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## Drop-Shipping at a Promotional Products Distributor

Ramanan Veeraragavan  
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**DROP-SHIPPING AT A  
PROMOTIONAL PRODUCTS DISTRIBUTOR**

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science in Engineering

By

RAMANAN VEERARAGAVAN  
Bachelor in Technology, SRM University  
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2008

2011

Wright State University

WRIGHT STATE UNIVERSITY  
SCHOOL OF GRADUATE STUDIES

March 18, 2011

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Ramanan Veeraragavan ENTITLED Drop-Shipping at a Promotional Products Distributor BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Engineering.

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## **ABSTRACT**

Veeraragavan, Ramanan. M.S.Egr., Department of Biomedical, Industrial and Human Factors Engineering, Wright State University, 2011.  
Drop-shipping at a Promotional Products Distributor.

During the current economic times, companies are trying to reduce costs by incorporating new strategies into their business plan. Supply chain, in particular the distribution network is one area where an improvement can bring in a healthy return on investment to a company. Drop-shipping is a distribution strategy whereby customer orders are fulfilled by directly delivering products from manufacturer's facility, instead of storing these products at the warehouse. Drop-shipping helps in reducing inventory and material handling costs at the warehouse, but may increase transportation costs due to frequent shipments. This research was motivated by the current operations at a promotional products distributor in the Midwest US. This distributor wanted to decide which products to drop-ship versus stock in the warehouse. We develop a mixed integer programming (MIP) model to categorize the products as 'to be drop-shipped' or 'kept in warehouse' with the objective of minimizing the total distribution cost. This single-period MIP model assumes deterministic demand, all-unit transportation LTL and parcel rates, and warehouse space. To solve larger problem instances, a Ruin and Recreate (RR) based heuristic is proposed. Numerical results indicate that a savings in warehouse space ranging between 28-53% and an additional cost savings of up to 5.2%. A case study involving realistic data obtained from the distributor is presented and avenues for future research in this area are discussed.

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**Ramanan Veeraragavan**

# 1 Introduction

During the current economic situation, companies are trying to improve their operations by incorporating new strategies into their business plan. These strategies may be based on pricing, product variety, marketing, or innovation. One such area where an improvement can bring in a healthy return on investment to the company is its supply chain. The reason behind this is because a large part of their expenditure is involved in transportation and storage of the products they supply.

Inefficiencies in the supply chain, such as unnecessary transportation of the products between supply chain nodes and over stocking of products in the warehouse (which may increase the handling and warehouse space cost), can eat away a major share of its profit. Consequently, companies must analyze their distribution network in their supply chain to see if their design suits the nature of their business. Distribution networks can be classified into six types [1]. These involve manufacturer or in-house storage, in-transit merge, drop-shipping of the order, customer pick-up, etc. Every network has its own benefits and limitations.

This research considers a specific type of distribution strategy that allows for drop-shipping as an option, while allowing for inventory at the warehouse. Drop-shipping is a distribution strategy in which a vendor ships products directly to customer locations bypassing the warehouse [1]. It has been commonly used for non-perishable, make-to-stock products like shirts, mugs, pens, etc. [2]. Table 1 compares and contrasts the drop-shipping strategy with the ‘via warehouse’ strategy.

Table 1. Differences between drop-shipping and via warehouse networks [1]

<i>Drop-shipping</i>	<i>Via Warehouse</i>
Enables distributor to offer large variety of products	Offers limited variety of products
Inventory is at the vendor's location	Inventory is at the warehouse
Savings in handling cost	Involves handling cost for the product
Highly suitable for low demand products	Low demand products in warehouse for long time increases inventory costs
Lead time may be high	Lead time is low
Fragmentation of an order from various vendors to a customer	Involves single shipment of an order to the customer

### **1.1 Motivation and Problem Statement**

This research is motivated through our interactions with a leading promotional products distributor in the Midwest U.S., who will be referred to as Distributor X from now on. Distributor X supplies products like shirts, pens, mugs, etc., that have customer's logo printed on them. Such logoed-products are typically used by a customer at various promotional events (e.g., trade shows and employee appreciation). To stay competitive, Distributor X offers a large variety of products (typically in thousands) to customers with offices in multiple cities at hundreds of locations.

Distributor X's supply chain comprises of vendors who manufacture the products and print the logo, a warehouse where the products are stocked based on the annual demand of each product, and customer locations. To provide excellent service, Distributor X strives to fulfill customer demand quickly by shipping the order within a day. To do so, the distributor stocks all products at the warehouse based on the annual demand (as negotiated with the customer). The present distribution strategy follows the typical vendor-warehouse-customer product flow. The promotional products distribution strategy differs from others as it involves products that are specific to a customer only. The supply

chain involves high variety of products with lower volume because of which parcel shipment are largely used on outside.

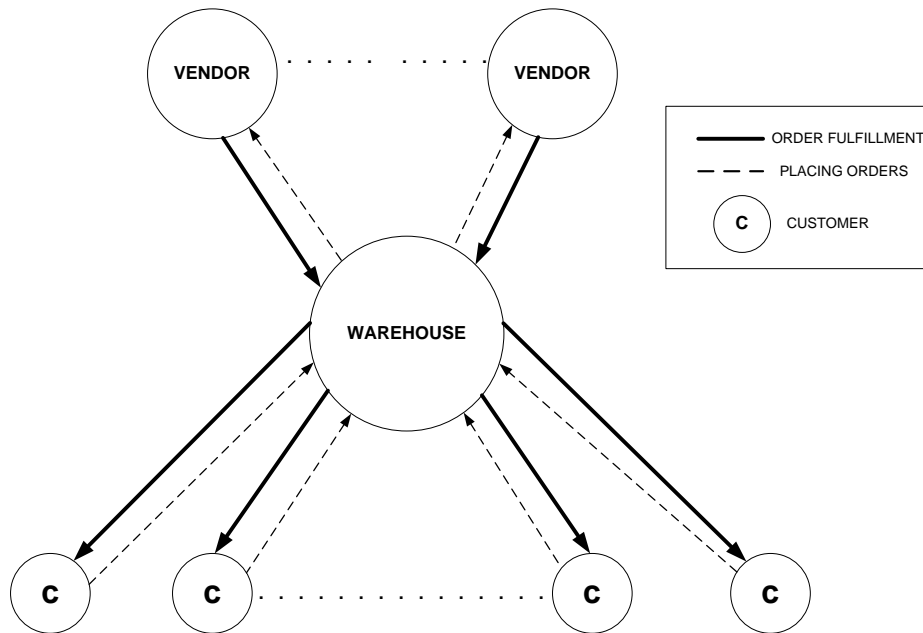


Figure 1. Distribution network with in-house inventory

The operations at Distributor X have been affected significantly due to the recent economic downturn, more so due to its current distribution strategy. A few of its key customers either went out of business or shrunk their business resulting in a significant drop in the demand of already stocked logoed products at the warehouse. These products, however, cannot be sold to any other customer because of the company logos on them. The capital tied up with these products has led this distributor to consider alternate distribution strategies. Additionally, the distributor has been leasing warehouse space from a 3PL and is charged for it on a monthly basis. The distributor has to pay an amount every time a product is moved in and out of the 3PL's warehouse.

