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I, Heng Zhou, hereby submit this original work as part of the requirements for the degree of Master of Science in Mechanical Engineering.

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Inventory Management and Inbound Logistics Optimization for a Food Processing Company

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Abstract

Inbound logistics can be described as a process where large sets of raw materials from numerous vendors are transported to their designated factories to fulfill the production needs. Traditionally, more emphasis has been put on outbound logistics management. Inbound logistics share the same important role as the outbound one since it'll determine the raw material purchasing price from each vendor for the company.

This work focuses on the inventory management and network distribution design part by measuring the new inventory holding policy and transportation strategy adopted for a food processing company in the Midwest. The current inventory management situation of the company is that too much safety inventory amount has been carried. Regarding to the inbound logistics, the raw material vendors seldom do the freight consolidation, as a result more trucks have to be dispatched to fulfill the production needs of the factories.

First a normal distribution inventory consumption model will be introduced to calculate the optimal safety inventory amount in the inventory management part. Next in the transportation network design part, Gurobi linear optimization tool will be used to determine the best consolidation location for each particular material. A "Grouping method" based on different constraints will be adopted to transport goods from

consolidation points to their designated factories.

After the implementation of the new inventory management strategies, the new safety inventory amount has been dramatically cut down which will lead to a much lower inventory holding cost for the company. Also through the consolidation and grouping processes for the raw material, we are able to fully utilize the capacity of each truck and dramatically decrease the truck dispatching times to further lower the inbound transportation cost for the company.

In this study, we are facing up to several new constraint like the goods with different temperature cannot be transported together which has seldom been done before. Also to treat either of the factories as a consolidation point is a feasible method to avoid extra transshipment point building cost. This study deals the inventory management and transportation design part separately. In the future study, we may try to integrate them into a single problem to further discover their interaction.

Table of Contents

Abstract	1
Table of Contents	4
Acknowledgement	6
1. Introduction	8
2. Literature Review	10
2.1 Introduction to Inbound logistics	10
2.2 Ways to Improve Inbound Logistics Supply Chain	12
2.2.1 Using Cross-docking Terminals	12
2.2.2 Through Modularization	15
2.2.3 Through Just-in-time (JIT) procurement-production and delivery system	16
2.2.4 Introduction to JIT delivery system	17
2.2.5 Introduction to JIT procurement-production system.....	19
2.3 Two Models of Inbound Logistics Formulation Methods	20
2.3.1 A nonlinear integer programming model	20
2.3.2 Model based on JIT system.....	24
2.3.3 Comparison and Limitation analysis of the two formulations	30
3. As-is Inbound Logistics Network Description	34
4. Inventory Management	39
4.1 Problem Formulation	39
4.2 Baseline Analysis	40
4.3 New Inventory Management.....	42
4.4 Sensitivity Analysis.....	49
5. Transportation Network Distribution Design	52
5.1 Problem Formulation	52
5.2 Baseline Transportation Cost	55
5.3 Consolidation Point Determination.....	56
5.4 Transportation Costs to Consolidation Points	60
5.5 Transportation Costs to Designated Factories.....	61
6. Results and Conclusions	64
7. Limitations and Future Research Scope	65
References	67

List of Figures

Figure 1: Schematic Representation of a Cross-docking Terminal

Figure 2: Multi-vendor milk-run transportation system

Figure 3: JIT procurement-production system with a shared transporter

Figure 4: Current Inbound Network Map

Figure 5: Baseline Cost for the 4 Factories

Figure 6: A Typical Example for Inventory Management Condition

Figure 7: Safety Inventory Profile

Figure 8: Calculation Interface in Excel

Figure 9: Optimized Total Costs for the Company

Figure 10: Safety Inventory Quantity for Factory A by Varying CSL

Figure 11: Safety Inventory Quantity for Factory B by Varying CSL

Figure 12: Safety Inventory Quantity for Factory C by Varying CSL

Figure 13: Safety Inventory Quantity for Factory D by Varying CSL

Figure 14: Fixed costs based on weights and temperatures

Figure 15: Baseline Transportation Cost

Figure 16: Grouping Example

Figure 17: Transportation Costs to Consolidation Points

Figure 18: Mileage Chart among Factories

Figure 19: Total Transportation Cost to Factories

Figure 20: Inventory Holding Costs Comparison

Figure 21: Transportation Costs Comparison

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1. Introduction

This work mainly deals with the inventory management and transportation strategy optimization aspects within the inbound logistics for a food processing company in the Midwest. In the current scenario, the company holds exceeding amount of safety stock and this will lead to high inventory holding cost. Regarding to the current raw material transportation method, the company seldom do the freight consolidation which will lead to high truck dispatching times and waste of truck capacity, all these will incur high inbound transportation cost for the company. The baseline total costs for both parts will be calculated and further compared with the optimized results.

The inbound logistics are comprised of several elements, namely the vendors, factories and the consolidation points. It's extremely crucial to coordinate well among these elements to lower the raw material purchasing cost for the company.

A normal distribution weekly consumption rate model will be adopted to calculate the optimal safety inventory amount.

In the transportation design part, Gurobi optimizer tool will be used to determine the ideal consolidation point for each particular raw material from different vendors. Then the raw materials will go through grouping process to their destination based on the several constraints like the temperature and designated factory to fully utilize the

capacity of each truck.

2. Literature Review

2.1 Introduction to Inbound logistics

Inbound Logistics can be defined as “all the activities of receiving, storing and disseminating incoming goods or material for use”. [1] It mainly deals with the management of transport and storage for raw materials received by a business. While outbound logistics may involve the management of transport and storage for finished goods dispatched by a business.

In nowadays global competitive environment, supply chain management is a major concern for a company. Two key factors are transportation and inventory management within the supply chain. In order to achieve great savings, companies should select the suitable distribution strategy for delivering a family of products from a set of suppliers to a set of plants so that the total transportation and inventory costs can be minimized. These require a company to integrate the two issues (transportation and storage) instead of treating them separately in the inbound logistics management. [2]

We know in a typical supply chain, there exist sets of supplier and plants. Products like raw material or parts are shipped from suppliers to plants to be further processed. Take an example, consider a car assembling plant, the plant will not produce all the parts required for the whole assembly. It typically procures the required parts from

sets of suppliers, such as engine supplier, a tire supplier, etc. One supplier may produce one or more types of assembling parts. Usually it will satisfy the demands of one or more assembling plants. For most of the companies, products are shipped from a supplier to a plant by trucks. [2] In our case of the food processing company, the factories will procure raw materials like beef, pork, cheese etc. from numerous of vendors. It will also order some finished materials like the plastic containers from related vendors. Here we classified the truck delivery strategies within inbound logistics into three categories:

1. Direct: Trucks travel directly from a supplier to a plant without any stop.
2. Milk-run (peddling): Trucks pick up products at one or several suppliers and deliver them to one or several plants and this policy is adopted by the food processing company.
3. Cross-dock: Products are delivered from suppliers to a cross-dock, and then from the cross-dock to plants.

For different distributions strategies, there are different transportation cost and time. Direct delivery has the shortest distance, and therefore the lowest transportation cost and the shortest delivery time. A delivery through a cross-dock has the longest distance, and therefore the highest transportation cost and the longest delivery time.

When each truck is fully or almost fully loaded (which is appropriate for the case when the amount to be shipped is fairly large), because direct delivery can only consolidate the products from the same supplier to the same plant, low delivery frequency and high plant inventory are incurred. Cross-dock can combine products from different suppliers, which leads to high delivery frequency and low plant inventory. [2]

In today's inbound logistics management, Direct and Cross-dock options are the most commonly used ones. We can easily see that there is a trade-off relationship between transportation costs and inventory holding costs within the two options. The aim of inbound logistics planning is to minimize the total transportation and storage costs by selecting the best distribution strategy.

2.2 Ways to Improve Inbound Logistics Supply Chain

2.2.1 Using Cross-docking Terminals

A cross docking terminal is an intermediate node in a distribution network which is exclusively dedicated to the transshipment of truck loads. Compared to traditional warehouse, a cross dock carries no or at least a considerably reduced amount of stock. [3] It served as a consolidation point of inbound products and offers short cycle

times.[4] Incoming shipments delivered by inbound trucks are unloaded, sorted and loaded into outbound trucks waiting at the dock, which forward the shipments to the respective locations within the distribution system. Compared to traditional warehousing, the costs of storage and retrieval of goods is eliminated by a synchronization of inbound and outbound flows. A major advantage of cross docking is that economies in transportation cost can be realized by consolidating divergent shipments to full truckloads without depending on inventories at the cross dock. [5][6]

As can be seen above, the primary purpose of a cross dock is to enable a consolidation of differently sized shipments with the same destination to full truck loads, so that the economies in transportation costs can be realized. [6] This advantage makes cross docking an important logistics strategy receiving increased attention in today's globalized competition with its increasing volume of transported goods. Success stories about considerable competitive advantages realized due to the use of cross docking terminals are reported for many industries with high proportions of distribution costs like rental chains, mailing companies, automobile producers and less-than-truckload logistics providers [5]

A schematic representation of the material handling operations carried out at a cross docking terminal is depicted in Fig. 1. [3] Incoming trucks are either directly assigned to a receiving door upon arrival, or have to wait in a queue on a yard until they are assigned. Once docked, the products, i.e. pallets, packages or boxes, of an inbound

trailers are unloaded and scanned to identify their respective destinations. [7] Then products are taken over by some means conveyance. This might be a worker running a fork lift, e.g. in retail industries, or some kinds of automated conveyor belt system, e.g. in mail distribution center. The goods are forwarded to the designated shipping door, discharged in front of the outbound trailer and then loaded onto it. Once an outbound (inbound) trailer has been completely loaded (unloaded), it is removed from the dock, replaced by another trailer and the course of action repeats. [5]

