipments [Clo12]. They found this solution resulted in increased operational efficiency and a reduction in transportation costs by enabling them to fit more shipments per truck. They also employed just-in-time packaging, which could be incorporated in the approach of the present problem. JIT packaging reduces costs and warehouse space from storing large inventory of delivery boxes [BBdLL+19].

Mason Companies also developed a solution for a similar problem where they focused on the difference between paying for shipping based on dimensional weight (DIM) versus actual weight [Moh17]. Dimensional weight pricing calculates costs based on package volume divided by a certain DIM factor (this will be treated and explained later). They identified that under this pricing structure shipping packages with large amounts of empty space was unnecessarily increasing their shipping costs. Their solution was to implement box sizing that would fit the product exactly. By reducing empty space in shipping packages, they were also able to see cost savings in elimination of dunnage and fitting more orders per truck load [BBdLL+19].

In addition to these warehouse management cases, it is also of relevance to examine the research done on the optimization of box dimensions. In a very instructive paper by Jan Brinker and Ibrahim Gunduz Halil, a p-median approach is applied to find a specified number of optimal, demand-related packaging sizes, given the set of orders and the set of packaging sizes [BG16]. What is being analyzed there is a very similar optimization problem to the one presented in the present project. This last paper not only covers the minimization of void in the boxes, but it also includes a range of 12 different basic packing strategies in its algorithm. The simplified algorithm they use to find volumetric efficiency with each packaging criteria is shown in Figure 4, which is the previous step before they do the minimization of void.

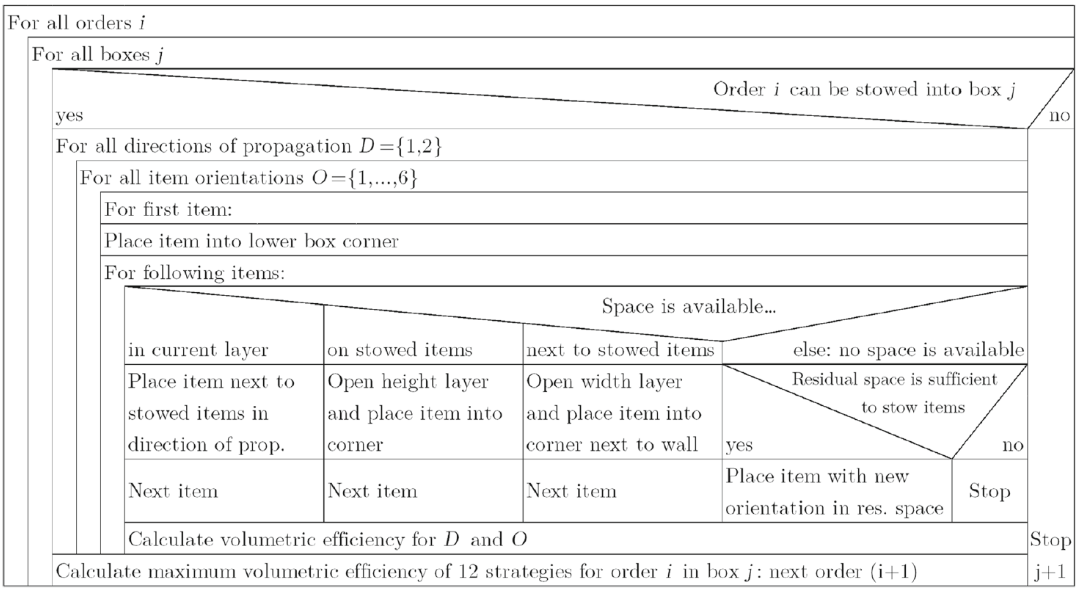


Figure 4. Simplified Procedure of the Packaging Algorithm

It is a tremendously interesting approach to the problem, but in the analysis here performed, these strategies were not looked at, since the Company did not consider it would be beneficial. However, as it would be discussed later, the team considered these strategies to be extremely important.

Chapter 3

Description of the Developed Model

THE problem in question involves a highly extensive list of factors, from which it will be important to distill the ones that will end up building the solving strategy. As most of the action takes place in a DC, there will be apart from quantitative measures and data, many factors coming from DC managers' opinions and experience, or others coming from tests performed at the workplace.

As it has already been mentioned, the Company asked for a set of 5 (or less) package dimensions that would be optimal for the DC activity. The initial plan included the acquisition of 4 case erectors and 2 BoxSizers which can only take in a maximum of 5 different box sizes.

Together with the search for optimal new box dimensions, the Company expects to receive an analysis of the implementation of the new equipment, including research on the impact on the transportation side, an economic justification of the project and all sort of pertinent recommendations. These objectives will specifically be defined in the section that follows.

3.1. Project Objectives and Specification

Throughout the past explanations the environment of the project has been depicted and some of its objectives outlined. Next, they will be specified. The principal goal of the project is comprised by two main sections. The first, to determine 5 (or less) new box dimensions that will substitute the existing 13 and will be needed when the BoxSizer starts running. The second one consists in supporting the whole implementation of the equipment, ranging from justifying it from the operational and economic points of view, to providing all kind of insights for a successful procedure.

In order to accomplish all the above mentioned, the action will be split into three different analysis that will be carried out. So as to be able to detail them thoroughly, a chapter will be dedicated to each of them.

3.1.1. Study on the Dimensions of the New Boxes

First of all, the new dimensions of the boxes have to be determined. The importance of this step is worth considering, since every product that the Company distributes to the area of America (their largest market) will be packed in these boxes. This means that if the package size is not efficient, there will be void space in the packages, leading to higher costs in transportation. This increase in costs not only comes from paying for empty space in the trucks, but also because each box is bigger than it should, meaning that the carrier will charge more per package (this is due to DIM pricing, which will be explained in chapter 5).

This study aims to be developed analytically, that means, through numerical methods. However, numerous qualitative factors affecting the election will arise. Thus, a balance will need to take place. This will be further discussed in chapter 4.

3.1.2. Analysis on Transportation Impact

This analysis was also asked by the sponsor. The transportation department of the DC is the area that will experience the most all the changes that will be taking place. The savings in which the investment should eventually result, will mostly take place there. Therefore, once the optimal 5 dimensions are found, a deep analysis will be conducted on the transportation side. The new set will be compared with the original one (13 box sizes), and also with those 5 dimensions that the Company initially proposed.

3.1.3. Cost Analysis

Finally, in a cost analysis, all the effects of the implementation will be taken into consideration. Hence, it will be the decisive test to justify the project for the Company. To perform the analysis, the results from the two previous sections will be the used, together with past data from the company.

3.2. Data

Over the course of the project, the Company provided all the data sets they considered relevant as well as the ones that were requested. As it has been repeatedly said, in addition to these documents and the ones coming from other sources, all the insights from the visits to the DC, managers' recommendations and non-measurable considerations will be regarded. The main data sets used throughout this project are summarized below:

- **Order history.** The Company provided a data set with 224,243 orders from a recent period of time. It included many important details, especially the ones concerning the volume of the product being shipped or the size of the box being used. These were crucial for the optimization that would take place later, explained in chapter 4.

- **UPS shipping rates.** The rates that the carrier charges for shipping are necessary to calculate the impact on transportation and doing the cost analysis. This data set is organized in spreadsheets, in which there is a shipping fee for every package weight (lbs.) and zone of destination, and it has been provided by the Company [UPS19].

  A key factor in this data set is its irregularity, since there is no linear correlation between weight and fee. In addition, the Company has a few specific agreements with the carrier that are not included in the above data set. This was handed in a separate text document which explains the characteristics that a package should have in order to apply for those custom conditions [TU]. The most relevant one rewards small packages, by giving an increased DIM factor to packages under 5184 cubic inches (1 cubic foot), resulting in a smaller DIM weight, hence a smaller fee (terminology explained in chapter 5). In spite of the mentioned irregularities, they were all included in the calculations for the transportation analysis of chapter 5.

- **Previous analysis.** Two analysis performed prior to this project were of great use:

- UPS On-Site Assessment [UPS17]. This document, mentioned earlier in chapter 1, is the report from the analysis conducted by UPS in order to find possible solutions to the high costs that the Company had. Here, UPS draws the conclusion of reducing the number of package sizes. Therefore, many of the results they obtain in the process were very valuable to the present project.
- Original cost analysis. The Company had already performed the cost analysis for the 5 dimensions they proposed. Although those dimensions will have nothing to do with the analysis performed in this project, it will be the foundation for the economic study that will be done in chapter 6.

3.3. Assumptions

In order to clearly define the project scope a number of assumptions were created regarding the logic behind how boxes are packed, picked, and shipped. An assumption was that demand would be steady and that in the future there would not be drastic alterations. Also, it was supposed that the size of the SKUs would not vary excessively either in their sizes, as the calculations were done with the existing ones.

In the put-to-light station, ideal conditions were assumed to be able to model the problem. All sizes of cartons are normally cycling through the PTL station for workers to match orders to their precalculated carton size. However, sometimes specific carton sizes (usually the sizes used the least) are not passing through put-to-light at the specific time workers are completing an order. The worker then has to retrieve the right carton or use an inefficient size which causes time and material losses. These losses were neglected by assuming that all cartons are equally available and at the exact moment a worker needs it. In other words, it was assumed that there are no inefficiencies or differences in time for retrieving the correct size to satisfy a put-to-light order [BBdLL+19].

Additionally, it was assumed that packing strategies or methods were homogeneous. Two different orders of the same volume will be packed identically from a labor standpoint, and two different orders of different volumes will require the same amount of labor and packing rate (this addresses the fact that larger boxes will inherently require more packing). That is, if two smaller box sizes were used to replace an order meant for just one larger sized box (assuming the smaller sized boxes can hold half the volume of the larger box), both scenarios will have the same rate for items packed per second. However, it is important to note that such an approach should not necessarily be chosen as two smaller boxes will require two stages of sealing, scanning, and sizing, as well as an increase in material usage (and cost). Since the top priority for associates is performance, as it was explained in chapter 1, it was assumed that packers do not neatly organize the contents of each box. Due to this fact, it can be assured that the human element allocated to packing is uniform [BBdLL+19].

When designing the optimization model, several assumptions were needed. The data used was taken from P05 and P06 (two periods near the holiday season). It is assumed that these periods will provide a good representation of all order channels that the Company covers, that is, DTC, wholesale, retail, and outlet. Also, in the actual model the suppositions were: all orders were supposed to be placed in exactly one box, every order was accounted for, and the volume of the items were liquid [BBdLL+19].

In the transportation impact analysis, it was also assumed that every order would be packed into one box, like in the optimization. Moreover, it is assumed that the conclusions from the study of the cost reduction on the transportation side for only one freight carrier (UPS) will apply to the other carriers too.

In the cost analysis, a factor of 10% was set for the void rate in each box, which would allow for tolerances in the results. Also, a final a factor of 0.8 was applied to the savings in order to be conservative, and a contingency of 30% was included. A last assumption was the linear escalation from the savings (from a 64,000 order sample) to the quantity equivalent to an annual timespan.

Chapter 4

Optimal Box Dimensions Analysis

FIRST of all, the starting point should be made clear. Currently, the Northeast Florida Distribution Center runs 13 different box sizes, displayed in Table 1.