Furthermore, the future goal of the distributor is to offer more variety of products to its customers. However, this may lead to huge amounts of inventory to be stocked, which will subsequently increase the warehouse space requirement.

Motivated by this situation at Distributor X, we consider the problem where the distributor must decide which products in the supply chain to be either drop-shipped or stocked at the warehouse.

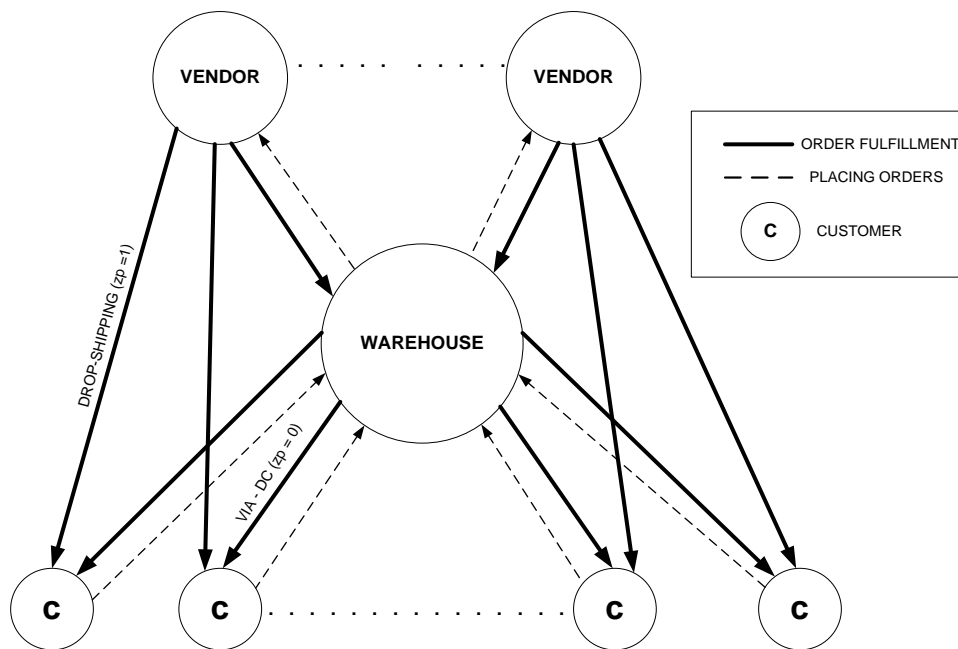


Figure 2. Distribution network with drop-shipping option

In making this decision Distributor X needs to consider various factors, such as overall product demand, frequency of customer orders, space requirements, holding cost at the warehouse, vendor and customer locations with respect to the location of the warehouse, and transportation costs. Two possibilities exist for a product to be shipped; (i) only one option is available for a product (either drop-shipped or stocked in the warehouse) and (ii) both options may be available for a product (which may require an order-fulfillment

policy that determines from where to fulfill the demand first, warehouse or drop-shipping). We consider the first possibility in this research.

## **1.2 Thesis Outline**

The rest of the thesis is organized as follows. A brief review of literature is presented in the Chapter 2. Following that a mixed integer programming model is presented in Chapter 3. Chapter 4 presents the heuristic algorithm developed to solve large problem instances. In Chapter 5 a case study involving realistic data obtained from Distributor X is presented. Finally, in Chapter 6 potential areas for further research are discussed.

## 2 Literature Review

Several strategies exist for a supply chain to deliver products from vendors to customers. Chopra [1] describes the various factors for selecting a distribution strategy for a company. The author indicates that at the highest level, the performance of a distribution strategy should be evaluated along two dimensions; customer needs that are met and the cost of meeting customer needs. The author mentions that the transportation costs are generally higher in drop-shipping as the customers are generally far. Henceforth, the products are shipped using package carriers. The author also mentions that drop-shipping would save handling costs and space costs significantly. He also suggests that only medium to fast moving items should be stored in the warehouse/DC, while the slower moving items should be drop-shipped. Chopra gives a detailed comparison of different network strategies explaining their advantages and disadvantages.

Khouja et al. [3] develop a mathematical model for an e-business supply chain. Drop-shipping is considered as a viable option in cases when there is shortage in stock while satisfying the orders, similar to possibility mentioned above. The authors suggest that mixing drop-shipping option with in-house inventory in their supply chain networks helps the company benefit from the advantages of the drop-shipping and also avoid the effects of its drawbacks. Their results also show that drop-shipping would be effective when the lead time is long and the ordering cost in relative to holding cost is small. However, they consider aggregate unit cost of drop-shipping a product, instead of individual cost components (warehousing and ordering) and volume discounts on transportation rates. In another work Khouja [4], using a similar aggregate unit cost approach, presents an analytical model that maximizes the profit for a stochastic demand

in a drop-shipping environment. The author suggests that products that have lower per unit cost are most appropriate for drop-shipping.

Ayanso et al. [5], through a simulation model, suggest that drop-shipping would be effective only when the inventory of low margin orders goes below the threshold level or during an occurrence of a stock out. By differentiating customer orders in-terms of their priority and reserving inventory for the high priority orders using an appropriate threshold level can provide e-retailers with higher profit opportunities. Instead of considering various distribution cost components they assume that the unit profit margin per product to be drop-shipped is known a priori. Bailey et al. [6] presents a work where they try to balance an e-retailers supply chain network using in-house inventory and drop-shipping option. They handle an internet book retailing network where they talk about how a product's popularity or frequency of ordering affects the decision on their stocking policy. They do not account for warehouse handling and space costs, and volume discounts on transportation rates.