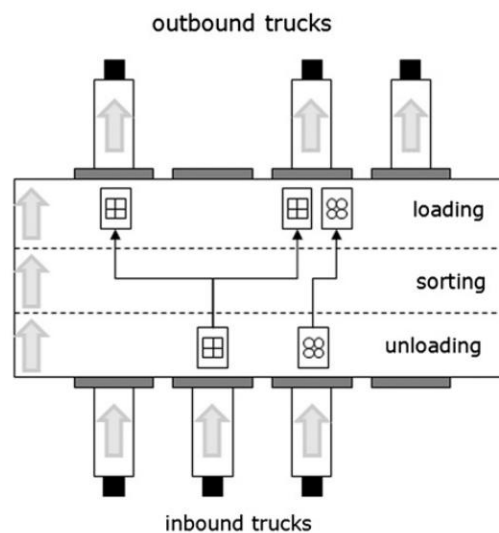


Fig. 1 Schematic Representation of a Cross-docking Terminal [3]

In contrast to traditional point-to-point deliveries, an additional transshipment of goods at the cross docking terminal slows down the distribution process and generates a significant amount of double handling. Consequently, efficient transshipment processes are required where inbound and outbound truckloads are synchronized, so that intermediate storage inside the terminal is kept low and on-time deliveries are ensured. [3]

In order to realize the purposes posted above, people introduced several scheduling procedures to work out the truck scheduling problems. Normally, these scheduling problems mainly deals with the distribution or arrangement of resource over time to carry out sets of tasks being part of some processes. We are going to make some optimal decisions during the life cycle of a cross-docking terminal. The decisions are as follows:

- (1) Location of cross docking terminal(s).
- (2) Layout of the terminal.
- (3) Assignment of destinations to dock doors.
- (4) Vehicle routing.
- (5) Truck scheduling.
- (6) Resource scheduling inside the terminal.
- (7) (Un-)Packing loads into (from) trucks.

2.2.2 Through Modularization

In this introduction, modularization is related to inbound logistics as the combination of different components or say modules which allow for the assembly of the final products.

Starr (1965) first introduced the concept of Modularization in the literature. It implies a product design approach whereby the product is assembled from a set of standardized constituents units. Different assembly combinations from a given set of standardized units give rise to different end-product models and variations. Thus, modular design effectively marries flexibility (of the end product) with standardization (of constituent parts). It provides opportunities for exploiting economies of scope and scale from a product design perspective. The key issue here is to design for efficient linkage mechanisms in the constituent units so that any required combination can be conveniently assembled. This implied flexibility has other related advantages in a manufacturing context. In particular, the higher the level of modularization, the easier it is to outsource manufacturing or its constituent components. [8]

2.2.3 Through Just-in-time (JIT) procurement-production and delivery system

Just-in-time (JIT) procurement is one of the important elements of lean production system. Successful implementation of JIT needs vendor-manufacturer cooperation on small lot size delivery and inbound logistics cost reduction. [9]

JIT or lean production is primarily an empirical philosophy, which was initially successfully implemented in Toyota Company. Broadly, a JIT system is a strategically

optimal combination of purchasing, inventory control and production management function. The JIT ideas contain high quality, small lot sizes, frequent deliveries short lead times, close contact with suppliers, kanban control, total employee involvement and continuous improvement and refinement of the stated system parameters over the past data. Because JIT is an overall organization phenomenon, significant gains can be achieved when JIT is practiced in an integrated system. Therefore, developing a long-term cooperative relationship between buyers (manufacturers) and the suppliers (vendors) for purchasing is important for a successful JIT operation. JIT purchasing is an integrated procurement-production system, which emphasizes on vendors (suppliers) and a manufacturer's cooperation based on mutual trust and sharing benefit and risk. Thus, JIT purchasing practice has attracted more attention than any other practices. [9]

2.2.4 Introduction to JIT delivery system

The main problem exists in the JIT procurement system is the trade-off between reduction of inventory cost due to small lot sizes and the increase of transportation cost due to the high materials delivery frequency. Transportation is of primary concern in JIT procurement as the transportation cost is dependent on the number of trips between the vendors and the manufacturer. There are two types of procurement delivery systems in a multi-vendor supply network: (1) shared transportation system in which each vendor shares a common truck (which is also called milk-run

transportation system), (2) independent (dedicated) transportation system in which each vendor has its individual transportation trucks. Both transportation systems have advantages and disadvantages. Actually in reality, a transportation system may be operated by the manufacturing company itself, or by an independent third party (company) which is commonly known as third party logistics (TPL). [9]

Here we suppose a manufacturer has three vendors supplying parts as shown in Figure 2. [9] Thus, the manufacturer and three vendors form a JIT procurement-production system in which a shared transporter delivers parts from the vendors just in time to the manufacturer. That is, in production cycle, the truck goes around three vendors to pick up parts from the vendors and transport those (parts) to the manufacturer. Hence, the transportation cost is expected to be reduced. [9]

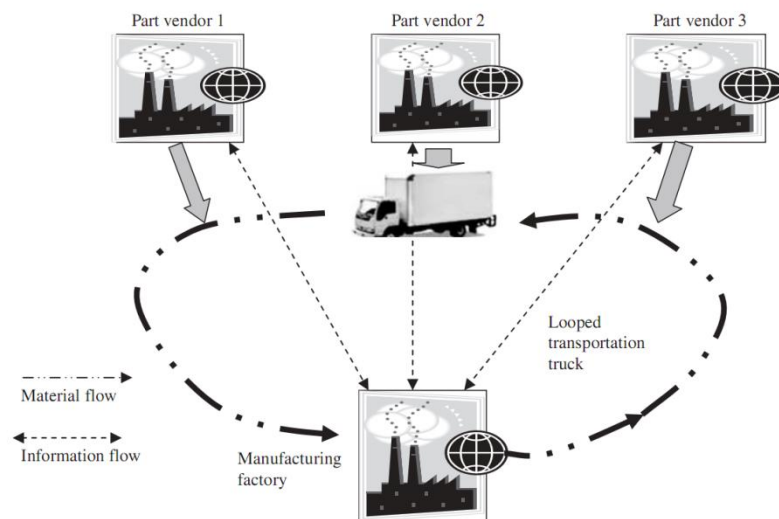


Fig 2. Multi-vendor milk-run transportation system [9]

2.2.5 Introduction to JIT procurement-production system

Suppose an assembly (manufacturing) system requires different parts/components supplied by several vendors. In a JIT procurement system, vendors form a long-term partnerships with a manufacturer, and they share demand information. Under this condition, a supply system is different from those of non-JIT vendors in that it is not necessary to frequently place orders to vendors. It can utilize JIT partnership to construct a supply and demand coordination mechanism to reduce the ordering cost (eg, through a yearly meeting at a fixed time to reduce the number of orders). Meanwhile, the inventory cost is also reduced by small lot size delivery policy. Nevertheless, the total transportation cost increases due to the increased numbers of deliveries. In order to reduce the transportation cost, a JIT delivery of shared transportation system is proposed. Figure 3 [9] depicts this JIT procurement-production system. [9]

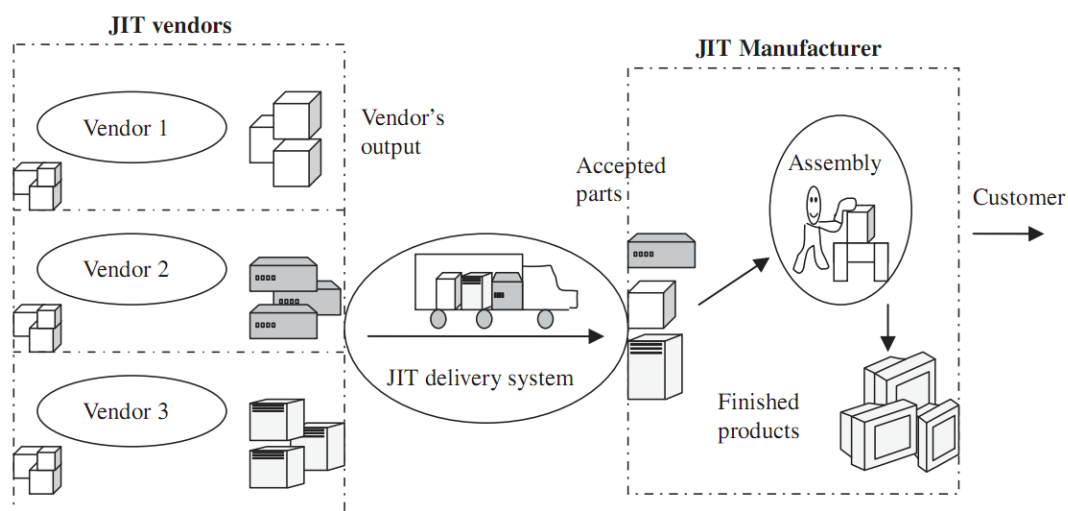


Fig 3. JIT procurement-production system with a shared transporter [9]

2.3 Two Models of Inbound Logistics Formulation Methods

2.3.1 A nonlinear integer programming model

This proposed model is a typical one which is used to solve the problem of choosing the optimal distribution option for transporting a family of products from a set of suppliers to a set of plants so that the total transportation, pipeline inventory and plant inventory costs can be minimized. Our formulation purpose here is to establish the objective function ready to be minimized.

Before we carry on to construct the objective function, we should make several assumptions about our product quantities and frequencies:

- (1). We assume that the products can be infinitely split, that is product can be shipped in any quantity within a vehicle shipment.
- (2). The delivery frequency can be assigned to any positive number and is not limited to a set of potential numbers.

Some operational details have been ignored by assuming that:

- (3). Products are always available for shipping at suppliers, not matter which distribution strategy is chosen.
- (4). Inbound-outbound coordination at the cross-dock is ignored.
- (5). All units of the same flow (a flow is a combination of supplier, plant, and product)

are assigned to the same transportation option, i.e., direct or through the same cross-dock.