Current Carton	Units/Yr	% Usage of TTL RSC
22	195,184	12%
28	117,548	7%
37A	106,231	7%
37B	73,268	5%
39	107,194	7%
41A	137,525	9%
41B	124,035	8%
43	147,457	9%
51	28,453	2%
52	42,041	3%
56	58,627	4%
60	144,032	9%
64	289,529	18%

Table 1. Current 13 Boxes at the NFDC

At the current stage, the NFDC is experiencing very high shipping costs on their ground, air, and water shipments due to the current dimensions of their packaging as well as the logic behind how packaging is selected for an order. Inefficient packaging leading to void spaces in the packages is one of the first reasons to look at. Figure 5 below shows data from the UPS analysis [UPS17], depicting current volumetric efficiency of each box by box size, that is, the percentage of space that is occupied by the products in each package that the DC is shipping. This comes from observing 126,092 orders.

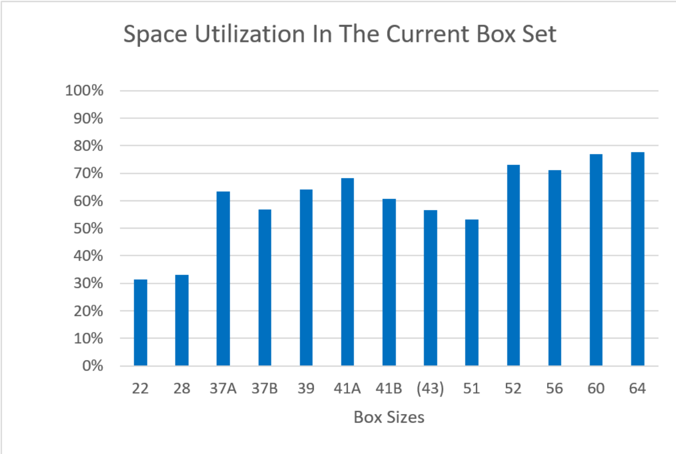


Figure 5. Space Utilization in the Current 13 Boxes

It is clear from the utilization measures in Figure 5 that there is a significant opportunity for improvement. From this point, a solution that improves the current situation will be pursued, but first, the strategy with which the problem will be faced will be defined in the next section.

4.1. Maximizing Box Utilization vs. Minimizing Shipping Costs

The first aspect to focus on is to fully understand whether the model should maximize box utilization or minimize shipping costs. These are the two main aspects to examine. Optimizing purely around box utilization would logically lead to selecting box sizes that cover every possible range of order volumes. Rather than requiring a large number of different boxes to cover every possible range of order volumes, the BoxSizer that the NFDC purchased allows a box to be cut down so that one box can cover a range of possible volumes. Then, a group of box sizes could be selected that it could cover *every* possible range of order volumes. Therefore, by properly selecting 5 box sizes that cover every possible order volume, box utilization would significantly improve. Box utilization, however, does not always lead to a reduction in shipping cost due to a few exceptions where it is cheaper to ship an order in a larger box [BBdLL+19]. This is where the distinction between box utilization and shipping cost comes into play.

In order to tackle these exceptions, it would be logical build a linear program to take into account the exceptions as constraints while determining optimal box sizes that covered the entire range of order volumes. On the other hand, rate shopping (comparing and understanding the different rates) is a difficult and tedious process, especially because the shipping rates are not necessarily linear [BBdLL+19]. Therefore, that will not be the focus of the project, and the main target will be to find the set of dimensions that minimizes the amount of void space in the orders. It is, however, recommended that the company looks further into these factors and different possible approaches in the future.

4.2. Data Management

The first step in creating the optimization model included organizing the data and calculating the fraction of void in each order. In order to perform the analysis, a set of information with real orders was provided by the Company. The data provided included a spreadsheet of 224,243 orders with the following details: Carton Number, Pick-ticket, Unit Volume, Packed Units, Carton Size, Carton Volume, Actual Weight, Zip, and Ship Via. While Actual Weight, Zip, and Ship Via were not necessary for the optimization, they were useful when looking into transportation impacts, discussed in chapter 5. A sample of a few orders can be seen in Table 2, which gives an idea of what the initial input looked like.

Ship Date	Carton #	Pickticket	Carton Volume	Carton Size	Actual Weight	Ship Via	Unit Weight	Unit Volume	Packed Units
CHSHDT	CHCASN	CHPCTL	CHCTVL	CHCRSZ	CHACWT	CHSVIA	CDUNWT	CDUNVL	CDPAKU
20180904	00000923031858508341	A021573250	2758.92	41A	3.73	UPZG	2.03	1355.47	1
20180904	00000923031858508686	A021573588	816.15625	28	1.72	UPZG	1.35	514.29	1
20180904	00000923031858595525	A021574842	1888.56442	39	3.6	UPZG	2.6	1783.28	1
20180904	00000923031858591886	A021575283	428.21	22	0.94	UPZG	0.57	107.38	1
20180904	00000923031858591985	A021575366	1888.56442	39	3.8	UPZG	2.95	1774.08	1
20180904	00000923031858514328	A021573377	10022.4	64	7.68	UP01	1.32	1530.9	1
20180904	00000923031858514328	A021573377	10022.4	64	7.68	UP01	1.06	336	1
20180904	00000923031858514328	A021573377	10022.4	64	7.68	UP01	0.7	230	1
20180904	00000923031858322046	A021569381	428.20312	22	0.44	UPFG	0.068	3.19	1
20180904	00000923031858323456	A021569826	1888.56442	39	5.02	UPFG	1.3	351.36	1
20180904	00000923031858323456	A021569826	1888.56442	39	5.02	UPFG	2.5	1339.464	1

Table 2. Sample Orders From the Initial Data Set

As Table 2 depicts, each row is not an individual order. Instead, a row is one kind of product (SKU) going into an order. To see each order, one has to look at the Pick-ticket or the Carton Number. All the lines with the same Pick-ticket/Carton Number mean an individual order, and all the products in that order will be packed in the same box. Thus, it will be needed to group each order into one single piece of information, to be able to keep going with the analysis. That is the motivation for using Microsoft Access. After the data was imported from Microsoft Excel into Access, a select query was designed to pick: Carton Number, Pick-ticket, "Order Volume", Carton Size, Carton Volume, Actual Weight, Zip and Ship Via. The "Order Volume" was determined by the expression in Equation 1:

$$Order\,Volume = \sum(Unit\,Volume \times Packed\,Units) \tag{1}$$

This allows to get a realized volume for each order, which is what will actually be useful. The organization in Access was vital to group the carton numbers and pick-tickets together, and when this process was complete, the data was exported back into MS Excel.

Once the data was in Excel again, in order to sort them randomly, a random value was generated for each order and then these values were sorted from smallest to largest.

4.3. Building the Model

After having the data necessary for the optimization, a model was built in accordance with the conclusions drawn from the discussion in section 4.1, resulting in an optimization based on the minimization of the empty spaces in the boxes. As it was explained in the State of the Art, our approach was inspired by the p-median problem which, although it is meant for problems of minimization of distances between demand and facilities, was thought to be useful in our case [DM15]. The final model used in the project was a linear program that, for a set of orders $i \in O$ that can be packed in boxes $j \in B$, takes their percentage of empty space c_{ij} and minimizes it so that it selects only one box size for each order by giving a binary value to x_{ij}, that represents the box size j used for order i. This has to be done with a restriction on the number of box sizes that can be used, s.

The key to understand this is that, for each order only one box size can be selected (binary x_{ij}), and only a finite number of box sizes (s) can be used in total. In other words, the program is being forced, not to choose the best box for each order (it would be the one with smallest c_{ij} and all box sizes would end up being chosen, breaking the restriction on the number of possible boxes s), but the box sizes that *overall* end up yielding the smallest total empty space. This means that for some orders, a box with a c_{ij} that is not the smallest for that order could be selected because it compensates this loss in other orders where it has very low c_{ij}'s. The output is given by the binary variable y_j, that will take a "1" for each of the final box sizes from set B that are selected. The model is outlined in Figure 6 [BBdLL+19] in algebraic terms:

Objective:		
Minimize total void in the orders	$min \quad \sum_{i \in O} \sum_{j \epsilon B} cij * xij$	
Subject to:		
All orders are placed in exactly one box	$\sum_{j \epsilon B} xij = 1$	$\forall i \epsilon O$
At most s boxes are selected (4 or 5)	$\sum_{j \epsilon B} yj = s$	
A box that is not selected (y_j=0) cannot take orders	$\sum_{i \epsilon O} xij \leq Myj$	$\forall j \epsilon B$
All x_{ij} and y_j variables are binary	$xij, yj \, \epsilon \, \{0,1\}$	

Figure 6. Optimization Model in Algebraic Form

Where:

- O is the set of all orders considered
- B is the set of all potential box sizes
- c_{ij} is the amount of empty space in box j when allocated with order i
- s is the fixed number of boxes
- M is an arbitrary large constant

The equation used to find the empty space in each box is included in Equation 2.

$$c_{ij} = 1 - \frac{volume\,of\,order\,i}{volume\,of\,box\,j} \tag{2}$$

This optimization opens the door to testing fictitious box sizes, since for a hypothetical box of dimensions *lwh*, after finding its volume, the amount of empty space that it would have with a *real* order would be easily calculated with the stated equation. This will be key for the interest of the project.

Within Excel, VBA was utilized to calculate the fraction of void c_{ij} that every order would have in each of the box sizes tested whichever they were (the sets of box dimensions tested are explained later). The Visual Basic code used to calculate the c_{ij}'s is included in the Appendix, subsection A.1.1. Once the c_{ij}'s were determined, the values were copied to a separate table to be applied in the optimization. A sample of c_{ij}'s is shown in Table 3, with the orders on the rows and the void spaces of the boxes under examination on the columns, showing the amount of void they would have for each specific order.

	Cij 1	Cij 2	Cij 3	Cij 4	Cij 5	Cij 6	Cij 7	Cij 8	Cij 9	Cij 10	Cij 11	Cij 12	Cij 13
Order 54278	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.042	0.129
Order 54279	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.333	0.351	0.472	0.583	0.681	0.710
Order 54280	0.992	0.996	0.997	0.998	0.998	0.998	0.999	0.999	0.999	0.999	1.000	1.000	1.000
Order 54281	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.042	0.129
Order 54282	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.166	0.362	0.419
Order 54283	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.304	0.323	0.449	0.565	0.667	0.697
Order 54284	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.123	0.306	0.469	0.517
Order 54285	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.076	0.159
Order 54286	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	0.167	0.243
Order 54287	5.000	5.000	5.000	5.000	5.000	5.000	0.099	0.430	0.446	0.549	0.644	0.727	0.752
Order 54288	0.636	0.809	0.841	0.890	0.917	0.928	0.943	0.964	0.965	0.972	0.978	0.983	0.984
Order 54289	5.000	5.000	5.000	5.000	5.000	5.000	0.099	0.430	0.446	0.549	0.644	0.727	0.752

Table 3. Sample VBA Output of c_{ij}'s Calculation

Whenever an order could not fit in the box size (*volume of order i > volume of box j*), the c_{ij} resulted negative, so it would be changed to a value of "5" to reinforce the (minimization) model to *not* pick that size for that particular order. If the model selected that box, it would be strongly penalizing the objective value.