Jang et al. [7] develop an algorithm which integrates production, allocation and distribution with drop-shipping in a stochastic demand scenario. Unit transportation costs are used in this model. A waiting cost is levied upon the distributor when the order delivery to the customer is delayed. They try to minimize the total production and waiting costs using the model. To reduce the transportation and waiting costs drop-shipping is used to deliver shipments. The authors present a comparison of a mathematical model with the heuristic they have developed. They do not describe about the sensitivity of the parameters and the effect of drop-shipping on the model.



Li et al. [8] evaluate the performance of drop-shipping in the distribution strategies for the inventory routing problem through an analytical approach. They observe that under vehicle capacity and delivery frequency constraints, the effectiveness of drop-shipping is at least the square root of the smallest utilization ratio of the vehicle capacity for each delivery to the retailers. According to their analysis, when the demand is even and the demand is also close to vehicle capacity the drop-shipping proves to be a good method.

Rabinovich et al. [12] perform a study on retailer profit margin and distribution service in internet retailing. The study is based on fulfilling the customer demand faster in a drop-shipping scenario. The results obtained from their model show that the product margin is inversely proportional to the margins on transportation and handling.

Even though there is a common idea that drop-shipping would affect the quality of the products delivered and involve higher transportation rates for certain networks, research proves that there are strategies available to tackle them. Quality of the product is a concern in drop-shipping models. Yao et al. [11] propose a different strategy where the quality of the order is maintained by providing incentives to the vendors on drop-shipping orders. In spite of higher transportation costs involved in drop-shipping for certain networks, Chien [13] develop a model where inventory, transportation and stochastic demand are integrated in a drop-shipping scenario. The author shows how to maximize profit with a drop-shipping scenario.

This review of the literature indicates that no existing models consider the following aspects that are key to the Distributor  $X$ 's problem together: *0-1 decision on drop-shipping for each product, consideration of warehousing cost (inventory holding and handling), all-unit transportation rate (LTL and parcel rates), and differential ordering*

*costs*. Essentially, the problem is to decide whether or not to drop-ship a product completely versus stocking it in the warehouse, instead of a strategy where drop-shipping is used during stock outs at the warehouse.

## **2.1 Contributions**

The key contribution of this research is the joint consideration of warehouse handling and holding costs, space availability, transportation costs (LTL and parcel), and differential ordering costs to optimize the distribution strategy considering drop-shipping in a single optimization model. Such a joint consideration has not been addressed in the literature previously and is essential in addressing the problem faced by supply chains similar to that of Distributor X

### **3 Mathematical Model Formulation and Methodology**

Distributor X wants to avoid the risk of holding inventory for customers if the demand drops due to market conditions. Furthermore, as a future goal, they want to increase the variety of products that can be offered to their customers. Stocking a wide variety of products in the warehouse is not a viable option as inventory holding cost would be extremely high given the relatively low demand of these products. Warehouse space is also an issue as they presently lease space from a third-party provider to manage their current product offering.

The goal of this research is to develop a mixed integer programming (MIP) model that the Distributor X can use when restructuring its business around reducing risk and cost, and staying competitive by carrying a large portfolio of a variety of products. The objective of the model is to reduce the total cost of distribution by deciding whether to stock a product at the warehouse (i.e., via-warehouse strategy) versus drop-ship from the vendor. Total cost comprises the cost of transportation, warehouse inventory and handling, and ordering.

The products this distributor handles are generally pens, shirts, mugs, etc., for which the unit weight is typically low (under 1 lb). Considering that customer's order frequently in small quantities, the entire customer order typically weighs less than 150 lbs. Consequently, a parcel shipper (such as UPS or FedEx) has been a preferred choice for Distributor X when delivering these parcel shipments from warehouses to customer locations. We assume that the shipments inbound to the warehouse from vendor weight more than 150 lbs, hence, a common carrier delivering products via LTL shipments is employed.

Cost of ordering a product from warehouse to vendor depends on whether the product is ordered once (as in the ‘via warehouse’ strategy) or frequently (as in the drop-shipping strategy). In the ‘via warehouse’ strategy, it is assumed that the warehouse places one bulk order of all products to be purchased from a vendor during the time-horizon. We refer to the ordering cost associated with this bulk order as the *bulk ordering cost*. In contrast, in the drop-shipping strategy, customer orders (each order having one or more products) are immediately forwarded by the distributor to vendors to be fulfilled via the drop-ship option. Consequently, such small orders are placed more frequently to the vendor leading to more phone calls or e-transactions, in turn increasing the per-product ordering cost. This cost is termed as the *individual ordering cost*.

### **3.1 Assumptions**

We make the following assumptions in developing our mathematical programming model.

- A fixed time-horizon is assumed; this time-horizon corresponds to a period in which each product is ordered from the vendor only once. Essentially, the distributor has adopted a joint replenishment policy for all products sourced from a vendor.
- Sourcing decisions have already been made; accordingly, a product can be supplied by only one vendor.
- Vendors have sufficient supplies to meet the demand at the warehouse and customer locations.

- All products ordered from a single vendor are consolidated and delivered to the warehouse via LTL shipments once during the time-horizon. Outbound shipments to the customer locations are parcel shipments.

Tables 2 and 3 describe the parameters and decision variables of the MIP model, followed by the model itself.

Table 2. Parameters for the MIP Model

Parameter	Description
$p$	index for products; $p = 1, 2, 3, \dots, P$
$r$	index for request (i.e., order) for product $p$ ; $r = 1, \dots, R$
$c$	index for customers; $c = 1, 2, 3, \dots, C$
$v$	index for vendors; $v = 1, 2, 3, \dots, V$
$l$	levels in parcel cost $l = 1, 2, 3, \dots, L$
$m$	levels in LTL cost $m = 1, 2, 3, \dots, M$
$\Omega_{vp}$	1, if product $p$ is sourced from vendor $v$ ; 0, otherwise
$N_{crp}$	1, if product $p$ appears in request $r$ of customer $c$ ; 0, otherwise
$W_p$ ( $V_p$ )	weight (volume) of each item of product $p$ ; lbs ( $\text{ft}^3$ )
$Q_{crp}$	quantity ordered by customer $c$ during request $r$ for product $p$
$C_p^I$ ( $C_p^B$ )	ordering cost of individual (bulk) order of product $p$ from warehouse to vendor in the drop-shipping ('via warehouse') mode; \$/order of product $p$
$C_p^H$	per unit average holding and handling cost for product $p$ during the time-
$\lambda_{vm}^f, \lambda_{vm}^v$	fixed and variable all-unit LTL rates between vendor $v$ and warehouse at level $m$ ; \$/lbs
$\lambda_{cl}^f, \lambda_{cl}^v$	fixed and variable parcel rates between warehouse and customer $c$ at level $l$ ; \$/lbs
$\lambda_{vcl}^f, \lambda_{vcl}^v$	fixed and variable parcel rates between vendor $v$ and customer $c$ at level $l$ ; \$/lbs
$S_{max}$	maximum space in the warehouse available for storage during the time-
$A_m$	bounds for weight-level $m$ for LTL shipments
$B_l$	bounds for weight-level $l$ for parcel shipments