(6). Each truck is fully loaded. Only the volume of products is concerned when calculating truck capacity usage. The transportation costs are only determined by the source and destination, regardless of the weight. [2]

We want our case here to be a special one, so we made the assumptions as follows:

- (1). The demand rate for each product at each plant from each supplier is constant.
- (2). Only direct and cross-dock distribution strategies are considered.
- (3). Only one truck type is available.

Next we shall define a list of notations before further formulation. The notion of “period” has been introduced for measuring quantities. Note that the period can be defined as a week, a month or any time unit preferred. Here we use t_{ij}^d , t_{ik}^i , and t_{kj}^o to express the ratios of transportation time to their designated periods. Take an example, if a period is one week, then $t_{11}^d = 3/7$. Also we may decrease the number of categories of products by grouping the similar products together. For example, consider a paint supplier which supplies paints to automobile assembly plant. The color of the paint may varies a lot for like tens or thousands, however the price and the capacity each kind occupies are almost the same. Therefore we can group all these paints as a single product. Also through using this method, we are able to reduce the goods flow within the supply chain dramatically. The listings are as follows [2]:

I : set of suppliers

J : set of plants

P : set of products

K : set of cross-docks

C : truck capacity

c_{ij}^d : direct transportation cost of shipping one truckload of products from supplier i to plant j

c_{ik}^i : inbound transportation cost of shipping one truckload of products from supplier cross-dock k to plant j

t_{ij}^d : direct transportation time (periods) from supplier i to plant j

t_{ik}^i : inbound transportation time (periods) from supplier i to cross-dock k

t_{kj}^o : outbound transportation time (periods) from cross-dock k to plant j

T_k : time spent in transferring from inbound to outbound at cross-dock k

b_p : truck capacity occupied by one unit of product p

h_p : inventory-carrying cost of one unit of product p per period

d_{ijp} : demand of product p required from supplier i by plant j per period

$F = \{(i, j, p) : i \in I, j \in J, p \in P, d_{ijp} > 0\}$, set of flows

$F_j = \{(i, j, p) : i \in I, p \in P, d_{ijp} > 0\}$, set of flows to plant j

$F_{ij} = \{(i, j, p) : p \in P, d_{ijp} > 0\}$, set of flows from supplier i to plant j

$P_{ij} = \{p : (i, j, p) \in F_{ij}\}$

$IP_j = \{(i, p) : (i, j, p) \in F_j\}$

Here, our ultimate function should be a compact one. So here we introduce a dummy variable, that is cross-dock 0. If we assigned a flow to cross-dock 0, this means it is actually shipped directly. We can make this variable equal to 1, if the flow is shipped through the cross-dock, or otherwise 0. The mathematical formulation of the problem

can be expressed as follows:

$(P) \min \sum_{k \in K^0} g_k(X)$ (1) which subjects to:

$$\sum_{k \in K^0} x_{ijk} = 1 \forall (i, j, p) \in F, (2)$$

$$x_{ijk} \in \{0,1\} \forall (i, j, p) \in F, k \in K^0, (3) [2]$$

Here X is the vector of the decision variable. $g_k(X)$ can be treated as the total sum of transportation, pipeline inventory and the plant inventory costs incurred from the shipping flows through the cross-dock. Constraint (2) can guarantee that each flow is transported while (3) ensures that one specific flow must follow the same route.

Now let's establish the objective function. We shall first establish function $g_0(X)$ as the total cost of the direct delivery. We can divide this function into several parts: frequency of shipment, transportation cost and the plant inventory costs and they are:

$$f_{ij}^d = \sum_{p \in P_{ij}} b_p d_{ijp} x_{ijp0} / C$$

$$f_{ij}^d c_{ij}^d$$

$$f_{ij}^d c_{ij}^d = \sum_{p \in P_{ij}} t_{ij}^d h_p d_{ijp} x_{ijp0}$$

$$\sum_{p \in P_{ij}} h_p d_{ijp} x_{ijp0} / (2 f_{ij}^d) [2]$$

The next step is to add the equations above together then derive the total direct delivery cost. Also through using some mathematical relationship (not presented here for their complexity), we have:

$$g_0(X) = \sum_{i \in I} \sum_{j \in J} \left[\sum_{p \in P_{ij}} \bar{c}_{ijp0} d_{ijp} x_{ijp0} + \frac{\sum_{p \in P_{ij}} h_p d_{ijp} x_{ijp0}}{\sum_{p \in P_{ij}} \bar{b}_p d_{ijp} x_{ijp0}} \right] [2]$$

After that, let's present the ultimate objective function $g_k(X)$ which is the total cost

of shipping flows that travel through cross-dock k . Here our transportation costs are comprised of two sections. They are inbound and outbound transportation costs. We can also express the frequency of the inbound shipment, total inbound transportation cost, frequency of the outbound shipment and the total outbound transportation costs (not presented here, they can be seen from the ultimate function)

Because the transportation time for shipping flow (i, j, p) through cross-dock k is $(t_{ik}^i + T_k + t_{kj}^o)$, the pipeline cost is $(t_{ik}^i + T_k + t_{kj}^o)h_p d_{ijp} x_{ijpk}$ and the plant inventory cost is $d_{ijp} x_{ijpk} / (2f_{kj}^o)$. Hence, the final function is obtained by adding all sections together [2]:

$$g_k(X) = \sum_{j \in J} \left[\sum_{(i,p) \in IP_j} \bar{c}_{ijpk} d_{ijp} x_{ijpk} + \frac{\sum_{(i,p) \in IP_j} h_p d_{ijp} x_{ijpk}}{2 \sum_{(i,p) \in IP_j} \bar{b}_p d_{ijp} x_{ijpk}} \right]$$

From the function above, one can easily see that this function is neither concave nor convex. So this model can be seen as the so-called “nonlinear integer model”.

2.3.2 Model based on JIT system

This proposed model is a joint-inventory one which is constructed under a situation of multi-vendor and single buyer. This situation tends to be much more practical compared to the traditional single-vendor and single-buyer one. The model integrated JIT delivery node and transportation cost into one model and it formulates a new ordering policy which can greatly cut down ordering cost compared to the traditional multiple , repetitive ordering policy.

The JIT policy for procurement, production and delivery will be adopted as a fundamental for modelling this inventory system in building this model. Our ultimate goal is to know the production lot sizes and the JIT delivery frequency for the vendors and manufacturers through formulation of this model. Before the formulation of the model, we shall introduce several assumptions and notations here:

Assumptions:

- (1) Multiple vendors supply parts to one manufacturer, note that this one just pretty much similar to the one made for our study case later (multiple vendors to a single factory)
- (2) The manufacturer and part vendors have contracts on a long-term basis to supply parts as demanded. JIT philosophy works between vendors and the manufacturer.
- (3) Demand of parts, finished products and delivery lead time are deterministic.
- (4) No shortages and backlogs are allowed.
- (5) The production rates at vendor's site are greater than the demand rate (as the vendor produced on demand).
- (6) The outbound logistics of the manufacturer is not considered in this integrated system.

Parameters:

c_0 : Production cost of a finished product (\$/unit)

c_s : Setup cost at the manufacturer (\$/setup)

c_i^v : Production cost of a vendor i ($i = 1, 2, \dots, n$) (\$/unit)

D : Demand of the finished product (unit/year)

D_i : Annual demand of parts from a vendor i ($i = 1, 2, \dots, n$) (unit/year)

F_0 : Fixed transportation cost per delivery trip (from a vendor to the manufacturer)
(\$/shipment)

H_i^M : The holding cost of part i at the manufacturer's site (\$/unit/year)

H_i^V : The holding cost of part i at the vendor i (\$/unit/year)

H^M : The holding cost of a finished product at the manufacturer (\$/unit/year)

p : Production rate of the manufacturer (unit/year)

P_i : Production rate of vendor i (unit/year)

S_i : The production setup cost of vendor i (\$/setup)

w_i : Weight of a unit part i (lbs/unit)

Decision variables:

m_i : Numbers of shipments of part i per vendor's (batch) cycle

q_i : Delivery quantity of part i per trip, $q_i = Q_i / m_i$ (units/shipment)

Q_i : Production lot size of parts of vendor i , $Q_i = m_i q_i$ (unit/year)

Q : Production lot size of the manufacturer (unit/year) [9]

Next we first model the cost function for vendors, manufacturer and transportation, and the total cost function is a composite function of these cost functions. The solution of this formulated problem is to minimize the total cost function.

Vendors' cost function

The problems for the vendors' are to determine the production policy (production lot sizes), delivery quantities and number of deliveries per production batch. The vendor's total cost (TC^V) can be expressed by adding the setup cost (TC^{setup}), production cost ($TC^{production}$) and the work-in-process (WIP) inventory cost (TC^{WIP}) together:

$$TC^V = TC^{setup} + TC^{production} + TC^{WIP} \quad [9]$$

For annual demand rate D_i of part i ($i=1,2,...,n$), holding cost of part at vendor i , H_i^V , and production rate P_i , the total cost $TC_i^V(Q_i, m_i)$ can be expressed in terms of batch size, Q_i and number of shipments, m_i as:

$$TC_i^V(Q_i, m_i) = \frac{D_i}{Q_i} S_i + c_i^V D_i + \frac{Q_i H_i^V}{2m_i} \left((2 - m_i) \frac{D_i}{P_i} + m_i - 1 \right). \quad [9]$$

We can see from the above equation, the first two terms are the setup cost and production cost for the vendor, the last term is the WIP holding cost which is worked out by Joglekar (1998).