4.4. Implementation

After having gathered the necessary data and having constructed an optimization model the next step was to put it into action, for which it was necessary to select the appropriate input data (not only the orders, but also the set of box dimensions) and the software that would employ it.

First, this was attempted in Microsoft Excel using the tool *Solver*. However, the boundaries were far too small than what the optimization required [Fro12]. The problem with the optimization model designed was that had it a huge number of variables, and constraints over them. The Solver within Excel could not handle the model but with very few orders. With an illustrative purpose, an execution of the model in Excel is included in the Appendix, chapter B, where it is seen how the boxes selected do not have the least void space for each order, but they lead to the minimum total void.

As a consequence of the problems with Excel, a stronger optimization software had to be used. In the next step, it was attempted with the algebraic modeling program GAMS. The code had to be developed for this new software. It is included in the Appendix, subsection A.1.2, in a sample of 431 orders. Although this sample has merely an explanatory purpose, the size of the sample depended on the input file, thus the code stayed the same with bigger samples.

As the full version could not be obtained, and without a license to the software, still only insignificant samples of data could be used [GAM]. In order to find a solution to the size problems, a software capable of handling the amount data in question had to be found.

The software that finally met the requirements of the project was NEOS. NEOS is a free online numerical optimization solver with access to over 60 solvers [NEO]. This way, the code that had been designed in GAMS could be uploaded to NEOS which would report an output. To upload a model or the input data, it would let the user enter local files and put them into a web form [GM97].

As NEOS offered different options for solvers, it had to be discussed which one was to be used. Bernhard Meindl and Matthias Templ found that commercial solvers outperform open source solvers when applied to real-world scaled problem sizes. Among those tested, CPLEX displayed the best performance with respect to running times even outperforming other commercial solvers such as GUROBI [MT13]. Since size was one of the largest roadblocks, the decision was to use the CPLEX solver on the mixed-integer linear program [BBdLL+19].

NEOS took in a GAMS code, but the way to import the input file (the table with the c_{ij}'s) was through a file in .gdx format (GAMS Data eXchange). GAMS generates this file whilst executing, from any data that is given to it from a different source. Therefore, every time that NEOS was run, GAMS had to be previously used to generate the appropriate .gdx file of the data being used. The code used in NEOS is also included in the Appendix, subsection A.1.3.

NEOS made it possible to use much bigger samples of data, but still it had a limit of 3GB of RAM for solving problems and a limit of 16 MB for input files. That 16 MB limit for input files restricted the possibility of making an input of all the orders and thousands of possible box sizes, which would have been the ideal situation.

Furthermore, in an initial optimization with NEOS, the sample exceeded the 16 MB limit for input files in NEOS. Therefore, apart from a limitation on the number of orders, it was also on the number of box sizes tested in the optimization. Therefore, a sample size calculator was used to determine how many orders were needed to generate a high confidence interval. From the 224,243 orders, a sample 64,000 of these orders generated a confidence interval of $99\% \pm 0.431054\%$, which is depicted in Figure 7 [Sur]. Those 64,000 were taken from relevant periods of the data, for example, including the periods with seasonal peak volume of orders (e.g. Black Friday).

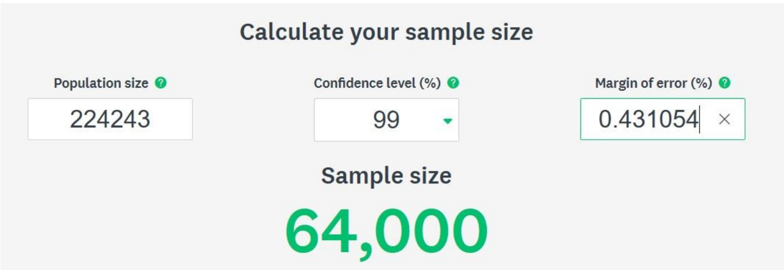


Figure 7. Confidence Interval

It was understood that due to the size limitations, an only optimization giving us the final results would not be possible. The way to work around this was to make use of an iterative approach. That is to say, the algorithm would find the best dimensions from the set inserted as input, and the process would be repeated for many different sets of dimensions, until it resulted in a solid conclusion.

For each of these iterations, all the steps described previously had to be performed. They can be summarized in:

1. Selecting the boxes that will be tested in the iteration, existing or fictitious.
2. Calculating (through Excel VBA) the c_{ij}'s for those boxes. This means, calculating the void spaces that these boxes would have, in order to give it as an input to the algorithm.
3. Running the program in GAMS, not to get results but to generate the .gdx file of the c_{ij} data.
4. Finally, upload the code and the .gdx file to NEOS and around 30 minutes later the output would be received.

Each of the iterations yielded a set of optimal boxes from the ones that had been inserted as input. This was obtained from variable "Y", depicted in Figure 8a. On the other hand, a value for

x_{ij} was given for each of the boxes and each of the boxes, of which the output from NEOS is shown in Figure 8b.

```
                          LOWER     LEVEL     UPPER    MARGINAL

---- VAR emptyspace        -INF  19737.262     +INF       .

---- VAR Y

      LOWER     LEVEL     UPPER    MARGINAL

1       .         .       1.000      EPS
2       .       1.000     1.000      EPS
3       .         .       1.000      EPS
4       .         .       1.000      EPS
5       .         .       1.000      EPS
6       .         .       1.000      EPS
7       .         .       1.000      EPS
8       .         .       1.000      EPS
9       .         .       1.000      EPS
10      .         .       1.000      EPS
11      .         .       1.000      EPS
12      .       1.000     1.000      EPS
13      .       1.000     1.000      EPS
14      .       1.000     1.000      EPS
15      .       1.000     1.000      EPS
```

(a) Output of Variables "Y", "emptyspace"

```
4251 .6      .        .       1.000    5.000
4251 .7      .        .       1.000    5.000
4251 .8      .        .       1.000    5.000
4251 .9      .        .       1.000    5.000
4251 .10     .        .       1.000    0.154
4251 .11     .        .       1.000    5.000
4251 .12     .        .       1.000    5.000
4251 .13     .        .       1.000    5.000
4251 .14     .      1.000     1.000    0.084
4251 .15     .        .       1.000    0.167
4252 .1      .        .       1.000    5.000
4252 .2      .        .       1.000    5.000
4252 .3      .        .       1.000    5.000
4252 .4      .        .       1.000    5.000
4252 .5      .        .       1.000    5.000
4252 .6      .        .       1.000    5.000
4252 .7      .        .       1.000    5.000
4252 .8      .        .       1.000    5.000
4252 .9      .        .       1.000    5.000
4252 .10     .        .       1.000    0.081
4252 .11     .        .       1.000    5.000
4252 .12     .        .       1.000    5.000
4252 .13     .        .       1.000    5.000
4252 .14     .      1.000     1.000    0.005
4252 .15     .        .       1.000    0.095
4253 .1      .        .       1.000    5.000
4253 .2      .        .       1.000    5.000
4253 .3      .        .       1.000    5.000
4253 .4      .        .       1.000    0.264
4253 .5      .        .       1.000    0.554
4253 .6      .        .       1.000    0.673
4253 .7      .        .       1.000    0.782
4253 .8      .        .       1.000    0.816
4253 .9      .        .       1.000    0.855
4253 .10     .        .       1.000    0.885
4253 .11     .        .       1.000    5.000
4253 .12     .      1.000     1.000    0.402
```

(b) Output of Variable x_{ij}

Figure 8. Fragments of the Output From the Iterations With NEOS

4.4.1. Iteration Process

The first step was to test that from the original 13 sizes all were selected by the model (with no box number constraint) and the same for the 5 originally proposed sizes. This was only to check that no size was bad enough to be taken away directly. The rest of the iterations are explained below:

1. In the first iteration, the set with the best 5 from the original 13 was determined. This would result in the 5 boxes of the current 13 that yield the least void space. Recommendation: *28*, *39*, *43*, *60*, *64*.

2. Then the resulting best 5 were taken and tested alongside the 5 originally proposed sizes by the Company. Those proposed sizes were chosen with only a qualitative perspective and therefore they did not perform well. The best 5 from the original 13 were still the best solution from this iteration. Recommendation: *28*, *39*, *43*, *60*, *64*.

3. For the third iteration, the last 5 were tested alongside 10 new sizes that encompassed popular box sizes in the industry and gave a full coverage of sizes. The best way to do the optimization would have been to use as many possible box sizes as possible, but due to the file sizes it could not be done. In this iteration, 4 of the 5 previously deemed as best were still part of the solution, but the smallest size was replaced by one of the new sizes. Recommendation: *b*, *39*, *43*, *60*, *64*.

4. For the fourth iteration, the 5 best from the previous iteration were tested alongside 10 new sizes that were variations of the current 5 best (one larger and one smaller than each size). This resulted in 4 out of the previous 5 being chosen as part of the solution with the largest box being replaced by the bigger variation of itself. Recommendation: *b*, *39*, *43*, *60*, *64b*.

5. Since it had been understood that the Company did not want to pursue a box larger than the largest original box, one more iteration was made without this larger box, found optimal in the previous stage *64b*. This fifth and last iteration had the same results as iteration three. Recommendation: *b*, *39*, *43*, *60*, *64*.

A more visual representation of these steps is shown in Figure 9.

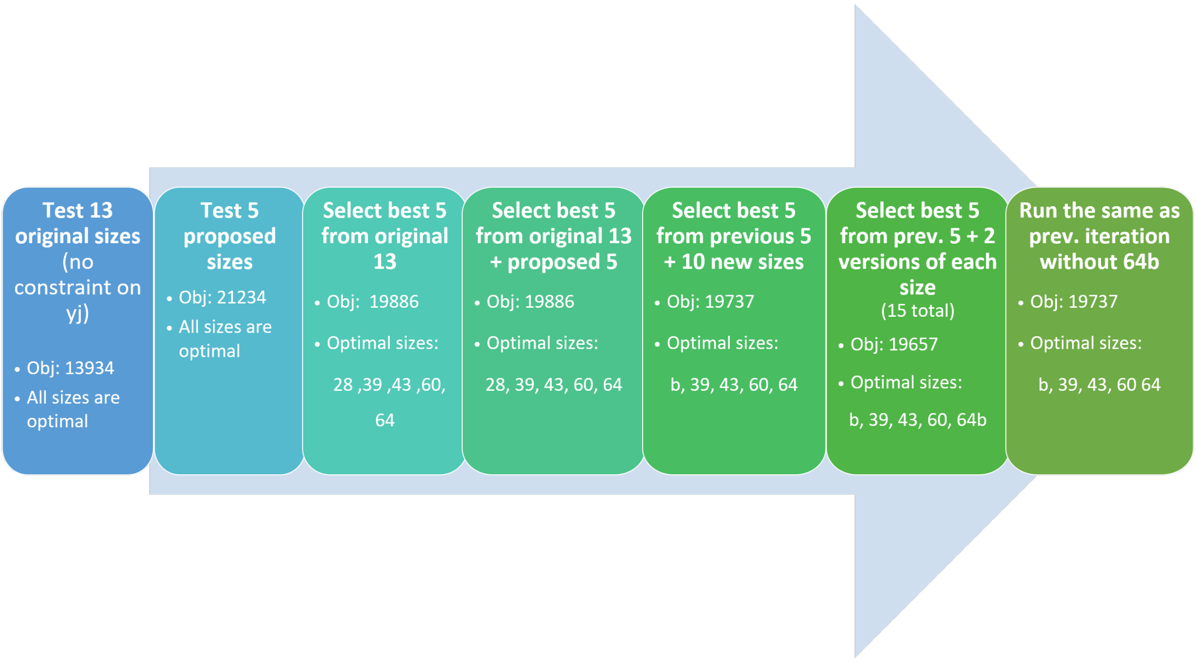


Figure 9. Iteration Process Diagram

4.5. Results

As it has been explained, what was being introduced as an input was the box volume (in the form of a c_{ij}). Therefore, the final outputs from the algorithm were box volumes, but not their dimensions. This is of great importance, since once those optimal volumes were known (*b*, *39*, *43*, *60*, *64*), the dimensions *lwh* had to be defined. This was done attending to qualitative factors which were discussed with the NFDC managers, and a set of 5 optimal boxes was proposed.