Table 3. Decision variables for the MIP Model

Dec. Var.	Description
$z_p$	1, if product $p$ is drop-shipped; 0, otherwise
$y_{vm}$	total weight of product $p$ shipped from vendor to warehouse at level $m$ ; lbs
$y_{crl}$	total weight of product $p$ shipped during request $r$ from warehouse to customer $c$ at level $l$ ; lbs
$y_{vcrl}$	total weight of product $p$ shipped during request $r$ from vendor to customer $c$ at level $l$ ; lbs
$x_{vm}$	1, if $y_{vm}$ corresponds to level $m$ ; 0, otherwise
$x_{crl}$	1, if $y_{crl}$ corresponds to level $l$ ; 0, otherwise
$x_{vcrl}$	1, if $y_{vcrl}$ corresponds to level $l$ ; 0, otherwise
$q_{vp}$	average quantity of product $p$ received from vendor $v$ to be stocked in the warehouse during the time-horizon

### 3.2 MIP Model

A mixed integer programming model for the problem stated above is presented below.

minimize

$$\begin{aligned}
 & \left( \sum_{vp} C_p^H \left( \frac{q_{vp}}{2} \right) \right) + \left( \sum_{vm} \lambda_{vm}^f x_{vm} + \sum_{crl} \lambda_{cl}^f x_{crl} + \sum_{vcrl} \lambda_{vcl}^f x_{vcrl} \right) \\
 & + \left( \sum_{vm} \lambda_{vm}^v y_{vm} + \sum_{crl} \lambda_{cl}^v y_{crl} + \sum_{vcrl} \lambda_{vcl}^v y_{vcrl} \right) \\
 & + \left( \sum_p C_p^B (1 - z_p) + \sum_{crp} C_p^I N_{crp} z_p \right)
 \end{aligned}$$

s.t.

*vendor-customer*

$$\sum_p z_p Q_{crp} W_p \Omega_{vp} = \sum_l y_{vcrl} \quad \forall vcr \quad (1)$$

$$y_{vcrl} \leq B_l x_{vcrl} \quad \forall vcrl \quad (2)$$

$$y_{vcrl} \geq B_{l-1} x_{vcrl} \quad \forall vcrl \quad (3)$$

$$\sum_l x_{vcrl} \leq 1 \quad \forall vcr \quad (4)$$

*warehouse-customer*

$$\sum_p (1 - z_p) Q_{crp} W_p = \sum_l y_{crl} \quad \forall cr \quad (5)$$

$$y_{crl} \leq B_l x_{crl} \quad \forall crl \quad (6)$$

$$y_{crl} \geq B_{l-1} x_{crl} \quad \forall crl \quad (7)$$

$$\sum_l x_{crl} \leq 1 \quad \forall cr \quad (8)$$

*vendor-warehouse*

$$q_{vp} = (1 - z_p) \Omega_{vp} \sum_{rc} Q_{crp} \quad \forall vp \quad (9)$$

$$\sum_p q_{vp} W_p = \sum_m y_{vm} \quad \forall v \quad (10)$$

$$y_{vm} \leq A_m x_{vm} \quad \forall vm \quad (11)$$

$$y_{vm} \geq A_{m-1} x_{vm} \quad \forall vm \quad (12)$$

$$\sum_m x_{vm} \leq 1 \quad \forall v \quad (13)$$

*warehouse space*

$$\sum_{vp} (q_{vp})V_p \leq S_{max} \quad (14)$$

*bounds*

$$y_{vm}, y_{crl}, y_{vcrl} \geq 0 \quad \forall vcrlm \quad (15)$$

$$q_{vp} \geq 0 \quad \forall vp \quad (16)$$

$$x_{vm}, x_{crl}, x_{vcrl} \in \{0,1\} \quad \forall vcrlm \quad (17)$$

$$z_p \in \{0,1\} \quad \forall p \quad (18)$$

The objective of the above model is to minimize the total distribution cost. The cost elements considered include LTL and parcel cost (inbound and outbound for warehouse, and drop-shipping), warehouse handling and holding costs, and the ordering cost for warehouse under drop-shipping and via warehouse options. The constraints of the model are as follows. Constraints (1) ensure that the total weight of the products drop-shipped from a vendor to a customer in a request is equal to the total weight of the products ordered by the customer. The Constraints (2)-(4) ensure that total weight of drop-shipped products corresponds to only one of the two weight-levels ( $l$ ) indicated by the parcel shipper. Constraints (5) and (10) are equivalent to Constraints (1) and apply to warehouse-store and vendor-store channels, respectively. Similarly, Constraints (6)-(8) and (11-13) correspond to Constraint (2)-(4) but constraints (11)-(13) corresponds to only one of the four weight-levels ( $m$ ) indicated by the LTL shipper. Constraints (9) ensure that quantity of products shipped from the vendors is equal to the quantity ordered by the warehouse. Constraints (14) indicate that the space required to store the average



inventory across all products in the time-horizon is not exceeded. Constraints (15)-(18) provide bounds on the decision variables.

The MIP model presented in the previous section solves up to 25 products for 5 vendors and 100 customers to optimality on a Pentium 4 processor with 1GB RAM with a 6 hour time-limit. However, realistic problem instances involved thousands of products across hundreds of customer locations. To solve such large problem instances a Ruin and Recreate based heuristic algorithm is developed, which we discuss next.

## 4 Heuristics

Ruin and Recreate (RR) principle was introduced by Schrimpf et al. [9], according to which a previously obtained solution is partially ruined and then recreated. RR is a type of very large neighborhood search algorithm, where larger and bolder moves are made (instead of local moves) in an effort to avoid being trapped in a local optima. The authors applied this algorithm on a variety of supply chain problems, such as vehicle routing, network optimization, and traveling salesman, for which they were able to achieve good results. Based on the RR principle, a heuristic is developed for solving larger problem instances that could not be solved using Xpress optimization suite. The following sections present details of this heuristic.