Manufacturer cost function

After the materials are obtained from the vendors, they will enter the assembly procedure in order to procure the finished products. The costs for manufacturing are mainly comprised of four categories and they are: raw materials inventory cost,

machine setup cost, production cost and the finished product inventory cost. In order to make this problem simplified and present the result clearly and precisely, we may treat every stage for manufacturing process as one single stage. The JIT system will also operate via a single ordering pattern also there is no relationship between the ordering quantity and the ordering cost. So we don't need to consider ordering cost here. As a result, the total cost of manufacturer can be expressed as follows:

$$TC^M = TC^{raw} + TC^{setup} + TC^{production} + TC^{inventory} \quad [9]$$

Based on the above equation, from the right side, the first term is the holding cost of accepted parts from vendors which are stocked in the warehouse. The other remaining terms are machine setup cost, production cost and the finished inventory cost, respectively. We can express the above elements one by one through their relationship with demand rate D and the unit manufacturing setup cost c_s and the delivery quantity q_i . Here we are not going to consider the outbound cost for delivery of finished products from manufacturer to customers. The average inventory of finished products for the manufacturer is $Q(p-D)/2p$, the total annual inventory holding cost can be calculated as: $H^M Q(p-D)/2p$

So based on the above calculations, one can present the total manufacturing cost as:

$$TC_i^M(Q_i, q_i) = \sum_{i=1}^n \frac{q_i}{2} H_i^M + c_s \frac{D}{Q} + c_0 D + \frac{Q(p-D)}{2p} H^M \quad [9]$$

Transportation cost function

In the JIT delivery system, one of the key elements is transportation cost as can be seen in the above paragraphs. Actually the problem facing up to the JIT procurement is almost the same as other supply chain's. That is the trade-off between the inventory holding cost and the transportation cost. The purpose of adoption of JIT here is to select a best transportation strategy which can dramatically cut down the transportation cost.

The total transportation cost function is comprised of two parts. One is the fixed cost like shipment preparation and receiving cost. The other one is the variable cost because of goods volume variance. Here we use d_i to express the transportation distance from the manufacturer to vendor i , F_0 to represent the fixed cost stated above. Thus we can show the total transportation cost function as follows:

$$TC^{TPL} = TC^{FT} + TC^{VT} = F_0 N + \sum_{i=1}^n F_y^{TPL} D_i d_i w_i$$

Note that F_y^{TPL} is the freight rate in dollar per pound per mile which can reflect the comprehensive impact of transportation distance and weight on cost in the model. [9]

Total cost function of the integrated procurement-production system

Now it's pretty easy and straightforward to write our total cost function TC for the proposed model under JIT assumption as:

$$TC = TC^V + TC^M + TC^{TPL} \quad [9]$$

Combining all the equations (expansion form) stated above, we can obtain the total cost function $TC(Q, q_i, m_i)$ in details:

$$\begin{aligned}
TC(Q, q_i, m_i) = & \sum_{i=1}^n \left[\frac{D_i}{m_i q_i} S_i + c_i^v D_i + \frac{q_i H_i^v}{2} \left(m_i \left(1 - \frac{D_i}{P_i} \right) - 1 + 2 \frac{D_i}{P_i} \right) \right] \\
& + \sum_{i=1}^n \frac{q_i}{2} H_i^M + c_s \frac{D}{Q} + c_0 D + \frac{Q(p-D)}{2p} H^M \\
& + F_0 N + \sum_{i=1}^n D_i w_i d_i (1 + \alpha) F_x^{FTL} - \frac{\alpha F_x^{FTL}}{W_x} \sum_{i=1}^n (D_i d_i w_i \sum_{i=1}^n q_i w_i)
\end{aligned}
\tag{9}$$

Michelle L. F. Cheong [10] also proposed a Lagrangian Relaxation model to formulate a logistics network consolidation problem with lots of hubs and consolidations points. However in reality, there may be lots of suppliers, the number of hubs and warehouses will be very limited. The study case proposed in this paper will involve hundreds of suppliers. The Lagrangian model is also highly mathematical.

2.3.3 Comparison and Limitation analysis of the two formulations

For the above two formulations, the problems have all been converted into deterministic mathematical problems. Some assumptions and constraints shall be made before conducting further research. Then an ultimate objective function will be constructed ready to be optimized. The functions in most cases will deal with the final costs.

For the first nonlinear model, we divided the final objective function into two separate functions. The first function is regarding to the direct delivery costs which are consists of transportation cost, pipeline inventory cost and plant inventory cost. The other one is regarding to the costs of shipping flows that travel through the cross-dock k . This formulation didn't consider the situation for milk-run. We may also extend the model by including different types of truck and less-than-full-truckload strategies. We may have a truck fleet with different capacities. So choosing the type of truck of each route is also an important decision faced by management. Sometimes it may be beneficial to use the less-than-full-truck-load strategy, especially for expensive products with small physical sizes. In the future, we should include more details about the operation of the cross-dock issue, for example, the coordination issue and the inventory-holding issue at the cross-dock.[2]

For the second JIT model, we added the three cost functions for vendors, manufacturers and transportation together to achieve the final objective functions for the total costs. The model did provide a number of useful insights for improving the JIT supplying and procurement performance and collaboration between partners. But it also bears some limitations such as deterministic demand, simplified product assembly and cost structure, etc. In the future research work, several possible directions may be:

- (1). To combine safety factor into the inventory cost function. Although this is challenging, such an undertaking is more practical.

- (2). Since quality is always a problem and key factor in procurement behavior, another possible extension is to consider quality cost in the models when parts delivered from vendors do not qualify 100% acceptance.
- (3). To incorporate the transportation scheduling into the formulation, once the vendors opt to use independent trucks, this may resolve practical problems.
- (4). We all know this model only considers one single product. It would be valuable to extend this model to multiple products situation, in that it is also useful to analyze the optimal stock and delivery policy when some common parts can be used by different products.[9]

In this paper, the inventory storage cost and transportation costs have been treated separately. Opportunities will be discovered to consolidate the inbound shipments into multi-origin/destination routes, and highlight the freight savings potential for such routes to further lower the raw material unit price. In the distribution strategy, we will consider both the LTL (less than truck load) and the full truck load situation which tend to be more comprehensive. In the above first inbound logistics model, transportation costs have been assumed to have nothing to do with the weight, only with the distance which is far too idealized. This assumption may be suitable to the case of large truck load, but during our case, the truck loads may vary dramatically due to the highly-varied material demand rate.

Usually, the freights to be transported are normal temperature ones in most cases. This study will address raw materials with three different temperature transportation

problem. Such constraint like: goods with different temperature cannot be transported together will be considered here which have never done before. We will also take the plant itself as a consolidation point if needed, the regular stop-off charges can be waived in this method. Extra cross-dock facility construction fees have also been saved.

In the baseline situation, there are little integration and consolidation for the inbound logistics, only items from the same vendor can travel together. In this study, we may try to transport items from different vendors, and help the food processing company to carry out optimal inventory storage and transportation strategy.

3. As-is Inbound Logistics Network Description

The current inbound network is pretty simple and straightforward to understand, one can see below:

In the baseline inbound network of the company, there are two categories of nodes which form the current network. They are the “Vendors” and the “Factories”.

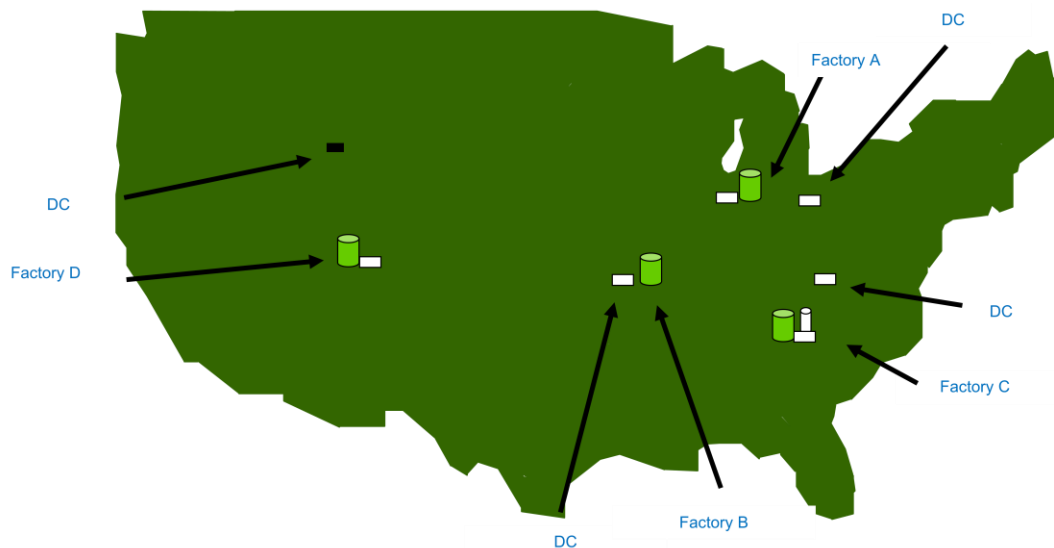


Fig 4. Current Inbound Network Map

As one can see above, there are 4 factories producing food across the US. They are A, B, C and D (for confidentiality reasons). Each factory will need different vendors to provide raw materials to fulfill its production needs. All the factories will run for seven days a week.

There are totally 213, 172, 179 and 160 vendors for factories: A, B, C and D respectively. According to the data, each vendor may supply raw materials to two or more factory, so the numbers presented above have overlapped part. For example, one of the vendors supplies one sort of powder both to A and C. Sometimes, within one factory, the same raw material can be supplied by different vendors. Take factory A as an example, one particular kind of beefs are provided by two different vendors. Also for a single vendor, it can provide different categories of materials to the same destination. For example, some vendor provides variety of peppers (color, box size and weight vary here) to factory A. We may consider grouping the goods here if the trucking capacity and temperature constraint permit, to cut down the transportation cost for the vendors to further lower the material purchasing price.

The raw material provided can be divided into “edible” and “non-edible” one. The edible material including cheese, pork, chicken, beef etc. which are added to make ingredients. Those food materials have different preserving temperature and here we assign them as: high, medium and low. For food safety concern, raw materials with different temperature cannot be transported together. Non-edible materials serve for packaging purpose such as trays and cartons. Based on my communication with the company, all the four factories share almost the same demand pattern except several raw material differences, thus they run concurrently. The data provide detailed information about which raw material is supplied to which factory and by what

vendor.