As a response from the Company and using their knowledge and experience on what dimensions could not be beneficial at the DC, they slightly modified the sizes that had been proposed, to make them more suitable for their use in real life. Changes could include making a box wider in order to make it more stable, for example. The optimization model was run with these sizes and although it yielded a worse objective value, the Company considered that some of these changes were necessary.

A final site visit was conducted where the final boxes proposed had been built in order to actually see them and test them at the DC. Actual orders were put in the original size (from the 13) they would go into, and also into the new size that would have fitted the order, in order to compare them. Also, other factors were noted, like the characteristic of the new boxes of not being stackable one into another, whereas the old ones could be nested perfectly. From various observations and together with the DC representatives, a final set of box dimensions was decided to be used. This included boxes from the optimization performed, and also sizes from modifications they had made.

When testing finished and after conducting further analysis, the final choice was to recommend 4 out of their lastly proposed 5 sizes because one size would yield in low utilization and was considered to be redundant when used with the other 4. The 4 final sizes were *b4*, *3*, *4*, *64_2* [BBdLL+19]. The final situation is detailed in Table 4, where the proposition of 5 box sizes resulted from the optimization is contrasted to the final set of 4 boxes.

	Size	L	W	H	BoxSizer H	Volume [in3]
Optimized	b	12.5	9	6.48	10.98	729
	39	15.13	15.13	8.25	15.82	1889
	43	21.88	17.13	11.6	20.20	4348
	60	24	20.25	18.75	19.75	9113
	64	24	20	20.88	21.88	10022
Recommendation	b4	14	11	12.5	13.5	1925
	3	17	15	11	18.5	2805
	4	24	20	12	13	5760
	64	24	20	21	22	10080

Table 4. Measures of the Optimized and the Final Set of Boxes Proposed

It is seen that the optimization results were not taken to the letter, and most of the dimensions changed. But the important part are not the dimensions but the volume, since that was what the optimization was calculating. The measures had been qualitatively selected afterwards, as it has been explained. What is concluded then is that two of the optimal dimensions from the optimization, *39* (adjusted to be *b4*) and *64*, were used in the final set of boxes. The other two boxes came mainly from the NFDC recommendations that were made as a feedback to the optimization results.

In consequence, the final recommendation ended up being a set of four boxes that had a background of both analytical and empirical analysis, for what it is believed that the solution has a high reliability.

4.5.1. Clarification: Height Nomenclature and Calculations

It may be noted that there is a column for BoxSizer height. Defining the height of the boxes was a confusing part. This is because one height was the one that the box had before going through the BoxSizer, but there was also a maximum height that the BoxSizer could cut to. This is set in order to avoid overlapping, which would occur when a box, after being cut the most of its height, would have its flaps going around the sides. There is also a minimum cut that the BoxSizer must do, so that the box has enough flaps to close.

In order to illustrate this problem, Figure 10 shows two images of the actual boxes taken during the testing at the DC. Figure 10a depicts the current kind of box used, a traditional box with built-in flaps. On the other hand, the new kind of box shown in Figure 10b would have no flaps from the beginning in order to have them defined once the box goes through the BoxSizer.

(a) Current Carton Type (RSC) **(b)** New Carton Type Suitable for BoxSizer

Figure 10. Carton Type Comparison

The maximum height (called watermark) was set according to Equation 3, which is the maximum cut that can be done before causing overlapping. In Table 4, the "BoxSizer H" is the height of the box before being cut at all. The height "H" is the watermark or minimum height the box can have.

$$Watermark = Height - \frac{min(L,W)}{2} \tag{3}$$

Finally, it is also seen in Table 4 that the biggest boxes or box *b4* do not follow the stated equation for the heights. This was because of the fact that large boxes would be too tall if they had the desired dimensions, since they would have a tremendous height "BoxSizer H" before being cut. On the other hand, too small boxes would have a similar problem but, in this case, for being too small. The solution to this was to make the largest and smallest sizes a different kind of box, using them with a lid. Having a lid stretches the range to heights they can be cut to. That way the "BoxSizer H" only has to go up by an inch, just to leave enough space for a proper collocation of the lid.

Chapter 5

Transportation Impact Analysis

COMPLEMENTING the work done finding the optimal box dimensions, an analysis on the impact that the implementation of the BoxSizer together with the reduction of box sizes would have was performed. This would take into account both the costs of shipping the boxes as well as their performance and utilization. For the study, the data used comprised the order history previously mentioned, the shipping rates set by the freight carrier and also the set of boxes under study, which were not only the original 13 that the DC had, but also the ones resulting from the optimization in chapter 4.

5.1. Determining the Shipping Rates

The transportation costs used in the analysis were determined from the approximately 20,000 orders in the sample that were shipped by various UPS services in the continental United States: next day air, next day air early, next day air saver, second day air, second day air AM, three day select, and ground. The shipping cost for each order was determined by the shipping rate tables for all the above shipping methods [UPS19] as well as including the specific agreements between the carrier and the Company. This big amount of data coming from different sources made it a laborious process to put together the rates.

The cost to ship any order is determined in a shipping rate table by two factors: the destination zone of the order, the method of shipment and the maximum between the actual weight of the order and the *dimensional weight* (DIM weight), which is a virtual weight of the order. The dimensional weight, also called DIM weight, is calculated with the formula listed in Equation 4 below using the dimensions of the shipping box and a DIM factor that is determined by the shipping method. This factor has an important effect on the shipping cost, and it is set by the major freight carriers (like UPS, FedEX), although it can be agreed by the company and the carrier [Pal16].

$$DimWeight \approx \frac{BoxVolume}{DimFactor} \tag{4}$$

As it has been said, in order to calculate the price for an order, the carrier will compare the DIM weight with the actual weight of the order. The larger of the two will be the weight which will be used in the shipping rate tables to determine the price. In the present case, the Company has some specific DIM factors for each of its shipping methods, which are shown in Table 5.

Shipping Method	Dim Factor
Ground (Volume ≤ 5184)	325
Ground(Volume > 5184)	250
Air	275
3 Day Select	300

Table 5. Dimensional Weight by Shipping Method

The most important insight from this pricing method is that one main goal should be to keep volumetric weight as close to gross weight as possible by packing efficiently [Ref17]. Many possibilities are considered by the companies in order to minimize the impact of this method apart from reducing the volume of the boxes, such as refusing to ship low-weight, high-volume goods, refusing to ship by air whenever possible, renegotiating the contract for a higher DIM factor, or using more than only one carrier [Ame15].

The NFDC Transportation Manager explained that most of the orders they shipped were charged for volumetric (DIM) weight rather than actual weight. Therefore, it was vital to fully comprehend the details of DIM pricing.

5.2. Calculations in Excel VBA

For each shipment, the cost was calculated from the zip code of the Northeast Florida Distribution Center to any zone in the continental United States (a "zone" refers to a range of zip codes). A shortened example of the shipping rate table for UPS Ground is listed in Table 6 below:

Zones	2	3	4	5	6	7	8	44**	45**	46**
1 Lbs.	$7.85	$8.65	$8.96	$9.36	$9.68	$9.80	$9.96	$30.24	$30.79	$39.84
2	8.65	9.48	10.15	10.37	10.82	11.24	11.43	33.64	34.45	43.23
3	8.87	9.89	10.70	11.14	11.59	11.98	12.57	36.56	39.27	46.04
4	9.13	10.05	11.24	11.75	12.08	12.87	13.47	40.14	41.84	49.93
5	9.37	10.41	11.67	12.27	12.80	13.46	14.22	43.52	45.42	53.12

Table 6. UPS Ground Shipping Rate Table

The process followed with VBA for the calculations in this analysis is summarized below. The code can be examined in the Appendix, section A.2.

1. First, the shipping code was determined from the order data (it is the "Ship Via" column). This shipping code refers to a shipping method from the ones shown before (next day air, next day air early, next day air saver, second day air, second day air AM, three day select, and ground), and specific states or areas. Each order was given a number from 1 to 7 meaning the method that its ship code stated. In Figure 11 below, it is illustrated how each code meant a specific method.

1	CODE	a	b	c	Destination
318	UPWS	PCL	UPSWWXPRV	UPWS	UPS Worldwide Express Saver
344	UPS3	PCL	UPS 3 DAY	UP03	UPS 3 Day SIG
346	UPSA	PCL	UPS 1 DAY		UPS Next Day AM SIG
347	UPS1	PCL	UPS 1 SVR	UP03	UPS Next Day PM SIG
348	UPFG	PCL	UPSGNDRESF	UPFG	UPS Ground Florida RES
349	UPFS	PCL	UPSGNDRESF	UPFG	UPS Ground Florida RES SIg
350	UPIG	PCL	UPSGNDRESI	UPIG	UPS Ground Illinois RES
351	UPIS	PCL	UPSGNDRESI	UPIS	UPS Ground Illinois RES SIG
352	UPNG	PCL	UPSGNDRESN	UPNG	UPS Ground New Jersey RES

Figure 11. Example of Shipping Codes and their Meaning

2. Then, the shipping "zone" was determined from a table that related the zip codes to the shipping methods (1-7).

3. Having the shipping zones, the shipping price was easily found in the tables, were for each zone and each weight there is a fee.

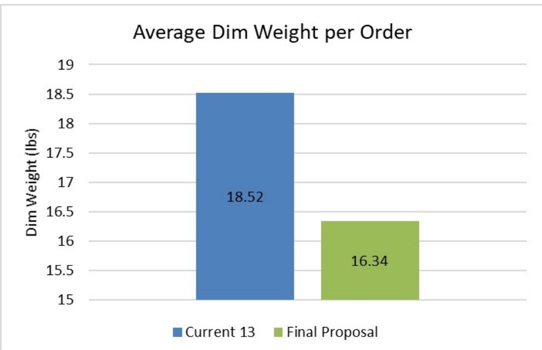
4. In the next step, after having defined the box set in question (13 original ones, optimized set, or final proposed one), the code would make each order go into the box in which it would leave the least void space, and the DIM weight and factor were calculated.

5. Having that, the results could be obtained by finding the total and average cost in each of the scenarios, so that the initial situation of 13 boxes could be compared to the solution proposed.