### 4.1 RR Heuristic

The Ruin and Recreate heuristic has the following two phases: (i) the ruin phase, in which a certain part of the existing solution is ruined; and (ii) the recreate phase, in which the ruined part is rebuilt using certain logical conditions in a hope that the solution might improve.

### 4.2 General Steps Involved in Ruin and Recreate

*Step 1      Generate an initial solution.*

*Step 2      Ruin the solution.*

*Step 3      Recreate the solution.*

*Step 4      Check if the solution has improved. If improved, accept it.*

Figure 2 illustrates an example of the Ruin and Recreate approach, while Figure 3 provides a flowchart of the entire RR heuristics.

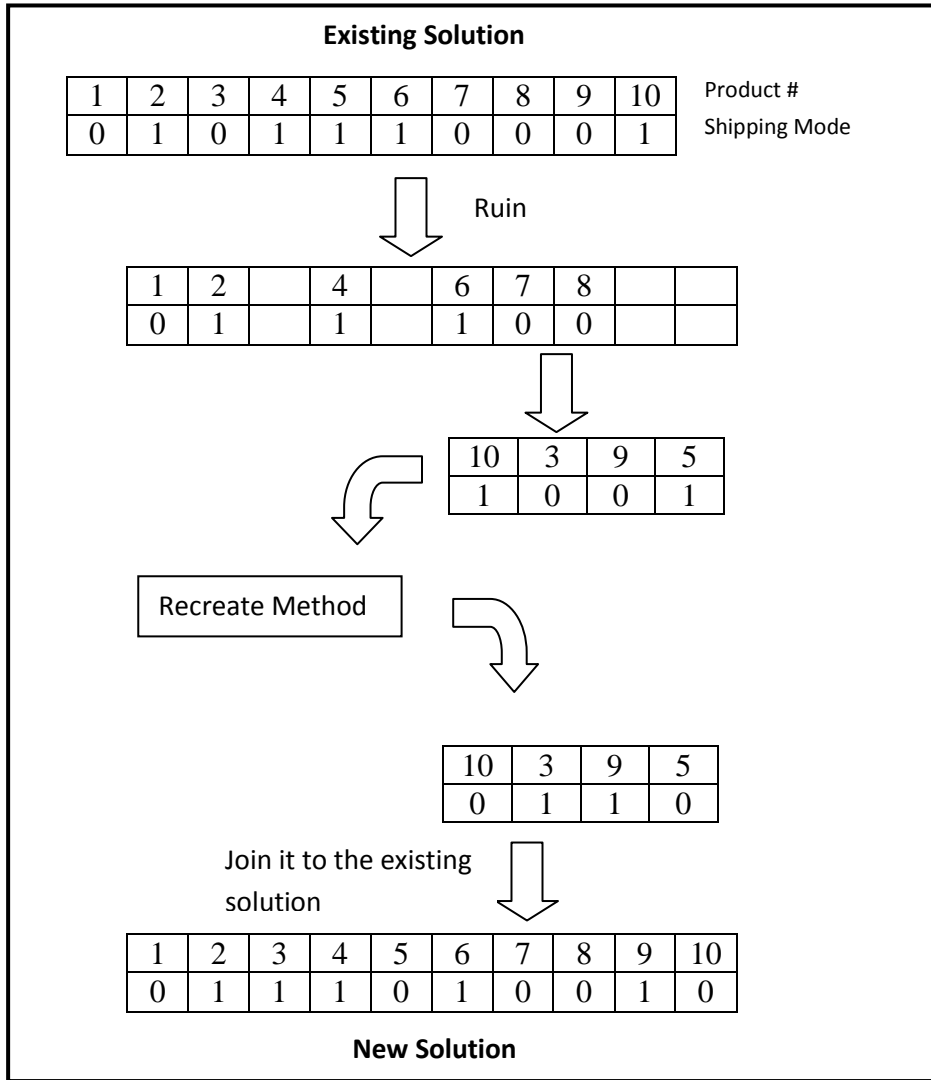


Figure 3. Obtaining a new solution through ruin and recreate process

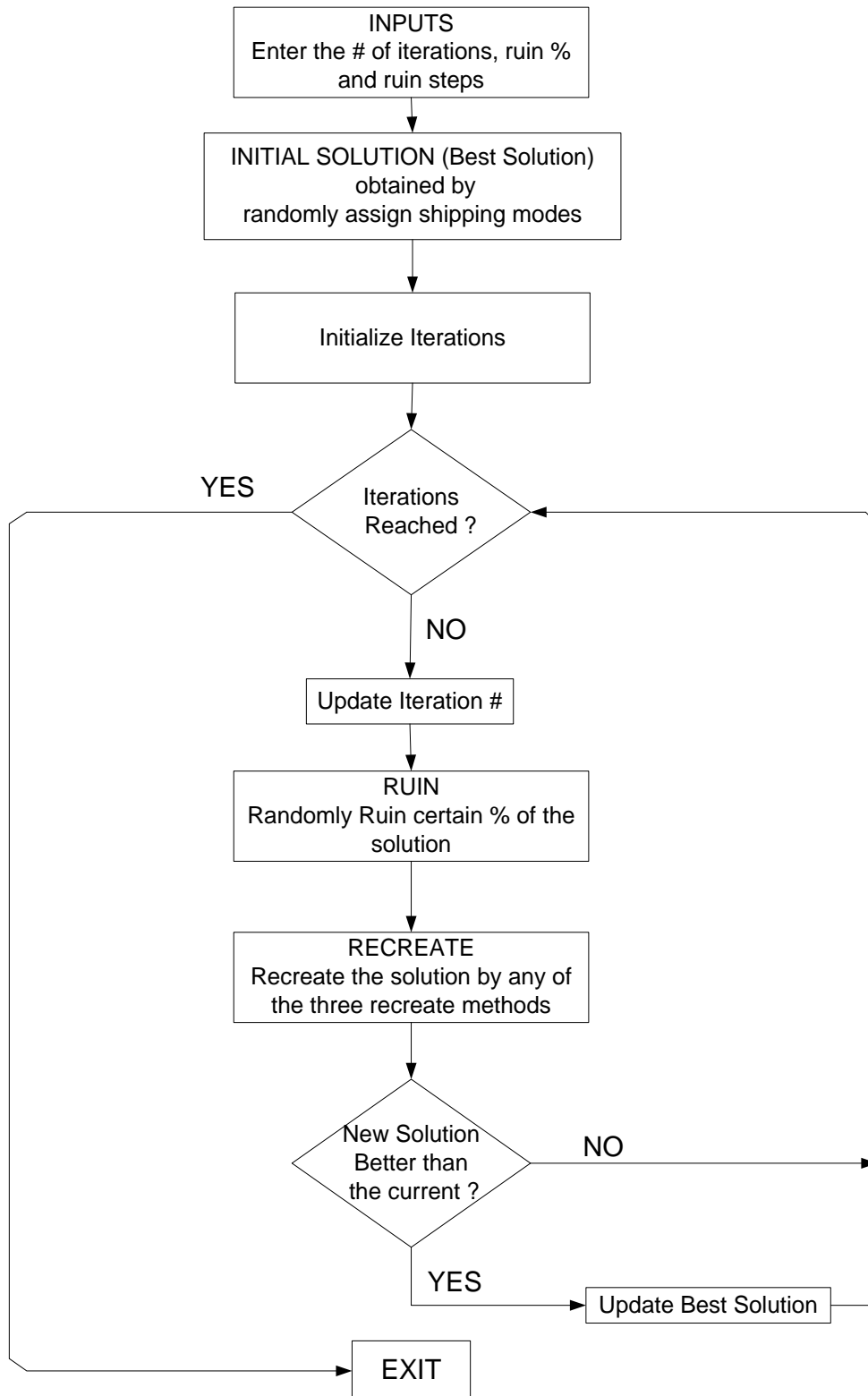


Figure 4. Flow chart of ruin and recreate algorithm

### **4.3 Steps Involved in the Proposed Ruin and Recreate Heuristic**

- Step 1* Randomly generate an initial solution and calculate total cost.
- Step 2* Treat the initial solution as the current best solution.
- Step 3* Randomly ruin certain % of the best solution and keep the rest of the solution as such.
- Step 4* Based on the recreate method chosen out of the three, assign new shipping modes to the products.
- Step 5* Separate the ruined products based on the new shipping modes assigned.
- Step 6* Check whether the products that are assigned with shipping mode '0' fit into the warehouse space, if they do keep their shipping modes as '0', otherwise change them to shipping mode '1.'
- Step 7* Join all the ruined products into the left over existing solution which makes it the 'new solution' and calculate total cost.
- Step 8* Check whether the new total cost obtained is better than the previously obtained. If the newly obtained solution has a lower cost, the replace the best solution with the newly obtained solution.
- Step 9* If the stopping criteria are not met, then go to Step 3; otherwise exit with the current best solution.

### **4.4 Ruin and Recreate Methods**

In the heuristic, we employ one ruin method and three recreate methods. Each iteration of the heuristic goes through a series of systematically designed ruin cycles, as detailed below.

#### **4.4.1 Ruin Method**

There are numerous ways in which an existing solution can be ruined such as random, sequential, sorted, and grouped [13]. In this heuristic a random ruin method is used to remove a part of the existing solution. The ruin is controlled by the percentage of solution to be ruined in each iteration. The products that are to be ruined are selected randomly from the pool of products each time. The number of products selected each time in turn depends on the percentage of solution to be ruined.

At initiation, the ruin ‘start percentage’ and the ‘end percentage’ are provided with a step count. For example, if the start percentage is 30% and the end percentage is 10% with a step count of 10%, during each iteration, the algorithm would randomly ruin 30% of the existing solution, then 20%, and finally, 10% in the third iteration. The solution is recreated using one of the methods described in the next section for each %-ruin and the new solution compared against the current best. The cycle would begin again from the start percentage during the next iteration.