There are no cross-docks or DCs (distribution center) in the current inbound network. Noted that the DCs in the above map belong to the outbound logistics network. Each vendor will hire a third-party truck company to transport raw materials directly to a single factory. So there are no correlations between vendors. Also the transportation cost will not be counted in the total cost for the company, it'll be paid by the suppliers. However the transportation cost has been invisibly built into the unit price of the raw materials, so helping suppliers to optimize transportation network can also decrease the unit price. Occasionally the company will ask the vendors to transport raw materials for different factory needs into one single factory and that is to treat this factory as a consolidation point.

For every sort of raw material, each factory may carry some safety stock for fear of running out of materials while some won't. The safety stock quantity are always the same and that is 1,000 for each kind of material. Most of the inventory will stay untouched, some will be used for only a little bit. All these will incur huge safety stock cost. Besides, each factory also sets up safety inventory for each category of material they use. So the total safety inventory quantity here is the sum of the two. Currently there are no specific inventory cost calculation method used in the food company, we may build a global parameter here to estimate the holding cost reasonably, such as we can take percentage of the unit price to get the inventory

holding cost per year for one specific material. The raw material consumption rate follows a regular pattern for each factory, weekly or even daily consumption rate data may be requested to determine their mathematical distribution status.

As a result, the total cost incurred for the company is mainly comprised by inventory storage and handling cost, and the raw material purchasing cost (this part can be minimized by optimizing vendor's network distribution design). Our goal here is to minimize both of the two costs.

Next are some Brief Introductions about the Notations in the database:

Number of PO Lines: This is the number of times the raw material was ordered by the company.

Base Unit: Unit of measure for each category of raw material.

Turns: This can be calculated by making the annualized consumption divided by the average inventory held by the factory.

DOS: This is the multiplicative inverse of turns.

Safety Stock: Safety stock units held by the factory.

Safety time (in workdays): This is the additional days added to the lead time.

DelivAvg Monthly: This is the average number of deliveries per month.

Con Avg Weekly: This is the average quantity consumed at the factory per week.

Cons CV Weekly: This is the coefficient of variation of quantity consumed and it can be treated as the standard deviation of the weekly demand rate.

Cons Weeks: This is the number of weeks in which material was consumed.

Spend % Direct to Factory: This is the percentage of spend coming directly into the factory from the vendor (versus the outside warehouse).

Orig City: This is the origin point where the raw material was manufactured (same for the Orig State and Orig Country).

Extended DOS: This is for pivot calculation used (same for the Extended LT and Extended Miles).

Miles: Estimated miles from the vendor the factory based on the origin information.

4. Inventory Management

4.1 Problem Formulation

Like usual, we shall formulate this problem as a mathematical deterministic problem.

Firstly a baseline scenario analysis will be conducted to determine the current total cost for the company. And then the optimized inventory management policy will be adopted to cut down the inventory holding/handling cost within the four factories. We will calculate the total cost after the implementation of the new inventory policy, this cost will be treated as a primary number and will be compared with the original total cost. After that, we shall involve transportation network optimization in our study to lower the transportation costs for the vendors to further reduce the unit purchasing price for our company.

Before advancing to the baseline study, we want to set some global parameters here.

1. For a particular raw material, the company might express the holding costs as 10% of the inventory cost [11]. So here we take 10 percentage of the unit price as our inventory holding cost per unit per year. (conducting sensitivity analysis)
2. Due to the lack of detailed daily material demand rate data, we assume that the

weekly demand rate standard deviation σ_w is just the Cons CV Weekly number as stated in the previous data explanation part.

3. Regarding to the Cycle Service Level, it means the probability of meeting customer demand during delivery lead time. Here it measures the reliability of the inbound supply chain. Given that a small delay in supply of the raw material will not result in huge loss or disaster in food industry, here we set the CSL as 90% which means the inbound logistics is capable of meeting the factory demand 90% of the times in the given lead time. The sensitivity of CSL will be analyzed later on.

4.2 Baseline Analysis

In the current scenario, the total cost for the company is comprised by total inventory holding cost and the raw material purchasing cost.

To calculate the raw material purchasing cost, we just sum the invoice amount for different material up.

For the total inventory holding cost, we use the expressions below:

Total Inventory Holding Cost = Safety Stock Cost + Regular Inventory Holding Cost

Safety Stock Cost = 10% of Unit Price * Safety Stock Quantity

Regular Inventory Holding Cost = 10% of Unit Price * Regular Inventory Quantity

As a result the total cost can be expressed by:

Total Cost = Total Purchasing Cost + Total Inventory Holding Cost

The calculations have been done separately for the four factories in their respective four spreadsheets. The calculation result is presented in Figure 5 below.

Total Cost for the Four Factories	
A	\$232, 544, 121. 52
B	\$154, 349, 817. 43
C	\$191, 879, 928. 43
D	\$265, 195, 862. 31
Total Cost for the Company	\$843, 969, 729. 69
Total Inventory Cost for the Four Factories	
A	\$980, 470. 89
B	\$562, 426. 19
C	\$660, 884. 73
D	\$800, 496. 36
Total Inventory Cost for the Company	\$3, 004, 278. 17

Fig 5. Baseline Cost for the 4 Factories

4.3 New Inventory Management

Naturally a company should maintain safety inventory in case a product shortage may occur which will lead to low CSL. However within inbound logistics scenario, the “factory” is just the “customer” itself which means the factory will consume the inventory. It’s not necessary for the factory to maintain high CSL level. The situation is that most of the raw materials have been assigned huge safety stock quantity, also the inventory holding quantity itself cannot be used up most of the time.

Material Desc	Factory Name	Spent Group	Base Unit	Safety stock	Inv Avg Qty	Inv Avg \$	Temp	Deliv Avg Quantity	Planned delivery time in days	Deliv Avg Monthly	Cons Avg Weekly	Cons CV Weekly	Cons Weeks
Juice	A	Raw	GAL	0	236	\$4,535	Medium	200	28	0.2	16.51111	3.077191	14

Fig 6. A Typical Example for Inventory Management Condition

Here we take factory A for example based on Figure 6. The weekly consumption rate of one sort of juice is 16.51 gallons. The consumption week is 14. By multiplying of the two we get the consumption per year and that is 231 gallons/year. However the inventory quantity held per year is 236 gallons, and this number is bigger than 231. Then let’s look at the delivery quantity 200 gallons/year which is very close to the consumption rate 231 gallons/year. So it seems that the company doesn’t need to hold so much safety inventory here, it’s possible to cut their inventory holding amount further.

So now the priority thing is to lower the safety inventory amount in order to cut down the inventory holding costs for the four factories.

We know that there are many factors to be considered before one can determine the ideal amount of safety inventory to be held. In order to simplify this problem, we are going to implement a continuous inventory review policy in this study, which means the inventory level will be monitored all-weather. Under this condition, the company needs to introduce an automated inventory monitoring system, or such system has already existed which may incur facility cost here.

Before marching into the optimal safety inventory level calculation, let me make some definitions here:

ROP : Reorder point, which is the inventory level that triggers a replenishment order.

L_i : The replenishment lead time for a particular type of raw material i , here it also means planned delivery lead time for the vendors.

D_{Li}^A : The expected demand rate of raw material i in factory A during lead time. The rest of the three factories can be expressed in the same manner.

σ_{Li}^A : The standard deviation for the expected demand rate of raw material i in factory A during lead time.

ss_i^A : The safety inventory amount for raw material i held in factory A . The rest of factories can be expressed in the same manner.

Now let's present the inventory profile with the proper level of safety inventory under the continuous review policy circumstance in Figure 7 below:

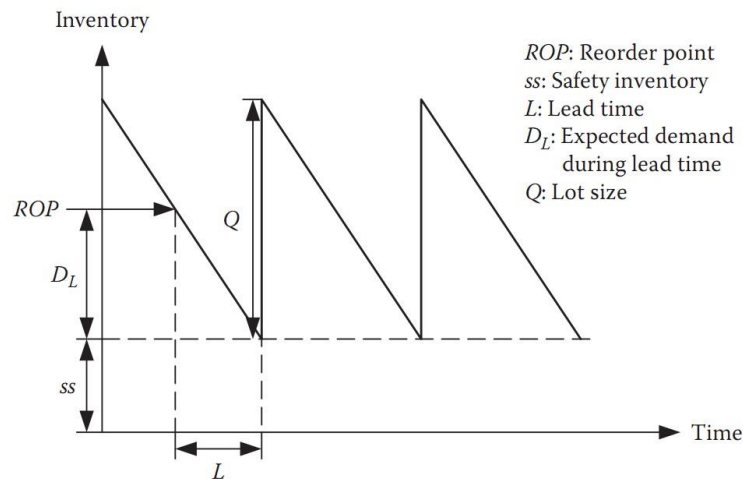


Fig 7. Safety Inventory Profile [12]

From the graph above, we know that the safety inventory is the difference between ROP and the estimated demand during lead time L. So we have:

$$SS = ROP - D_L$$

For a particular product in factory A, we have: $ss_i^A = ROP_i^A - D_{Li}^A$

As mentioned above, due to lack of further detailed daily demand rate data, here we assume demand during lead time follows a normal distribution to model the demand uncertainty, also the standard deviation of a particular raw material of the weekly demand rate in factory A σ_{Wi}^A has been given as the Cons CV Weekly data.

According to Figure 7, we know once the demand during lead time is less than ROP, then we are capable of meeting the demand. But once the actual demands during lead time exceeds the ROP level, we will bump into stock-out during the replenishment

cycle which means we are not able to meet the demand during lead time. So the CSL can be thought as a percentage of the replenishment cycles that all the demands have been satisfied.