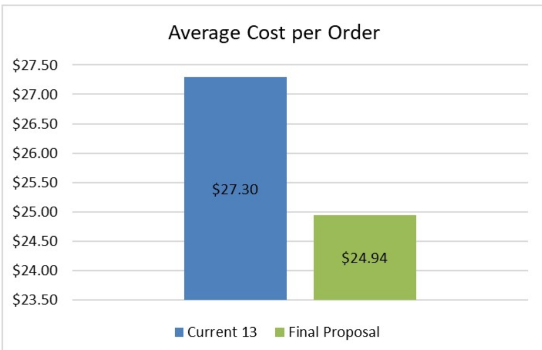
5.3. Results

From the set of 64,000 orders that were analyzed, as it has been already mentioned, around 20,000 were looked at in the transportation analysis. These orders were exposed to different scenarios. Firstly, the initial situation with 13 boxes, then the solution to the optimization resulting in 5 boxes, and finally the final proposal of 4 boxes. For each of the situations, the rates had to be recalculated, as the same orders would be placed in different boxes depending on which box set is being analyzed, hence changing the prices.

After comparing the shipping costs of the existing set of thirteen box sizes to the proposed four box sizes, it was determined that the Northeast Florida Distribution Center would save approximately \$2.35 per order. These important improvements are seen in Figure 12. In Figure 12a the improvements in means of average DIM weight per order are depicted, whereas in Figure 12b the average cost per order reduction is illustrated.



(a) Reduction in Average Dimensional Weight



(b) Reduction in Average Cost per Order

Figure 12. Key Performance Indicators for Final Proposal

The significance of the final solution becomes even more apparent when you separate it from the transportation savings and graph the range of volumes that each box covers, which is depicted in Figure 13, Figure 14, and Figure 15. These illustrations show that the void will be theoretically removed from every single order that is shipped, meaning they will always ship the minimum volume possible for every order [BBdLL+19]. In the first case, with the 13 initial boxes with no BoxSizer, their range of volume is fixed, for which Figure 13 has only crosses in the graph. Any gaps between the volumes of two consecutive box sizes indicate void in the box when it is shipped, meaning the box will potentially cost more to ship than it has to.

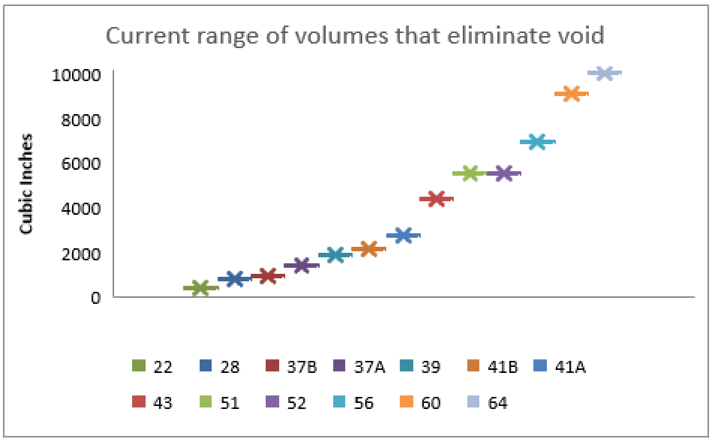


Figure 13. Original 13 Boxes by Volume

In contrast, Figure 14 shows that the optimized solution obtained in the analysis in chapter 4 is a significant improvement from the thirteen box system that is currently being used [BBdLL+19]. As it has been said, all ranges of volumes are being covered, and no possible void can exist in the boxes theoretically.

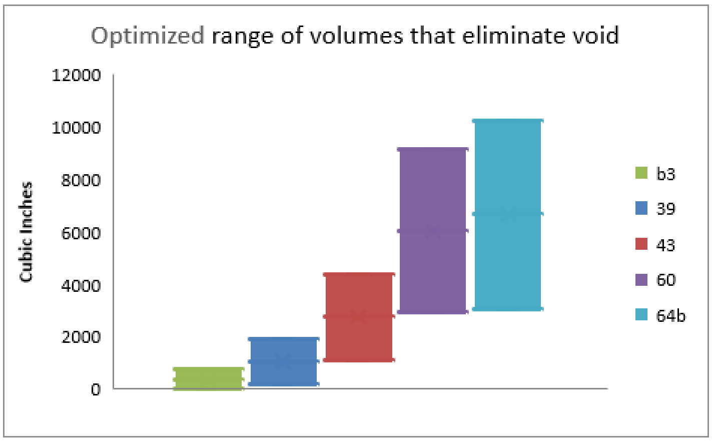


Figure 14. Optimized Box Sizes by Volume

Likewise, Figure 15 represents the final solution of 4 boxes that was collaboratively found in the last site visit, and it also shows progression in eliminating void.

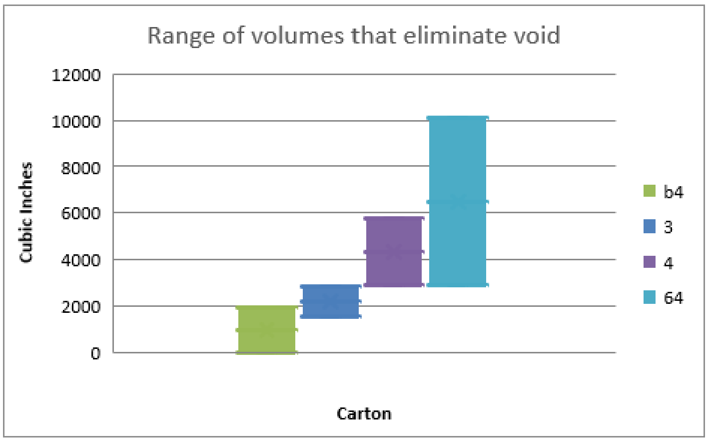


Figure 15. Four Proposed Sizes by Volume

It is easily understood by looking at Figure 15, that the final solution is a notable achievement since, not only does it cover all ranges of volumes, but it also eliminates one box from the system, with all the operational and economic benefits that it bears.

It is important to note that the final set of boxes is a combination of the analytic efforts of the team and the recommendations from the NFDC, driven by their experience. This makes the solution even more solid, as it will be discussed in chapter 7 in the Conclusions, but due to its nature it should not be an optimal solution in quantitative terms, which is the sacrifice made in order to have operational benefits at the DC. This explains why Figure 15 looks like there is a redundant box, which is box *4*. Not at all, since the factors for choosing the boxes were carefully studied, as it is explained in chapter 4.

Chapter 6

Cost Analysis

THE economic analysis of the whole project had the purpose of putting it through a final test to see if, apart from the operational benefits that were going to take place, some major profits would be made. The approach to the cost analysis was based on the one that the company had already performed for the initially proposed sizes. The costs and savings were split in three main areas: transportation, labor, and material. To these, the cost of the investment in equipment had to be added. It is important to take into account that the savings calculations come from the sample of 64,000 orders. Therefore, the savings for an annual timespan were obtained from a linear extrapolation to the annual number of orders: 1,571,124. The main parts of the analysis are summarized below:

- **Labor Savings.** As for the labor savings, they represent the reduction in the number of employees that would result from the implementation of the BoxSizer. The purchase of the case erectors would have an important effect here as the DC used to have several workers building the boxes manually, whereas now this process would be automated. After discussing it with the NFDC managers, it was concluded that the labor in charge of box erecting could decrease from 5 to 2, and from 7 to 4 in peak season. This calculation was performed attending to data from the Company, like salaries or number of shifts, and it is detailed in Table 7.

Carton Erecting Labour	Current Solution			Box Erectors			Saving
	Normal	Peak	Total	Normal	Peak	Total	
Number of personel per shift	5	7		2	4		
Operating hours per person per week	40	53.5		40	53.5		
Number of shifts	2	2		2	2		
Total number of working hours per week	400	749		160	428		
Weighted Labour cost per hour	$12.88	$14.51		$12.88	$14.51		
Labour cost per week	$5,152	$10,864		$2,061	$6,208		
Working weeks per year	44	8		44	8		
Labour cost per year	$226,688	$86,914	**$313,602**	$90,675	$49,665	**$140,340**	**$173,262**

Table 7. Savings in Carton Erecting Labor

On the other hand, the labor in charge of sealing the boxes would go down from 4 in normal season and 8 in peak season to only one or two workers in both cases. It is also shown in more detail in Table 8. Altogether, these changes would mean nearly $400,000 in annual savings.

Pack Sealing Labour	Current Solution				Boxsizer				Saving
	Normal	Peak	Total		Normal	Peak	Total		
Number of operatives per shift	4	8			1	1			
Operating hours per person per week	40	53.5			40	53.5			
Number of shifts	2	2			2	2			
Total number of labour hours per week	320	856			80	107			
Weighted Labour cost per hour	$12.88	$12.88			$12.88	$12.88			
Labour cost per week	$4,122	$11,025			$1,030	$1,378			
Operating weeks per year	44	8			44	8			
Labour cost per year	$181,350	$88,202	**$269,553**		$45,338	$11,025	**$56,363**		**$213,190**

Table 8. Savings in Pack Sealing Labor

- **Box Material Savings.** On the side of material savings, the analysis compared the costs of the cartons themselves in the current and the new scenarios. First, the amount of times a carton was used was identified with the sample data and the results generated from the optimization. Given that the Company had provided a similar pricing scheme for their initial proposition of boxes, a linear escalation was done with the price of each based on their volume. Since the final result was four boxes, it was carefully selected which of the boxes would be replaced by the new ones to account for the orders [BBdLL+19].

  Though it may seem surprising, the box material analysis determined that with the proposed solution of four boxes there would be more expenses on material to accommodate fewer boxes for a wider range of volume. This can be explained by the fact that the finally proposed box sizes were proportionally more expensive than the original 13 set. The result was an additional cost of nearly $9,000 in the sample of 64,000 orders, meaning around $200,000 annually. The calculations were performed in an extensive spreadsheet which, due to its crudeness, will not provide any type of support to the present explanation. It included, apart from the prices derived from the original 13 box set prices, the pertinent discounts from purchasing big quantities of boxes.

- **Void Filling Savings.** The reduction in the amount of dunnage needed (that is, the air pillows put in the boxes that are not entirely full, to make them more rigid and consistent) was also analyzed. In order to estimate the savings in void filling, the current percentage of void per box (18.8%) was compared with the one that was expected with the BoxSizer. The solution that had been proposed covered all ranges of possible order volumes and together with the BoxSizer would result in minimal to no void in the boxes (that would mean 0%). But, in the analysis, orders had been treated as if they were liquid volumes and it had been assumed that no space was between products or on the sides.

  Therefore, in order to be realistic, a factor of 10% was created to take into a account the void that inherently would be in each box. Due to the human factor and the irregular shapes of the products, there will always be a certain amount of void in the boxes, and it was attempted to consider it with the 10% factor. With that considered, the void per box would go down to 8.8%, which resulted in savings of around $120,000. Table 9 illustrates the calculations.