#### **4.4.2 Recreate Methods**

Three recreate methods are designed in an attempt to change the solution of the ruined products. These methods are approaches that a manager may pursue when solving this problem on a per-product basis. The algorithm randomly chooses the recreate method after each solution-ruin avoiding successive selections of the same method. The recreate methods employed in this research are described below.

##### **4.4.2.1 R-value**

The  $R$ -value for a product  $p$  is calculated using the following expression:

$$R - value = \frac{\text{Cost of drop - shipping}}{\text{Cost of shipping via - DC}}$$

If the cost of drop-shipping for a product  $p$  is cheaper than the cost of shipping via-DC, the  $R$ -value would be  $< 1.0$ . Similarly, if the cost of shipping via-DC for product  $p$  is cheaper than cost of drop-shipping, the  $R$ -value would be  $> 1.0$ .

After the  $R$ -values are calculated for all the ruined products, the products are then sorted in a non-increasing order of their  $R$ -values. Once sorted, the products that have  $R$ -value  $< 1$  are assigned the drop-shipping mode; i.e., ship mode,  $z_p = 1$ . The remaining products, starting with the product with the highest  $R$ -value, are checked for warehouse space. If the products fit into the warehouse they are assigned ship-mode,  $z_p = 0$ ; if not they are put on drop-shipping mode,  $z_p = 1$ .

#### **4.4.2.2 Based on Order Quantity**

The total order quantity across all customer requests for each of the ruined products is calculated. Based on the total order quantity, the ruined products are sorted in a non-increasing order. Once sorted, the product that has the highest order quantity is checked against available warehouse space. If the product can fit into the warehouse, it is so assigned; if not, it is assigned the drop-shipping mode. This logic follows the general understanding that fast moving products must be placed in the warehouse, rather than drop-shipping them.

#### **4.4.2.3 Based on Number of Requests**

Chopra [1] mentions that the fast moving products are to be stored in the warehouse where as the slow moving are meant to be drop-shipped. This recreate method is

designed accordingly. The number of times a request has been placed across all customers is calculated for each of the ruined products. These products are then sorted in decreasing order of their number of requests. The ruined products with the highest number of requests receive a higher priority of being stored in the warehouse than the rest. Eventually, every product is checked whether it fits into the warehouse based on available warehouse space. If the products fit into the warehouse they are assigned ship-mode,  $z_p = 0$ ; if not they are put on drop-shipping mode,  $z_p = 1$ .



## 5 Experimental Results

### 5.1 Parameter settings

The MIP results are based six randomly generated data-sets (DSs). Table 4 describes the ranges for product-weight, product-volume, and product-holding cost in the warehouse, individual ordering cost, and bulk ordering cost per product.