There is a normal relationship between CSL and ROP, so here we introduce a normal cumulative distribution function and its inverse function with mean μ and standard deviation σ respectively, they are:

$$F(x, \mu, \sigma)$$

$$F^{-1}(x, \mu, \sigma)$$

So now the CSL can be written as:

$$CSL = F(ROP, D_L, \sigma_L)$$

We take the inverse function of F and get:

$$ROP = F^{-1}(CSL, D_L, \sigma_L)$$

So the safety inventory calculation function can be expressed as follows:

$$ss = F^{-1}(CSL, D_L, \sigma_L) - D_L$$

Now we take the first raw material “One sort of juice” consumed by factory A for example to calculate its optimal safety inventory quantity.

Based on the information collected in Figure 6 in combined with the equations above, we have:

$$ss_1^A = F^{-1}(CSL, D_{L1}^A, \sigma_{L1}^A) - D_{L1}^A$$

The delivery lead time is 28 days which can be converted into 4 weeks. The average weekly demand rate is 16.51 gallons. The standard deviation of weekly demand rate is 3.077 can be find in the data. CSL is a global parameter which will always remain to be 90%.

We assume the weekly demands are independent, so:

$$ss_1^A = F^{-1}(CSL, D_{L1}^A, \sigma_{L1}^A) - D_{L1}^A = F^{-1}(CSL, D_{L1}^A, \sigma_{L1}^A)$$

$$D_{L1}^A = 4D_{W1}^A = 4 \times 16.51 = 66.04$$

$$\sigma_{L1}^A = \sqrt{\sum_{i=1}^{L_1^A} \sigma_{W1}^A} = \sqrt{L_1^A} \sigma_{W1}^A = \sqrt{4} \times 3.077 = 6.154$$

So:

$$ss_1^A = F^{-1}(90\%, 66.04, 6.154) - 66.04 \approx 8$$

Now let's follow the same calculation rules above to get the optimal safety inventory quantities for the rest of the products within the four factories based on the data provided in spreadsheet.

After that we are able to calculate the optimal total inventory cost and the optimal total cost. Pretty much similar as the baseline scenario with some tiny differences, we have:

Optimal Total Inventory Holding Cost = Optimal Safety Inventory Holding Cost

Optimal Safety Inventory Holding Cost = 10% of Unit Price * Optimal Safety Inventory Quantity

Optimal Purchasing Cost = Unit Price * (Weekly Demand Rate * Consumption Week + Optimal Safety Inventory Quantity)

As a result the optimal total cost can be expressed by:

Optimal Total Cost = Total Optimal Purchasing Cost + Total Optimal Safety Inventory Holding Cost

Below is a print screen of the calculation interface in Excel. Noted that the data is not 100% completed. So before doing calculation, we first eliminated those raw materials from the list, or simply treated them as nil.

fx =NORMINV(0.99,Z3,AA3)-Z3							
	X	Y	Z	AA	AB	AC	AD
	Total Inventory Cost	Delivery Lead Time (in weeks)	Demand Rate During Lead Time	Standard Deviation of Demand Rate	Optimal Safety Inventory Quantity	Optimal Safety Inventory Cost	Optimal Purchasing Cost
	\$453.46	4	66.04444	6.154383	14,3172349	\$27.52	\$4,717.99
	\$31.15	2	462.9464	4.502672	5.770406291	\$1.39	\$4,490.22
	\$546.83	4	10387.31	1.879601	2.408805663	\$0.17	\$73,199.71
	\$615.83	4	10387.31	1.879601	2.408805663	\$0.19	\$82,436.43
	\$63.71	2	60.40733	2.765104	3.543623727	\$1.81	\$1,874.53
	\$30.12	4.285714	1110.391	1.577149	2.021197539	\$0.13	\$7,507.80
	\$45.08	4	249.6178	5.026248	6.441396321	\$1.69	\$1,161.37
	\$53.02	2	376.9184	1.712672	2.194877965	\$0.30	\$11,057.64
	\$16.45	2	28.91658	3.246312	4.160316522	\$0.81	\$291.04
	\$0.00	0	0	0	0	\$0.00	\$271.30
	\$125.54	4.285714	238.3434	2.906878	3.725313649	\$1.37	\$5,744.12
	\$401.89	4	11817.78	4.398652	5.637099399	\$0.32	\$15,036.69
	\$162.56	4.285714	387.7492	2.457778	3.149769336	\$1.67	\$15,893.28
	\$328.37	4.285714	565.8943	2.90689	3.72532887	\$0.70	\$7,238.51
	\$90.52	4.285714	463.0533	2.793175	3.579598261	\$0.98	\$6,845.62
	\$137.99	0	0	0	0	\$0.00	\$1,965.81
	\$137.71	0	0	0	0	\$0.00	\$1,961.86
	\$1,617.92	4	60359.94	1.545195	1.980247248	\$0.19	\$579,144.27
	\$1,631.25	4	60359.94	1.545195	1.980247248	\$0.20	\$583,913.40

Fig 8. Calculation Interface in Excel

By comparing the optimized calculation results with the baseline numbers presented in Figure 5, we get the below saving chart.

Optimized Results	
Optimal Total Cost For the Four Factories	
A	\$187,608,642.96
B	\$98,966,370.27
C	\$158,984,502.00
D	\$284,106,689.37
Optimal Total Cost for the Company	
Total Saving for the Company	\$114,303,525.11
Optimal Total Inventory Cost For the Four Factories	
A	\$914.78
B	\$512.31
C	\$983.09
D	\$761.46
Optimal Total Inventory Cost for the Company	
Total Saving for the Company	\$3,001,106.53

Fig 9. Optimized Total Costs for the Company

From the results of Figure 9, we can see that this new inventory policy has incurred great savings on total cost and especially the inventory holding cost for the company. The optimal inventory cost for the company becomes merely \$3,171.65, for a huge enterprise, this number is almost close to none which means the company is capable of maintaining zero safety inventory level. However as a relatively large food processing enterprise, keeping some appropriate level of safety stock is needed to fulfill the make-to-order requirement in case the outbound customer needs may fluctuate dramatically, but should not exceed the level too much like the baseline status. Also one should be aware that, after the implementation of the new policy, the vendor delivery policy will remain unchanged, the company may adopt this new policy under the current vendor delivery scenario.

4.4 Sensitivity Analysis

In the above analysis, the inventory holding cost for a single material is assumed to be 10% of the unit price. CSL is assumed to maintain 90%.

Here we take all the first raw materials (total will be four) provided to the four factories in the database to conduct sensitivity analysis for the two global parameters.

First, by varying the inventory holding cost from 10% to 100% of the unit price, the safety inventory level will remain unchanged for all the four factory scenarios.

Now we want to know the influence of CSL by varying it from 0.90 to 0.99 while keeping the inventory holding cost ratio 10% unchanged. The results are shown below:

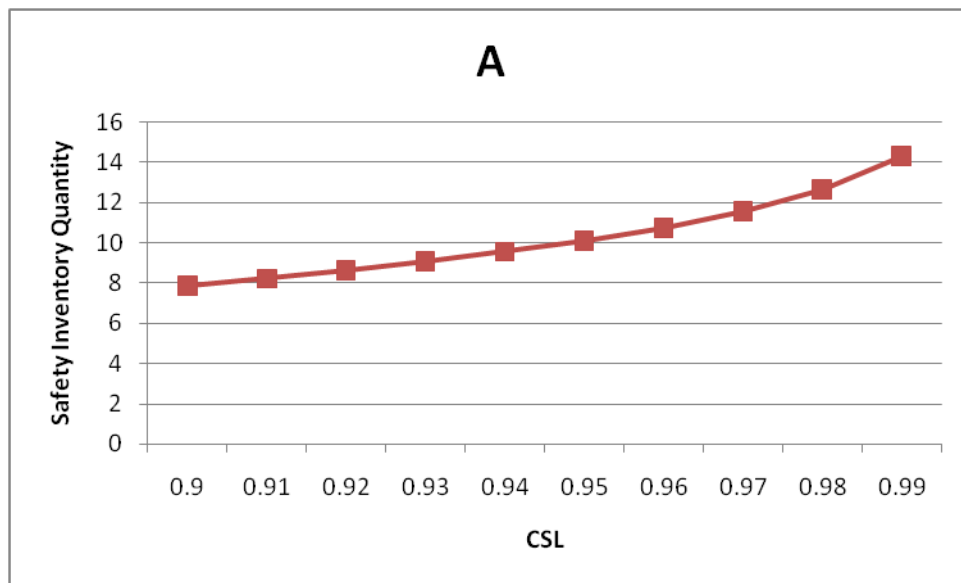


Fig 10. Safety Inventory Quantity for Factory A by Varying CSL

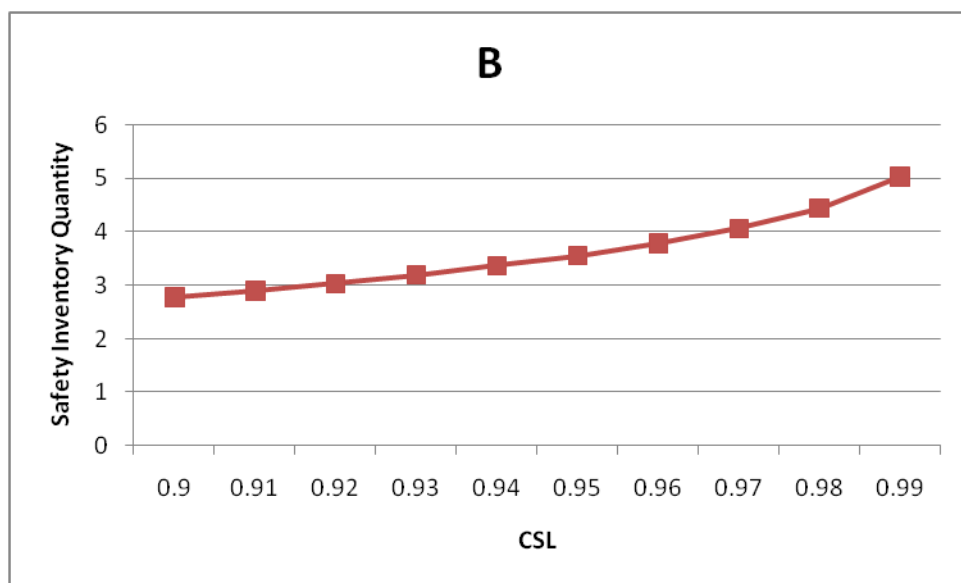


Fig 11. Safety Inventory Quantity for Factory B by Varying CSL

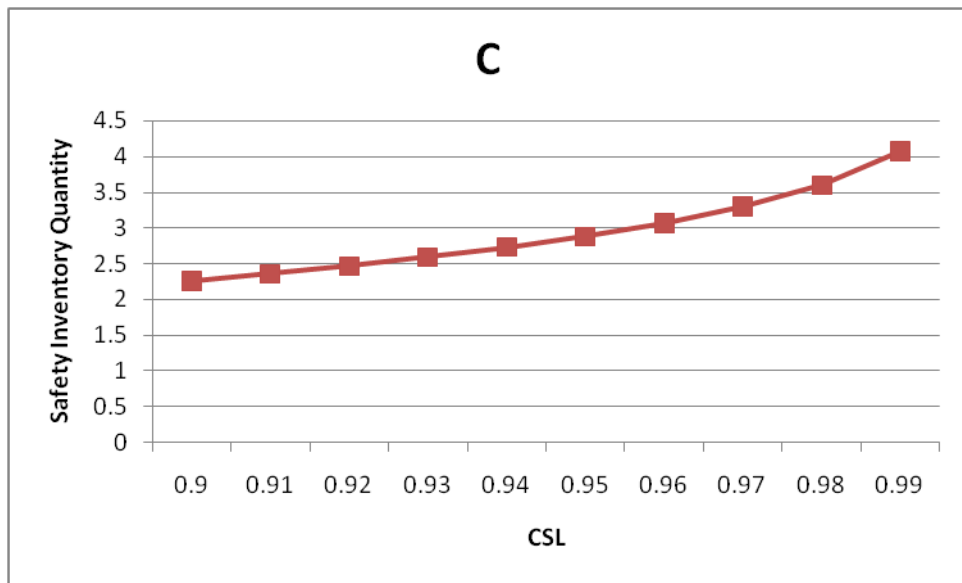


Fig 12. Safety Inventory Quantity for Factory C by Varying CSL

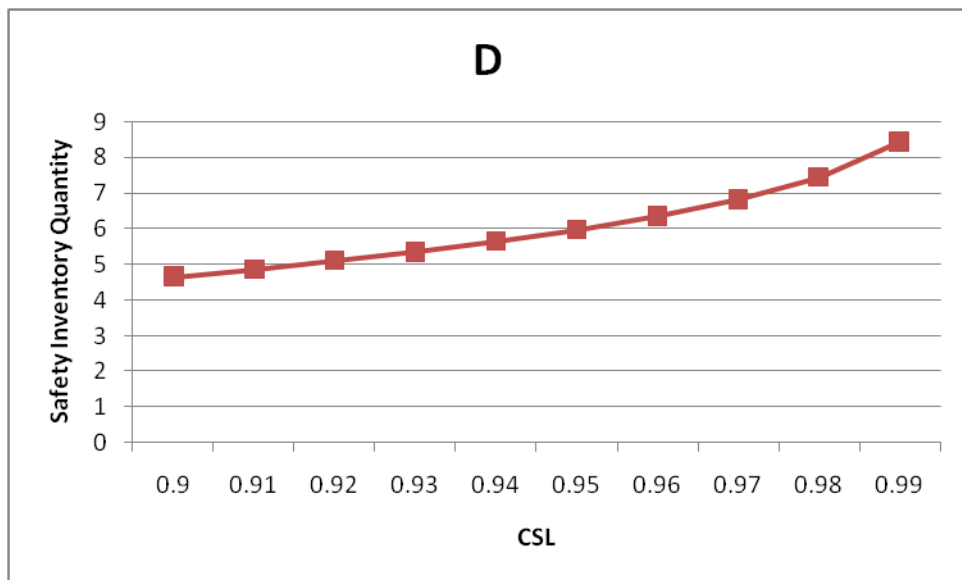


Fig 13. Safety Inventory Quantity for Factory D by Varying CSL

So, as expected, the required safety inventory level increases for the same raw material in different factories when CSL also increases.

As a result, the inventory holding cost ratio is not considered as a sensitive factor while the CSL is considered as a sensitive factor as the curves under all the four scenarios change above.

5. Transportation Network Distribution Design

5.1 Problem Formulation

Like the inventory management section above, we will also formulate the transportation problem as a deterministic mathematical one. However the difference here will be that we will use Gurobi optimization software to get the solution. This optimizer is a software tool that can be used to solve problem based on a linear programming approach.

We know the current inbound transportation status is that the vendors will transport one particular category of raw material directly to the factory, in most case, the capacity of the truck will not be fully utilized. Also materials from different vendors cannot be transported together which means there is no consolidation for the goods in the baseline scenario.

So in our new design here, we want to consolidate different materials from different vendors. However we don't want to build the extra transshipment point to incur extra construction cost. So here we may consider either of the four factories as consolidation points. In this way, not only we can eliminate the facility construction cost, but also the stop-off charges of the regular consolidation point.

The general optimization procedure may like this: first we will determine the optimal consolidation point for each vendor based on the principle of “shortest path”, and then we will group the raw materials with similar monthly average delivery times together on a single truck and transported them to their designated factory. So one can see that, we first do the consolidation and then transport the material to different factories. The baseline total transportation cost will be calculated first and will be compared with the optimal transportation cost later.

Before the further analysis, let me define some notations and make some assumptions here:

1. The weight of the raw materials can be split infinitely to satisfy mathematical needs.
2. We know the density for different edible materials can be unified, so we will only take their weight into consideration to further calculate the related transportation cost, the base unit using here is “Lb”.
3. There are several foreign vendors for the company, here we only consider local USA vendors and we further assume they are using the trucks with same configurations, like the same MPG, volume capacity etc.
4. Due to the incompleteness of the data, the items which lack of needed information have been filtered, so now only 652 categories of raw materials left to undergo the

consolidation process.

5. We assume the maximum loading limit for each truck is 40000 Lbs
6. The trucking cost is comprised by two parts. One is the fixed cost based on different weight intervals for different temperature of goods shown in Fig 14 below. From the chart, we know lower temperature goods will incur more transportation cost. The other is variable cost which is assumed to be 1.13 dollars per mile.

Fixed Costs (High)								
< 500lbs	500~1000lbs	1000~1500lbs	1500~2000lbs	2000~2500lbs	2500~5000lbs	5000~7500lbs	7500~10000lbs	10000lbs above
\$ 87.60	\$ 111.22	\$ 166.82	\$ 188.00	\$ 235.00	\$ 356.59	\$ 534.89	\$ 566.35	\$ 617.92
Fixed Costs (Medium)								
< 500lbs	500~1000lbs	1000~1500lbs	1500~2000lbs	2000~2500lbs	2500~5000lbs	5000~7500lbs	7500~10000lbs	10000lbs above
\$ 104.79	\$ 175.11	\$ 262.66	\$ 310.62	\$ 388.27	\$ 616.39	\$ 924.58	\$ 1,104.74	\$ 1,440.35
Fixed Costs (Low)								
< 500lbs	500~1000lbs	1000~1500lbs	1500~2000lbs	2000~2500lbs	2500~5000lbs	5000~7500lbs	7500~10000lbs	10000lbs above
\$ 133.96	\$ 228.11	\$ 342.17	\$ 383.69	\$ 479.61	\$ 833.80	\$ 1,250.69	\$ 1,367.81	\$ 2,051.71

Fig 14. Fixed costs based on weights and temperatures

7. The materials are divided into edible materials (denoted as “raw” in the database) and packaging materials and we assume they can be transported together to lower the grouping work-load. However materials with different temperature cannot be transported together as described in the inventory session.
8. The base unit for packaging materials have been converted from “fluid ounce” to “Lb” based on “16 floz is about 1 Lb”.
9. The distance information among vendors and factories are from “Google Map” checking by the author.

5.2 Baseline Transportation Cost

Here we will only focus on the filtered 652 products here for the comparison purpose later.

We know the transportation cost consists of the fixed cost and the variable cost. To calculate the baseline transportation cost, first we know the total delivery weight per year has been given already for each material. Then we can use the Delivery Times Monthly to get the delivery times per year for every material. The fixed cost here may vary depends on the weight transported and temperature difference, we can refer Figure 13 to get the fixed costs here. The calculation expression can be written like this:

Total Transportation Cost = SUM of the miles to each designated factory*Variable cost (\$1.13/mile) + SUM (Fixed Cost*Delivery Times per Year) = (161840 + 74721 + 174220 + 866644)*1.13 + 4464502.94 = 1443490.25 + 4464502.94 = \$5907993.19

The calculation results are shown in Figure 15 below.

Baseline Transportation Cost	
Factory A Total Miles	161840
Factory B Total Miles	74721
Factory C Total Miles	174220
Factory D Total Miles	866644
Total Miles	1277425
Total Fixed Cost	\$4, 464, 502. 94
Total Transportation Cost	\$5, 907, 993. 19

Fig 15. Baseline Transportation Cost

However we should pay attention that there is one item in the data, “one sort of chicken meat” which has an average delivery weight 127500 Lbs and this number has exceeded the maximum loading limit (40000 Lbs) for each truck. So this means we have to arrange $127500/40000 = 3.1875$ (round up to integer should be 4) trucks to transport the goods each time which will incur extra cost. The extra cost can be calculated as:

$$534.89*2.4*1 + 617.92*2.4*3 + 4*2.4*485*1.13 = \$10994.04$$

So the total transportation cost should be adjusted to: $5907993.19 + 10994.04 - 1483.01 - 485*1.13 = \5916956.17

5.3 Consolidation Point Determination

In this section, we want to first determine the optimal consolidation point (selected from the four factories for each vendor. Then in each consolidation point, the raw materials will be grouped into trucks and transported their designated factories. In order to determine the optimal consolidation point allocation, we need to set some

variables here for our later use.