Void Fill Savings

Current Boxes	N. of Boxes	Usage	Cost per Box	Total Cost
22	7174	11.21%	$0.100	$717.40
28	4338	6.78%	$0.100	$433.80
37A	3373	5.27%	$0.100	$337.30
37B	2405	3.76%	$0.100	$240.50
39	2835	4.43%	$0.150	$425.25
41A	1982	3.10%	$0.150	$297.30
41B	2816	4.40%	$0.150	$422.40
43	4151	6.49%	$0.150	$622.65
51	231	0.36%	$0.150	$34.65
52	1740	2.72%	$0.200	$348.00
56	2853	4.46%	$0.200	$570.60
60	6872	10.74%	$0.200	$1,374.40
64	23230	36.30%	$0.200	$4,646.00
Sample	64000			$10,470
Annual	1571124			$257,032

Proposed	N. of Boxes	Usage	Cost per Box	Total Cost
b4	19094	29.83%	$0.05	$1,015.64
3	8898	13.90%	$0.05	$473.30
4	7057	11%	$0.09	$656.90
64	28951	45.24%	$0.11	$3,079.89
Sample	64000			$5,226
Annual	1571124			$128,285
Annual Savings				$128,747

Table 9. Savings in Void Filling and Dunnage

All the costs outlined above belong to the operations side of preparing the boxes at the DC, and it was possible to combine them and compare them to the original cost derived from the thirteen boxes. Figure 16 shows the relation between costs and savings in each of the areas, for an order amount of 64,000.

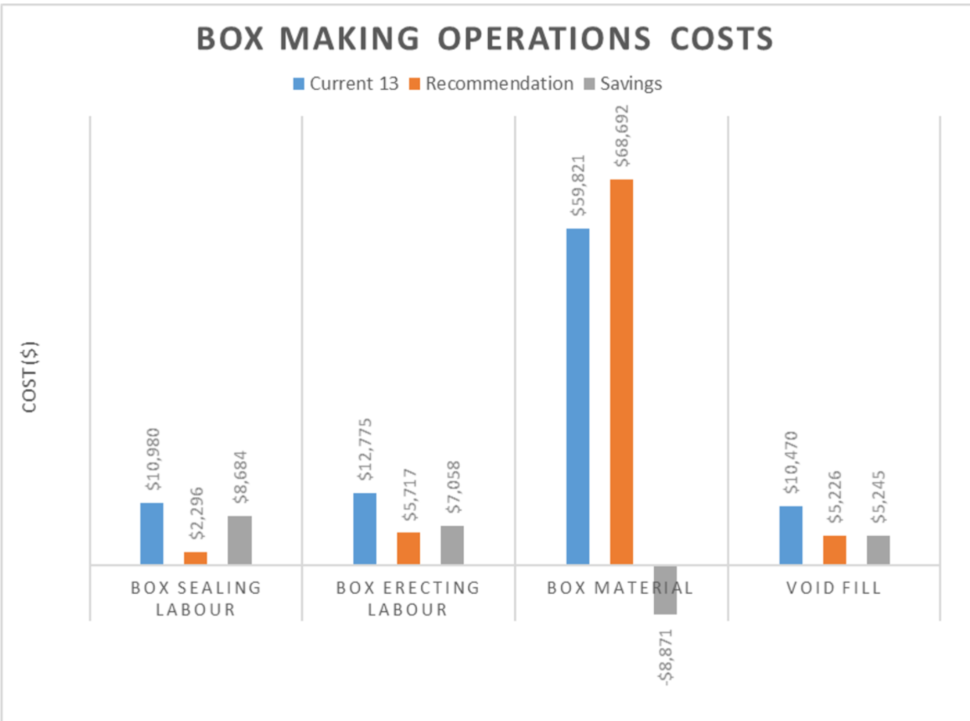


Figure 16. Cost Analysis of Box Making Operations

- **Transportation Savings.** From the transportation analysis in chapter 5, the savings on that side had already been found. These were $2.35 per order and that was only for the shipments carried by UPS. As it cannot be assumed that the rest of the orders would have the same level of savings, a value of $0.5 of savings per order was given to the rest of the orders. Then, the total amount of savings in this part was obtained by multiplying the savings per order times the number of orders, yielding savings of nearly $170,000.

Once all the savings from each area had been calculated, in order to make the savings applicable to the business of the Company, they were extrapolated to be representing the same timespan.

Some alterations were made in order to make the results more realistic, for which the motivation was the following: The present work is an industry project, where countless real-life factors can affect operations like production, shipping, or even the finance area. The project presented is mostly a purely theoretical approach to the problem, and thus all its results do not put enough weight on the qualitative factors that also concern the analysis. In consequence, it was decided that it was important to consider errors of this kind, such not having used a larger annual sample or not considering the pricing model for the other shipping companies used. Therefore, all the savings were multiplied by a factor of 0.8, which, despite it would make the results somewhat worse, they would be much more solid in the case that any of the assumptions made did not take place as planned.

The results of the cost analysis, that is concluded with two figures relevant in these kind of projects [Jul01], are exposed in Table 10.

Investment	
4 case erectors	$318,000
2 BoxSizers	$1,145,000
Contingency (30%)	$500,000
Total	$1,963,000

Annual Savings	
Box Sealing Labour	$170,552
Box Erecting Labour	$138,609
Box Material	-$217,771
Void Fill	$102,997
Transportation	$1,349,717
Total	$1,544,105

PayBack (yr.)	1.27
ROI	79%

Table 10. Final Results From Economic Analysis

Although the ROI is usually calculated using Net Income, it was considered that savings could be used for the same purpose, as (assuming constant income) they would result in a Net Income of that same amount. The annual savings were determined to be approximately $1.5 million and the Return On Investment, 79% [Mar16]. The Payback for the project is also calculated to find that the money invested would be recovered in nearly 1 year and 3 months. A representation is given in Figure 17.

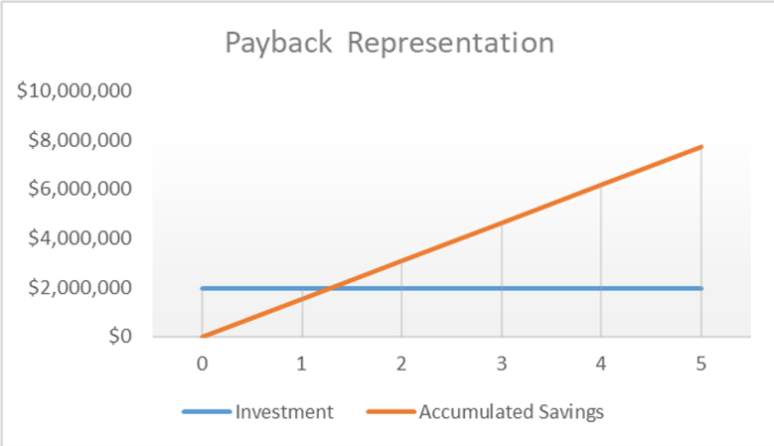


Figure 17. Payback Representation for Project Savings

For a project of this magnitude, involving a large investment, these results are excellent. It is known that in the end these figures represent only estimations but it is an outstanding baseline. The Company was highly satisfied with the recommendations and the results. The final reflections on the project and the results will be further discussed in the Conclusion in chapter 7.

Chapter 7

Conclusions

It can be confidently affirmed that the exposed solution to the box dimension problem will have positive operational, economic and environmental effects. The BoxSizer will considerably speed up the final part of the order preparation process, thus eliminating a potential bottleneck, which will improve fluidity throughout the Distribution Center and end up positively affecting all areas of the DC.

The solution also has recognizable environmental benefits. It is hoped that any reduction in void within the boxes will translate directly to a reduction in waste. Currently, the distribution center uses air pillows to account for wasted space in the box, but after the BoxSizer is implemented, the air pillows will no longer be necessary. Not only will this result in cost savings, but also major environmental impacts from the reduction in use of plastic. The retail stores will no longer have to dispose of countless numbers of air pillows which ultimately end up in landfills [BBdLL$^+$19].

7.1. Conclusions on Methodology

The methodology used throughout this project has a major analytic component, but the consideration of factors that could not be put into an optimization model for their non-quantitative nature was always present.

The key parts of the methodology were two. On one hand, the analysis of the problem, with a classical process of defining a model, gathering data, filtering it in order to get a relevant and useful set for the model, and finally obtaining and dissecting the results. The use of appropriate software systems was of big importance as well as the collaboration and originality of the team members to come up with ideas to overcome the appearance of problems, like the use of iterations when a size limit was imposed by the solving software. It is believed that the path taken to solve the problem yielded satisfying, solid results, with their reliability proven, for example, with an iterative process that converges, finally selecting always the same dimensions.

On the other hand, the cooperation with the sponsors from the Company was highly productive. The weekly e-meetings with the DC managers let the project keep going in spite of encountering barriers, giving helpful feedback and having both sides on the same page at all times. This collaboration and the team's analytic efforts were two sides of the same coin that made it possible to complete the scope of the project exceeding expectations.

7.2. Conclusions on Results

The investigation presented sought specific results in order to draw a conclusion on how to confront a project involving a large investment in equipment. Three of these results were measurable: the dimensions of the optimal boxes, the impact on transportation and the economic justification of the project.

Firstly, the optimization led to picking 4 box sizes which was an improvement to the initial objective which was to select 5. Furthermore, the optimization went through an iteration process and was later reinforced with the experience and empiric knowledge from the NFDC managers to make it more suitable for a DC and realistic. All in all, it is believed that the result of this part was substantial, and its effects are proved to be favorable in the transportation and economic analysis.

The transportation impact analysis showed that the implementation of the BoxSizer together with the reduction of boxes would have exceptional effects both economically and operationally. It found both an incredible amount of savings on the transportation side, the most significant ones among all savings, but also a reduction in the average DIM weight, together with important insights on the volumes covered by each box sizes set. It made possible to see that one of the boxes was a candidate for being removed from the set as the volumes it covered could also be covered by the other boxes. Thus, it can be seen that the results from this analysis were of great use.

Finally, the cost analysis. It is not a great finding to discover that there would be big savings in the new situation. The BoxSizer would in any case produce savings by reducing costs. However, it is believed that the proposed solution helped maximize those cost reductions from having selected the optimal box sizes. The two figures obtained, a ROI of 79% and a Payback of 1.27 years are indicators of the investment being commendable.

As for the non-measurable results, it is believed that the team has given valuable recommendations and insights to Company and the DC managers, from everything that was observed, analyzed and learned. It was always a concern to advice the managers on procedures with room for improvement. The Company found all the recommendations appropriate and highly constructive.

7.3. Recommendations for Improvements

As it can be expected from working at a DC, many areas were involved, and throughout the project numerous conclusions derived from the experience. As the scope of the project was limited, many aspects are left for improvement in the future. They are included below.

Some changes that will take place at the DC were not analyzed in the present project. For example, the way the boxes are transported around the facility will be affected, so the Northeast Florida Distribution Center needs to understand how the boxes will fit onto the current carts and if different carts need to be purchased to account for the new sizes. Additionally, they will need to explore where the boxes will be staged after they are assembled. Currently they are stackable, meaning that multiple boxes can fit within another, but with the absence of the flaps, the boxes are not flexible enough to do so [BBdLL+19].

In addition, due to the reduction in empty space in the boxes, more boxes will be able to fit in one container, resulting in less trucks to transport the orders. These factors are beyond the project scope so they were not included in the cost analysis, however, they are important to note and eventually monetize [BBdLL+19].

Lastly, the associates are accustomed to the current box sizes, so they have already developed their own personal packaging strategies for the various sizes. When the box dimensions change, the associates will have to readjust to the new sizes, which may initially affect their performance. It was one of the team's principal concerns that the packaging strategy was never looked at or examined. The managers believed, from their experience, that it was not worth to deepen in that matter, since if the DC workers spent time thinking how an order should be packed, the damage in wasted time and lost productivity would be bigger than the benefit of a well packed box in which no second box is needed for having created void spaces. In spite of this, the team encouraged the Company to, in the future, develop truly basic packing strategies that were easy to memorize and would, hopefully, have a big impact on the utilization of the boxes after being packed.