Table 4. Parameter settings

$W_p$ (lb)	$V_p$ (ft <sup>3</sup> )	$C_p^H$ (\$)	$C_p^I$ (\$)	$C_p^B$ (\$)
0.1-0.5	0.02-0.1	0.10-0.15	6.0-6.1	1.8-1.9

Product weight and volume, and warehouse handling and holding costs correspond well with the type of products offered by Distributor X; ordering costs were estimated based on discussions with the warehouse manager and depends on the time spent when ordering the current technology (paper/phone-based vs. internet-based).

#### 5.1.1 Transportation Rates

Realistic transportation rates are used for solving the problem. Parcel rates based on the UPS zone rate chart are used for Warehouse to Customer and Vendor to Customer shipments whereas realistic LTL rates are used for Vendor to Warehouse shipments.

##### 5.1.1.1 Parcel Rates

The seven zones that UPS uses were employed, wherein Zone 1 being the closest and Zone 7 being the farthest from the start point as shown in a Figure 5 [14].



Figure 5. A sample UPS zone map

Each shipment to these zones is classified into two levels based on the weight (lbs). Shipment-weights below 70 lbs are considered to be in level 1 and weights above 70 lbs and below 150 lbs are considered to be in level 2. Figure 6 shows the rate differentiation between the two levels across different zones.

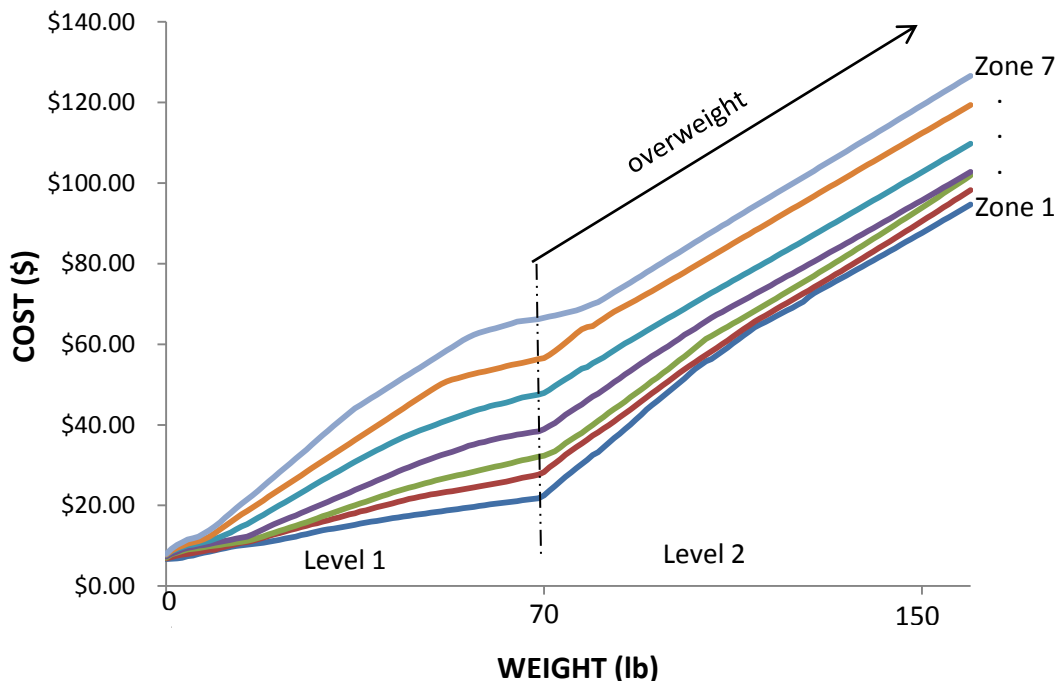


Figure 6. Parcel rate graph

**5.1.1.2 LTL Rates**

LTL rates are used for shipment weighing between 151 lbs and 20,000 lbs. Realistic LTL rates are used in the model for shipments between the vendor and the warehouse. Given that the warehouse orders products in bulk from each vendor, the shipments will usually weigh more than 150 lbs. The miles used in calculating LTL rates have been grouped into 4 zones and 4 levels similar to the parcel rates.

Table 5. Realistic LTL rates

	Level 1 (<1000 lbs)		Level 2 (1000-5000 lbs)		Level 3 (5000-20000 lbs)		Level 4 (>20000 lbs)	
	Fixed(\$)	Var(\$)	Fixed(\$)	Var(\$)	Fixed(\$)	Var(\$)	Fixed(\$)	Var(\$)
Zone 1 (<250 miles)	60.80	0.28	60.80	0.16	60.80	0.10	60.80	0.04
Zone 2 (250-500 miles)	128.39	0.36	128.39	0.22	128.39	0.14	128.39	0.06
Zone 3 (500-70 miles)	218.34	0.46	218.34	0.28	218.34	0.18	218.34	0.08
Zone 4 (> 750 miles)	379.59	0.66	379.59	0.39	379.59	0.26	379.59	0.11

Var - Variable costs

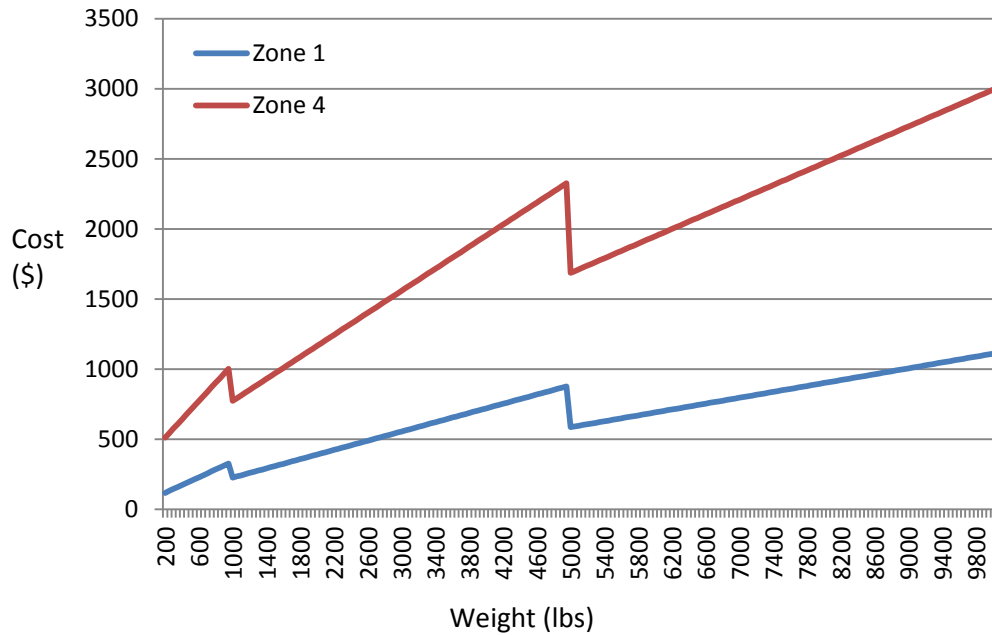


Figure 7. LTL rate graph

## 5.2 MIP Results

Table 6 shows results obtained from the five data-sets with increasing number of products. The data-sets are compared across three distribution strategies; all products in the warehouse (All in warehouse; current strategy at Distribution X), all products drop-shipped (All drop-shipped), and drop-shipping as an option (With DS option). The percentage of products to be drop-shipped completely varied between 30% and 56%, while the associated cost savings ranged between 2.9% and 5.2%.