1. i : index for the vendor locations, here we have 76 vendors so $i = 1$ to 76 (this range may vary due to the fact one vendor may have two or more locations). If a single vendor has two or more locations, the minor location (which has the lower productivity) will be assigned a larger number, take one particular vendor which has two locations for example, location with higher productivity will be assigned 1, the other location will be assigned 2 for it's a minor one.
2. j : index for the factories, here $j = 1$ to 4, they are A, B, C and D respectively.
3. X_{ij} : means vendor location i is assigned to factory j or not, the variable is binary here.
4. M_{ij} : means the mileage from vendor location i to factory j , note that for every particular M_{ij} , this variable is known.

We want to optimize or say minimize the total mileage among vendors and factories (principle of shortest path) to determine the optimal cross-dock for each vendor. Thus the liner programming objective function can be written as:

$$\text{Total mileage } T_M = \sum_{i=1, j=1} M_{ij} \cdot X_{ij}$$

Next we are going to use Gurobi optimization tool to minimize the above objective function. We should be aware that each vendor location can only be assigned to one factory, so we have the following constraints in the optimization codes.

1. All variables X_{ij} are binary.
2. $X_{i1} + X_{i2} + X_{i3} + X_{i4}$ is always 1.

To make each variable to integer, the variables are specified as general. The model is as follows, noted that the codes have been abbreviated to prevent the tediousness caused by 103 variables.

Minimize

\minimize the total mileage

$$\sum_{i=1, j=1} M_{ij} \cdot X_{ij}$$

Subject To

\matrix constraint

$$T_M = \sum_{i=1, j=1} M_{ij} \cdot X_{ij}$$

Bounds

\default is ≥ 0

Binary

All the variables X_{ij}

Generals

All the variables X_{ij}

End

The solutions are pretty long, here we only show portion of the results below:

Objective value = 45999

x11 1
x12 0
x13 0
x14 0
x21 0
x22 1
x23 0
x24 0
x31 0
x32 0
x33 0
x34 1
x41 1
x42 0
x43 0
x44 0
x51 0
x52 0
x53 0
x54 1
x61 0
x62 0
x63 1
x64 0
x71 1
x72 0
x73 0
x74 0
x81 0
x82 0
x83 0
x84 1
x91 0
x92 0
x93 0
x94 1

We can see the optimal total mileage is 45999 miles.

5.4 Transportation Costs to Consolidation Points

Based on the consolidation point allocation information provided by the Solution file above, we are able to calculate the transportation cost from vendor locations to their designated consolidation points. Also we will group different raw materials from the same vendor location together within the same truck to utilize its full capacity during the calculation process, but we should know goods with different temperature cannot be transported together. When the total weight of any group exceeds the truck loading limit 40000 Lbs, we will consider using more trucks. Figure 16 is an example of grouping raw materials by vendor location and temperature.

Material	Factory Name	Vendor	Spend Group	Invoice Qty	Number of PO Lines	Temp	Deliv Avg Weight (Lb)	Planned delivery time in days	Deliv Avg Monthly
22010012	D	100364181	Raw	472,676	14	Low	33,867	30	1.2
22014608	A	100364181	Raw	735,016	20	Low	35,387	30	1.6
22015460	D	100364181	Raw	25,794	5	Low	7,049	24	0.4
43244054	B	100364181	Raw	41,560	14	Low	4,014	24	1.4
43244079	D	100364181	Raw	91,700	17	Low	4,088	28	1.6
43271862	D	100364181	Raw	108,966	26	Low	4,263	30	2.6
43128480	A	100364181	Raw	142,770	16	Low	12,454	28	1
43162106	D	100364181	Raw	1,005,540	33	Low	28,345	28	2.6
43243702	B	100099158	Raw	5,334,102	128	Low	41,478	28	11.8
22002792	A	100089912	Raw	22,250	3	Low	6,000	60	0.2
43244055	D	100089912	Raw	27,000	10	Low	2,700	30	1
43244055	B	100350130	Raw	36,200	14	Low	3,367	28	1.2
43258881	C	100681695	Raw	231,120	32	Low	6,155	14	3.2

Fig 16. Grouping Example

Using the spreadsheet, we are able to calculate the transportation cost for every grouping sections, they are: high A, medium A, low A and high B, medium B, low B

and high C, medium C, low C and high D, medium D, low D, total is 12. The calculation results are shown in Figure 17 below:

Transportation Costs to Consolidation Points	
High A	\$83,956.41
Medium A	\$57,789.86
Low A	\$27,709.50
High B	\$191,596.91
Medium B	\$64,318.33
Low B	\$11,091.10
High C	\$411,722.35
Medium C	\$9,809.36
Low C	\$17,138.24
High D	\$23,902.48
Medium D	\$166,582.47
Low D	\$17,934.17
Total	\$1,083,551.18

Fig 17. Transportation Costs to Consolidation Points

5.5 Transportation Costs to Designated Factories

The next step is to transport the raw materials from the consolidation points to their designated factories. The raw materials which have already been transported to the designated factories will not be transported. Below is the mileage chart among the four factories which will be needed during the calculation process later.

	A	B	C	D
A	0	737	551	1760
B	738	0	644	1457
C	556	645	0	1999
D	1761	1457	1999	0

Fig 18. Mileage Chart among Factories

Like before, we will group the raw materials which belong to the same factory together, also we are aware that materials with different temperature should be transported separately. The raw materials can be categorized into: High A B, Medium A B, Low A B, High A C, Medium A C, Low A C, High A D, Medium A D and Low A D. The first letter stands for temperature, the second letter stands for consolidation point location and the third letter stands for the designated factory in each group. Here we just name a few, consolidation points B, C and D can follow the same pattern. There are $9 \times 4 = 36$ groups in total.

Using spreadsheet, we are able to calculate the transportation costs for each group.

Then we add them up to get the total transportation cost to the designated factories.

Here the total transportation cost to designated factories is divided into:

1. Total Variable Cost
2. Total Fixed Cost for LTL truck
3. Total Fixed Cost for Full-Load truck

The calculation results are presented in Figure 19 below:

Total Transportation Cost to Factories	
Total Variable Cost	\$1,053,701.27
Total Fixed cost for LTL truck	\$38,951.22
Total Fixed cost for Full-Load truck	\$596,764.78
Total Transportation Cost	\$1,689,417.27

Fig 19. Total Transportation Cost to Factories

Eventually, the new total transportation cost after this consolidation and raw material grouping implementation can be calculated as:

Total Transportation Cost to Consolidation Points + Total Transportation Cost to Designated Factories = $1083551.18 + 1689417.27 = \2772968.45 which is far below the baseline total transportation cost \$5907993.19.

6. Results and Conclusions

We can use the following two before and after study charts to illustrate our results and conclusions here.

Inventory Holding Costs Comparison			
Before		After	
A	\$980,470.89	A	\$914.78
B	\$562,426.19	B	\$512.31
C	\$660,884.73	C	\$983.09
D	\$800,496.36	D	\$761.46
Total	\$3,004,278.17	Total	\$3,171.65

Fig 20. Inventory Holding Costs Comparison

Transportation Costs Comparison			
Before		After	
Baseline Total	\$5,916,956.17	New Total	\$2,772,968.45

Fig 21. Transportation Costs Comparison

Based on the two charts above, we can conclude that after the implementation of the new inventory management policy and the new inbound logistics transportation policy, both the total inventory holding costs and the total inbound transportation costs have been dramatically reduced for the company.

7. Limitations and Future Research Scope

This study analysis treats the inventory management part and the network distribution design optimization part separately which will probably not lead to a perfect solution result.

In regards to the inventory management part, we merely worked out the optimal inventory management policy without changing the transportation strategy accordingly. Since the safety stock quantity has been dramatically reduced, the inbound raw materials amount must be reduced accordingly, but we didn't do the inbound logistics analysis after the implementation of the new inventory policy which may not constitute a complete analysis here. We also introduced a normal distribution model to formulate the weekly demand rate of raw material which might also lead to some imprecise results. We may need more detailed daily demand rate data to determine the statistical pattern of the demand rate. Also we adopted a continuous inventory review policy to calculate the optimal safety inventory amount which may incur extra monitoring facility construction cost and this cost is possible to surpass the inventory saving amount. An investigation for the price of monitoring facility should be conducted in the future study. We may also switch to another periodically review policy to obtain more practical and precise result.

In the network distribution part, we assume either of the four factories can be treated as a consolidation point for fear of incurring extra facility building cost which tends to

be innovative and highly useful, since large company will usually maintain inbound and outbound goods storage area to keep the high CSL level. Gurobi Optimizer tool has been used to determine the consolidation point for each particular raw material, the results shown are straightforward and quite exact. The same problem incurred in the inventory management part also happened here, when the new network distribution policy is adopted, the inventory holding amount held in each factory should also be adjusted accordingly, and we didn't do the new inventory calculation which may lead to incompleteness of our study. The network flow model for benchmarking purpose is the most basic one which might not be persuasive.

This study did show some merits like grouping the raw material based on the temperature constraint, treating factory itself as consolidation point which have seldom been done before. We also set lots of global parameters in our analysis, they all have to go through sensitivity analysis to test their feasibility. In the future research, we may introduce more highly-mathematical models to benchmark our results such as the Genetic Algorithm and the Lagrangian Relaxation Model stated before.

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