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PART II

APPENDICES

Appendix A

Complete Code

A.1. Optimization Code

A.1.1. c_{ij} Calculation in MS Excel VBA

```
Dim i, j, cij As Double
i = 0

Do Until Worksheets("combined 64k").Range("A2").Offset(i, 0).Value = ""

For j = 1 To 18 'calculate cij's for all 18 box sizes
cij = 1 - (Worksheets("combined 64k").Range("C2").Offset(i, 0).Value / Worksheets("combined
    64k").Range("AE2").Offset(j - 1, 0).Value)
' 1 - actual/theoretical = fraction of void

If cij >= 0 Then
Worksheets("combined 64k").Range("J2").Offset(i, j - 1).Value = cij
Else
Worksheets("combined 64k").Range("J2").Offset(i, j - 1).Value = 5
End If
'we want to make the number large if it is negative so the program will not pick this size as
     it is not feasible
Next

i = i + 1
Loop


End Sub
```

A.1.2. Initial GAMS Code (431 Orders)

```
***  Optimization Algorithm for 431 orders

Set j "Boxes" /1*13/;
Set i "Orders" /1*431/;

*=== Import cij from Excel using GDX utilities
*=== First unload to GDX file (occurs during compilation phase)
$call gdxxrw cij_table2.xls trace=3 par=C rng=Hoja1!A1

*=== Now import data from GDX
Parameter C(i,j);
$gdxin cij_table2.gdx
$load C
$gdxin

Display C

Free Variables
emptyspace;

Binary Variables
Y(j),
X(i,j);

Equations
NumBoxes,BoxUsed(i),ObjFunction,Eq3(j);

NumBoxes..          sum(j,Y(j))=l=5;
BoxUsed(i)..        sum(j,X(i,j))=e=1;
Eq3(j)..            sum(i,X(i,j))=g=10000000*Y(j);

ObjFunction..       emptyspace=e=sum(i,sum(j,X(i,j)*C(i,j)));

Model Optimization /all/;
Solve Optimization minimizing emptyspace using MIP;
```

A.1.3. NEOS Code Used for The Iterations

```
***  GAMS input for NEOS
***  Iteration 3
***  Best 5 + 10 new box sizes

Set j "Boxes" /1*15/;
Set i "Orders" /1*64000/;

Parameter C(i,j);

*=== As the .gdx is uploaded to NEOS separately the code is changed
$gdxin in.gdx
$load C
$gdxin

Display C

Free Variables
emptyspace;

Binary Variables
Y(j),
X(i,j);

Equations
NumBoxes,BoxUsed(i),ObjFunction,Eq3(j);

NumBoxes..          sum(j,Y(j))=l=5;
BoxUsed(i)..        sum(j,X(i,j))=e=1;
Eq3(j)..            sum(i,X(i,j))=l=10000000*Y(j);

ObjFunction..       emptyspace=e=sum(i,sum(j,X(i,j)*C(i,j)));

Model Optimization /all/;
option MIP=cplex;
Solve Optimization minimizing emptyspace using MIP;
```

Before being uploaded to NEOS, the code had to be run including the following line to generate the .gdx file:

```
$call gdxxrw 5best10new.xls trace=3 par=C rng=Sheet1!A1
```

A.2. Transportation Analysis Code in Visual Basic

A.2.1. Ship Code Determination From Order Data

```
'Matching the shipping codes to the codes in "ship via" worksheet to determine
'how the order is being shipped (getting #1-7)

Sub Num1_ContiguousStatesOrNah()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("H2:H64001")
Set ZONErng = Worksheets("Ship Via").Range("A2:A580")

For Each cell In rng
For Each shipCode In ZONErng
Dim code As String
code = shipCode.Value
Dim curCode As String
curCode = cell.Value

If code = curCode And shipCode.Offset(0, 5).Value = 1 Then
cell.Offset(0, 20).Value = shipCode.Offset(0, 6).Value
End If
```

```
Next shipCode
Next cell
End Sub
```

A.2.2. Taking the 3 Digit Zip Code

```
'Shortenning the Zip Codes to 3 digits here

Sub Num2_3DigitZipCode()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("G2:G64001")

For Each cell In rng
Dim zip As String
If cell.Offset(0, 21).Value <> "" And Len(cell.Value) <= 6 Then
zip = Mid(CStr(cell.Value), 1, 3)
cell.Offset(0, 22) = zip
'Else
'cell.Offset(0, 22) = "??????"
End If
Next cell
End Sub
```

A.2.3. Finding the Code Zones

```
Sub Num3_zoneCode()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AC2:AC64001")
Set ZIPrng = Worksheets("Zip Codes").Range("A10:A138")

Dim zoneCode As Integer

For Each cell In rng
Dim threeDigitCode As Integer
If cell.Value <> "" Then
threeDigitCode = CInt(cell.Value)

For Each zip In ZIPrng
If Len(zip.Value) = 7 Then
Dim zipLower As Integer
Dim zipUpper As Integer
zipLower = CInt(Mid(zip.Value, 1, 3))
zipUpper = CInt(Mid(zip.Value, 5, 3))

If (threeDigitCode >= zipLower And threeDigitCode <= zipUpper) Then
If (cell.Offset(0, -1).Value = 1 Or cell.Offset(0, -1).Value = 2) Then
zoneCode = zip.Offset(0, 6).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 3 Then
zoneCode = zip.Offset(0, 5).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 4 Then
zoneCode = zip.Offset(0, 4).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 5 Then
zoneCode = zip.Offset(0, 3).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 6 Then
zoneCode = zip.Offset(0, 2).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 7 Then
zoneCode = zip.Offset(0, 1).Value
cell.Offset(0, 1).Value = zoneCode
End If
```

```
End If
ElseIf Len(zip.Value) = 3 Then
zipLower = CInt(Mid(zip.Value, 1, 3))

If threeDigitCode = zipLower Then
If (cell.Offset(0, -1).Value = 1 Or cell.Offset(0, -1).Value = 2) Then
zoneCode = zip.Offset(0, 6).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 3 Then
zoneCode = zip.Offset(0, 5).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 4 Then
zoneCode = zip.Offset(0, 4).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 5 Then
zoneCode = zip.Offset(0, 3).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 6 Then
zoneCode = zip.Offset(0, 2).Value
cell.Offset(0, 1).Value = zoneCode
ElseIf cell.Offset(0, -1).Value = 7 Then
zoneCode = zip.Offset(0, 1).Value
cell.Offset(0, 1).Value = zoneCode
End If
End If
End If
Next zip
End If
Next cell
End Sub
```

A.2.4. Dimensions and Volume for Original Dimensions

```
Sub Num4_CartonDimensionsLengthWidthHeight()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("D3:D64001")
Set BOXrng = Worksheets("Carton Dimensions").Range("B3:B15")

For Each cell In rng
Dim box As String
box = cell.Value
If cell.Offset(0, 25).Value <> "" Then
For Each boxSize In BOXrng
If box = boxSize.Value Then
cell.Offset(0, 27).Value = boxSize.Offset(0, 6).Value
cell.Offset(0, 28).Value = boxSize.Offset(0, 7).Value
cell.Offset(0, 29).Value = boxSize.Offset(0, 8).Value
cell.Offset(0, 30).Value = boxSize.Offset(0, 6).Value * boxSize.Offset(0, 7).Value * boxSize.
    Offset(0, 8).Value
End If
Next boxSize
End If
Next cell
End Sub
```

A.2.5. Calculation of DIM Weight and DIM Factor for Original Set

```
Sub Num5_DimFactorAndDimWeight()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AB3:AB64001")
'Set BOXrng = Worksheets("Carton Dimensions").Range("B3:B15")

For Each cell In rng
Dim box As Integer
```

```
If cell.Value <> "" Then
box = cell.Value
If box = 7 Then
If cell.Offset(0, 6).Value > 5184 Then
cell.Offset(0, 7).Value = 250
Else
cell.Offset(0, 7).Value = 325
End If
ElseIf box = 6 Then
cell.Offset(0, 7).Value = 300
Else
cell.Offset(0, 7).Value = 275
End If

cell.Offset(0, 8).Value = Round(cell.Offset(0, 6).Value / cell.Offset(0, 7).Value, 0)
End If
Next cell
End Sub
```

A.2.6. Cost Calculation for Original Set

```
Sub Num6_DetermineOGcost()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AB2:AB64001")
Dim zoneCode As Integer
Dim dimWeight As Integer

For Each cell In rng

If (cell.Value <> "") Then
If IsNumeric(cell.Value) And IsNumeric(cell.Offset(0, 2).Value) Then
zoneCode = cell.Offset(0, 2).Value
dimWeight = cell.Offset(0, 8).Value
Dim i As Integer
Dim colNum As Integer

If cell.Value = 7 Then
Set zoneRange = Worksheets("UPS Ground").Range("A1")

colNum = 0
i = 0
For i = 1 To 10
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 6 Then
Set zoneRange = Worksheets("UPS 3 Day Select").Range("A1")

colNum = 0
i = 0
For i = 1 To 7
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
```

```
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 5 Then
Set zoneRange = Worksheets("UPS 2nd Day Air").Range("A1")

colNum = 0
i = 0
For i = 1 To 10
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 4 Then
Set zoneRange = Worksheets("UPS 2nd Day Air AM").Range("A1")

colNum = 0
i = 0
For i = 1 To 7
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 3 Then
Set zoneRange = Worksheets("Next Day Air Saver").Range("A1")

colNum = 0
i = 0
For i = 1 To 7
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
```

```
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 2 Then
Set zoneRange = Worksheets("Next Day Air").Range("A1")

colNum = 0
i = 0
For i = 1 To 10
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 1 Then
Set zoneRange = Worksheets("Next Day Air Early").Range("A1")

colNum = 0
i = 0
For i = 1 To 8
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 10).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 10).Value = "Something has gone terribly wrong"
End If
End If
Else
cell.Offset(0, 10).Value = "damn canadians"
End If
End If
Next cell
End Sub
```

A.2.7. Taking Product Volume From Sample

```
'Putting the product volume in a new column

Sub Num7_ProductVolume()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("C2:C64001")
'Set BOXrng = Worksheets("Carton Dimensions").Range("B3:B15")

For Each cell In rng
```

```
If cell.Offset(0, 25).Value <> "" Then
cell.Offset(0, 36).Value = cell.Value * 1.15
End If
Next cell
End Sub
```