It can be observed that there is a 28-53% space savings associated with the DS option as compared to the all-in-warehouse strategy. The saved space may now be used for value-added activities in the warehouse. In the case of Distributor X, space savings means less space to be leased from a third-party provider, which means further reduction in the distribution cost. The management of Distributor X also pointed out the possibility of leasing out to other companies (and generate revenue) any additional space that could be saved in their warehouse. They pointed out a specific company that closed its warehouse in the region, but wanted to lease space from Distributor X to support its current customer base in that region.

Table 6. Comparison of three distribution strategies

DS	Products	All in Warehouse (Whse) (\$)	All Drop-shipped (\$)	With drop-shipping option (DS opt) (\$)	% of prod drop-shipped	Space Savings (Whse vs. DS opt) (%)	Cost savings (Whse vs. DS opt) (%)	Gap %	Time Taken (sec)
1	10	49619.9	48513.7	48162.4	30.0	28.0	2.90	0	63.3
2	15	63028.0	64256.8	60784.5	40.0	38.6	3.60	0	28.2
3	20	64528.2	62760.9	61173.5	40.0	46.5	5.20	0	528
4	25	78912.2	76384.3	75183.8	56.0	53.3	4.70	0	3638
5	30	101254	102442	101254.0	50.0	52.6	4.10	1.01	21602
6	50	144149.1	155810	139574.3	53.0	57.2	3.17	3.1	21602
7	75	169101.5	165257.9	OM	-	-	-	-	21602

OM- Out of memory

Our initial experiments indicate that the model is sensitive to network structure (i.e., location of vendors, warehouse, and customer locations), demand pattern, and costs. The Xpress optimization suite is able to solve 30 products to optimality and the %-gap kept increasing for the datasets with product quantity above 30 (with a fixed 6-hr solution time-limit). In dataset 7, the system could not run the problem as it went out of memory.

### 5.3 MIP and Heuristic Comparison

The solution quality and performance of the RR heuristic is compared with that of the MIP model. The ruin start % is set to 30 and the end ruin % to 10 with a step of 10% decrease for iteration. The total number of iterations is set to 3000. The results are presented in table.

Table 7 indicates that the RR heuristic is able to achieve optimal solutions for small problem instances. The average % difference between the MIP and heuristic is found to be 1%, with a maximum of 3.4%.

Table 7. MIP-Heuristic comparison

DS	Products	MIP (\$)	RR Heuristic (\$)	%DS	% Difference
1	10	48162.4	48162.39	30.0	0
2	15	60784.5	60784.47	40.0	0
3	20	61173.5	61173.49	40.0	0
4	25	75183.8	75207.32	58.0	0.03
5	30	101254.0	104827.3	63.0	3.4
6	50	139574.3	143342.8	52.0	2.62

## 5.4 Case Study

Realistic data was obtained from Distributor X located in Midwest USA. Distributor X handles promotional products like shirts, mugs and pens etc. The data is of a particular customer who has offices across the US. There are about 159 customer locations and the demand data had order requests for 89 products from various customer locations across a time period of 6 months. The 89 products are manufactured by 23 vendors who are also spread across USA.

Using the cost parameters as mentioned in Section 5, the problem is solved using the MIP model developed. Table 8 shows the results obtained for the realistic data.

Table 8. Results obtained from the realistic data provided by Distributor X

<b>Products</b>	<b>All in Warehouse (Whse) (\$)</b>	<b>All Drop-shipped (\$)</b>	<b>With drop-shipping option (DS opt) (\$)</b>	<b>% of prod drop-shipped</b>	<b>Space Savings (Whse vs. DS opt) (%)</b>	<b>Cost savings (Whse vs. DS opt) (%)</b>
89	5903.11	4772.52	4028.27	15	23	31

## 6 Conclusion

Motivated by a real-world problem at a promotional products distributor, a mixed integer programming (MIP) model was developed to identify products that should be completely drop-shipped. The distributor's need to consider drop-shipping was largely driven by the difficulty in selling logoed-products to customers who had shrunk their business or had gone out of business due to the recent economic turmoil. This is the first model in the literature that jointly considers the location of vendors and customers with respect to the warehouse, warehouse space and handling cost, inventory holding costs, differential ordering costs, and all-unit transportation rates for both LTL and parcel.

Experiments using the MIP model on randomly-generated data-sets suggested that for small problem-sizes up to 25 products with 5 vendors and 100 customers, up to 56% of products may be amenable to drop-shipping in a promotional products environment. The corresponding space and cost savings ranged between 28-53% and 2.9-5.2%, respectively. Saved space also has cost savings implications as less required space means less (or no) space to lease from a third-party provider and/or it could be used to generate revenue by leasing it to other companies.

As the MIP model was not able to solve relatively large-sized problems (i.e., thousands of products across hundreds of customer locations), a Ruin and Recreate heuristic was developed. Preliminary results indicate that the RR heuristic performed reasonably well in terms of solution quality and time when compared to the MIP model.

A case-study involving realistic data obtained from Distributor X was presented. The problem was solved using realistic transportation and warehousing costs. We observed



that 15% of the products could be drop-shipped, resulting in a savings of 31% in both space and distribution costs.

The potential areas for future research include conducting sensitivity analyses on various demand patterns (order quantity and number of requests), network structures, and warehouse space availability. In so doing, we expect to develop managerial insights into this problem. It is possible to modify the MIP model to relax the 0-1 assumption on the product's shipping mode; via warehouse or drop-ship. Considering multiple warehouses and multiple sourcing across these warehouses vendors in the presence of stochastic demand would be an interesting avenue for future research.

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