A.2.8. Selecting the Box for Each Order in Sample

```
Sub Num8_NewBox()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AM2:AM64001")
'Set BOXrng = Worksheets("Carton Dimensions").Range("B3:B15")

For Each cell In rng
If cell.Value <> "" Then
'Dim vol As Double
'vol = cell.Value
Dim bVol, thirtyNineVol, FortyThreeVol, SixtyVol, SixtyFourVol, SixtyFourBVol As Double
Dim bH, thirtyNineH, FortyThreeH, SixtyH, SixtyFourH, SixtyFourBH As Double
Dim bL, thirtyNineL, FortyThreeL, SixtyL, SixtyFourL, SixtyFourBL As Double
Dim bW, thirtyNineW, FortyThreeW, SixtyW, SixtyFourW, SixtyFourBW As Double

bH = 5.5
thirtyNineH = 8.25
FortyThreeH = 11.63
SixtyH = 18.75
SixtyFourH = 20.88
SixtyFourBH = 20.25

bL = 12
thirtyNineL = 15.13
FortyThreeL = 21.88
SixtyL = 24
SixtyFourL = 24
SixtyFourBL = 23.5

bW = 11.05
thirtyNineW = 15.13
FortyThreeW = 17.13
SixtyW = 20.25
SixtyFourW = 20
SixtyFourBW = 21.5

bVol = 729
thirtyNineVol = 1889
FortyThreeVol = 4359
SixtyVol = 9113
'The two volumes below account for the boxes with lids
SixtyFourVol = 10022 + ((0.5 * SixtyFourW - 1) * SixtyFourW * SixtyFourL)
SixtyFourBVol = 10231 + ((0.5 * SixtyFourBW - 1) * SixtyFourBW * SixtyFourBL)

'Discount 64 and use 64b
Dim minVol As Double
Dim lengthOrWidth As Double
Dim newVol As Double
Dim curVol As Double
If cell.Value <= bVol Then
cell.Offset(0, 1).Value = "b"

curVol = bVol
If (bL < bW) Then
lengthOrWidth = bL
Else
lengthOrWidth = bW
End If
If (cell.Value <= bL * bW * (bH - 0.5 * lengthOrWidth)) Then
newVol = bL * bW * (bH - 0.5 * lengthOrWidth)
Else
newVol = cell.Value
End If
```

```
cell.Offset(0, 2).Value = newVol
ElseIf cell.Value <= thirtyNineVol Then
cell.Offset(0, 1).Value = "39"

curVol = thirtyNineVol
If (thirtyNineL < thirtyNineW) Then
lengthOrWidth = thirtyNineL
Else
lengthOrWidth = thirtyNineW
End If
If (cell.Value <= thirtyNineL * thirtyNineW * (thirtyNineH - 0.5 * lengthOrWidth)) Then
newVol = thirtyNineL * thirtyNineW * (thirtyNineH - 0.5 * lengthOrWidth)
Else
newVol = cell.Value
End If

cell.Offset(0, 2).Value = newVol
ElseIf cell.Value <= FortyThreeVol Then
cell.Offset(0, 1).Value = "43"

curVol = FortyThreeVol
If (FortyThreeL < FortyThreeW) Then
lengthOrWidth = FortyThreeL
Else
lengthOrWidth = FortyThreeW
End If
If (cell.Value <= FortyThreeL * FortyThreeW * (FortyThreeH - 0.5 * lengthOrWidth)) Then
newVol = FortyThreeL * FortyThreeW * (FortyThreeH - 0.5 * lengthOrWidth)
Else
newVol = cell.Value
End If

cell.Offset(0, 2).Value = newVol
ElseIf cell.Value <= SixtyVol Then
cell.Offset(0, 1).Value = "60"

curVol = SixtyVol
If (SixtyL < SixtyW) Then
lengthOrWidth = SixtyL
Else
lengthOrWidth = SixtyW
End If
If (cell.Value <= SixtyL * SixtyW * (SixtyH - 0.5 * lengthOrWidth)) Then
newVol = SixtyL * SixtyW * (SixtyH - 0.5 * lengthOrWidth)
Else
newVol = cell.Value
End If

cell.Offset(0, 2).Value = newVol
ElseIf cell.Value <= SixtyFourBVol Then
cell.Offset(0, 1).Value = "64b"

curVol = SixtyFourBVol
If (SixtyFourBL < SixtyFourBW) Then
lengthOrWidth = SixtyFourBL
Else
lengthOrWidth = SixtyFourBW
End If
If (cell.Value <= SixtyFourBL * SixtyFourBW * (SixtyFourBH - 0.5 * lengthOrWidth)) Then
newVol = SixtyFourBL * SixtyFourBW * (SixtyFourBH - 0.5 * lengthOrWidth)
Else
newVol = cell.Value
End If

cell.Offset(0, 2).Value = newVol
End If

End If
Next cell
End Sub
```

A.2.9. Finding the New DIM Weight

```
Sub Num9_NewDimWeight()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AO2:AO64001")
'Set BOXrng = Worksheets("Carton Dimensions").Range("B3:B15")

For Each cell In rng
If cell.Value <> "" Then
Dim dimFactor As Integer
dimFactor = cell.Offset(0, -6).Value
cell.Offset(0, 1).Value = Round(cell.Value / cell.Offset(0, -6).Value, 0)
End If
Next cell
End Sub
```

A.2.10. Cost Calculation for the New Set of Boxes

```
Sub Num10_DetermineNewCost()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AB2:AB64001")
Dim zoneCode As Integer
Dim dimWeight As Integer
Dim wrongCount As Integer
wrongCount = 0

For Each cell In rng

If (cell.Value <> "") Then
If cell.Offset(0, -25).Value <= cell.Offset(0, -23).Value Then
If IsNumeric(cell.Value) And IsNumeric(cell.Offset(0, 2).Value) Then
zoneCode = cell.Offset(0, 2).Value
dimWeight = cell.Offset(0, 14).Value
Dim i As Integer
Dim colNum As Integer

If cell.Value = 7 Then
Set zoneRange = Worksheets("UPS Ground").Range("A1")

colNum = 0
i = 0
For i = 1 To 10
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 6 Then
Set zoneRange = Worksheets("UPS 3 Day Select").Range("A1")

colNum = 0
i = 0
For i = 1 To 7
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
```

```
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 5 Then
Set zoneRange = Worksheets("UPS 2nd Day Air").Range("A1")

colNum = 0
i = 0
For i = 1 To 10
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 4 Then
Set zoneRange = Worksheets("UPS 2nd Day Air AM").Range("A1")

colNum = 0
i = 0
For i = 1 To 7
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 3 Then
Set zoneRange = Worksheets("Next Day Air Saver").Range("A1")

colNum = 0
i = 0
For i = 1 To 7
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
```

```
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 2 Then
Set zoneRange = Worksheets("Next Day Air").Range("A1")

colNum = 0
i = 0
For i = 1 To 10
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
ElseIf cell.Value = 1 Then
Set zoneRange = Worksheets("Next Day Air Early").Range("A1")

colNum = 0
i = 0
For i = 1 To 8
If zoneCode = zoneRange.Offset(0, i).Value Then
colNum = i
End If
Next
If colNum <> 0 Then
i = 0
For i = 1 To 140
If dimWeight = zoneRange.Offset(i, 0).Value Then
'Set cost here
cell.Offset(0, 15).Value = zoneRange.Offset(i, colNum).Value
i = 140
End If
Next
Else
'Accounting for not finding the zone we need in out table
cell.Offset(0, 15).Value = "Something has gone terribly wrong"
End If
End If
Else
'cell.Offset(0, 15).Value = "canadians"
End If
Else
cell.Offset(0, 15).Interior.ColorIndex = 37
wrongCount = wrongCount + 1
End If
End If
Next cell

Worksheets("combined 64k iteration 3").Range("BF22").Value = wrongCount
End Sub
```

A.2.11. Average Cost Calculation

```
'Determining the avg cost per order here

Sub Num12_AvgCost()
Dim rng As Range, cell As Range
Set rng = Worksheets("combined 64k iteration 3").Range("AL2:AL64001")
Dim count As Integer
count = 0
Dim sum As Double
sum = 0

For Each cell In rng
'checks that zoneCode, current cost, and new cost are not blank and are numeric
If cell.Offset(0, -8).Value <> "" And IsNumeric(cell.Offset(0, -8).Value) And cell.Value <> "
    " And IsNumeric(cell.Value) And cell.Offset(0, 5).Value <> "" And IsNumeric(cell.Offset
    (0, 5).Value) Then
sum = sum + cell.Value
count = count + 1
End If
Next cell



Dim rng2 As Range, cell2 As Range
Set rng2 = Worksheets("combined 64k iteration 3").Range("AQ2:AQ64001")
Dim count2 As Integer
count2 = 0
Dim sum2 As Double
sum2 = 0

For Each cell2 In rng2
'checks that zoneCode, current cost, and new cost are not blank and are numeric
If cell2.Offset(0, -13).Value <> "" And IsNumeric(cell2.Offset(0, -13).Value) And cell2.Value
     <> "" And IsNumeric(cell2.Value) And cell2.Offset(0, -5).Value <> "" And IsNumeric(cell2
    .Offset(0, -5).Value) Then
sum2 = sum2 + cell2.Value
count2 = count2 + 1
End If
Next cell2

Worksheets("combined 64k iteration 3").Range("AZ22").Value = sum / count
Worksheets("combined 64k iteration 3").Range("AZ23").Value = sum
Worksheets("combined 64k iteration 3").Range("AZ24").Value = count

Worksheets("combined 64k iteration 3").Range("BA22").Value = sum2 / count2
Worksheets("combined 64k iteration 3").Range("BA23").Value = sum2
Worksheets("combined 64k iteration 3").Range("BA24").Value = count2
End Sub
```

Appendix B

Optimization Model In Excel

Objective minimize total empty space: 0.398088365

Box j	Yj
1	0
2	1
3	0
4	0
5	0
6	1
7	0
8	1
9	1
10	1
11	0
12	0
13	0
Total Boxes	5

Xij Table

	box 1	box 2	box 3	box 4	box 5	box 6	box 7	box 8	box 9	box 10	box 11	box 12	box 13	SUM
order 1	0	0	0	0	0	0	0	0	1	0	0	0	0	1
order 2	0	1	0	0	0	0	0	0	0	0	0	0	0	1
order 3	0	0	0	0	0	0	0	1	0	0	0	0	0	1
order 4	0	0	0	0	0	0	0	0	0	1	0	0	0	1
order 5	0	0	0	0	0	0	0	1	0	0	0	0	0	1
order 6	0	1	0	0	0	0	0	0	0	0	0	0	0	1
order 7	0	0	0	0	0	1	0	0	0	0	0	0	0	1

Cij Table (Random values as an example)

	box 1	box 2	box 3	box 4	box 5	box 6	box 7	box 8	box 9	box 10	box 11	box 12	box 13	min.value
order 1	0.86	0.65	0.67	0.60	0.40	0.80	0.87	0.21	0.10	0.42	0.69	0.34	0.91	0.10
order 2	0.38	0.12	0.20	0.80	0.30	0.98	0.57	0.84	0.55	0.84	0.35	0.56	0.40	0.12
order 3	0.41	0.06	0.35	0.30	0.31	0.82	0.47	0.02	0.61	0.43	0.99	0.71	0.21	0.02
order 4	0.54	0.41	0.43	0.72	0.62	0.78	0.45	0.13	0.40	0.00	0.35	0.92	0.49	0.00
order 5	0.93	0.68	0.85	0.65	0.47	0.93	0.61	0.01	0.43	0.14	0.24	0.23	0.58	0.01
order 6	0.49	0.10	0.20	0.88	0.09	0.14	0.99	0.15	0.35	0.23	0.69	0.30	0.65	0.09
order 7	0.20	0.30	0.50	0.70	0.13	0.05	0.35	0.46	0.57	0.13	0.84	0.24	0.83	0.05