Evaluation of Bulk and Packaged Distribution Strategies in a Specialty Chemical Company

by

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ABSTRACT

A logistics cost model is developed for a chemical distribution system from a single plant using bulk and packaged transportation strategies. The purpose of this research is to provide a tool that helps understand the cost trade offs in the operation of a logistics system at a strategic level for large scale systems and complex distribution systems. An analytical modeling approach was used to determine variables that define transportation, storage and material handling costs in the system.

Several distribution strategies were evaluated and benchmarked in terms of costs against the current. Savings offered by the packaged distribution system for a single plant were marginal; extension of the current model to evaluate cost reduction opportunities across the complete network of plants and distribution centers is proposed for further research effort.

Thesis Supervisor: James Masters
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CONTENTS

List of Figures

List of Tables

1. Introduction

Over the last two decade logistics management has received increased attention by industry as a strategic source of competitive advantage[1]. This research is motivated by the initiative of a specialty chemical company to redesign their distribution system, referred throughout this document as Company A.

Company A manufactures and distributes bulk chemical products in the United States through a network of 4 plants and over 20 distribution centers, delivering directly to their 4,000 customers with a private fleet of roughly 70 tanker vehicles.

Their products are used as key performance enhancement agents directly into their customers' production process. Demand for more sophisticated products and increased market competition has driven research and development efforts to create new products. Their product line has been extended to over 50 products grouped in 9 different categories. In general, customers demand products from several categories in their production process.

To distribute different bulk products the company uses tanker trucks with 4 to 5 compartments to consolidate customer demand as efficiently as possible. However, as new products are introduced over time and customers demand diversifies, capacity utilization of vehicles is constrained by the number of available compartments.

In 2002 the company introduced the use of reusable plastic containers to ship product from plants to distribution centers, where transportation is provided by contract carriers. Containers are re filled at the plant, transported on standard flatbed trucks, pumped into storage tanks at the distribution center and then returned for reuse. Lower freight rates for flatbed trucks compared to specialized tanker trucks contributed to a significant reduction in the operating costs of direct product replenishment to distribution centers.

The redesign of the current distribution system is proposed to evaluate potential cost savings in introducing returnable containers for direct distribution to customers, as it would relax the current restrictions in capacity utilization imposed by compartmented tanker trucks.

1.1. Objective

The purpose of this research is a) to develop an analytical model that describes the cost trade-off from all relevant distribution costs, b) evaluate a set distribution strategies based on single and mixed system configurations and c) identify the alternative with minimum cost.

1.2. Scope

This research studies the logistics cost from point of production to point of consumption for a single plant distributing directly to a set of customers scattered along its service region. The scope is restricted to a single plant location in order to understand and quantify the cost trade-offs in transportation, handling and storage for bulk and packaged systems. The analysis and optimization of the company's complete distribution network is out of the scope of this research.

1.3. Relevance of the Research

The analytical model to be developed in this research would assist managers in tactical fleet sizing decisions and to facilitate the analysis of the long run cost average cost of a distribution system while explicitly considering operational details particular to the transportation method used. To the best of the author's knowledge while there has been previous work on analytical models that consider vehicle capacity constrains[2], no previous research studied the effect of compartmentalization in capacity and product compatibility at a tactical level.

The Council of Logistics Management defines Logistics as "*that part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements*". Physical distribution can be understood as a logistics sub-process defined from the *point of production* to the *point of consumption.*

A distribution strategy responds to customer requirements in alignment with a company's corporate strategy. Ballou[3] suggests three main objectives of a in a logistics strategy: *cost reduction, capital reduction,* and *service improvement*, each respectively supporting broader strategic corporate goals: *profit maximization, ROI maximization* and *increasing revenues*.

As a planning and design process, logistics decisions can be classified in three different categories according to the time horizon in:

- *Strategic*: long range, the time horizon is longer than one year
- *Tactical*: intermediate time horizon, usually less than a year

- *Operational*: short-range, day-to-day decision making

The three decision levels are interdependent[4]. Strategic planning often works with imprecise data, its goal is producing near-optimal plans, and operational planning deals with detailed information about customer requirements to produce detailed schedules. The integration of different levels of data availability is usually a key issue in integrated systems analysis.

1.4. Components of a Physical Distribution System

The scope of physical distribution involves generally the following activities[5]:

- Handling of products from the production area to the storage area.
- Holding in the storage area until product is requested.
- Loading of products into a transportation vehicle.
- Transportation to its destination.
- Unloading, handling at the destination
- Waiting for consumption at the destination.

Such operations incur in costs that can be broadly grouped in **transportation** and **storage**. **Transportation** operations provide location value to goods by overcoming the distance from the point of production to the customer location. **Storage** operations provide value by overcoming time from the event of production until the product is consumed by the customer[6].

The distribution system under study has three main components:

- The *storage system* at the *production site*.
- The *transportation* system
- The *storage system* at the *customer site*.

In the next section we review the different available distribution systems according to the characteristics of their main components.

1.5. Bulk Distribution System

Bulk distribution systems are traditionally used for distributing large quantities of products for which transportation costs are significant compared to the product cost. Chemicals, fuel and certain diary products, like milk, are typically transported in bulk.

The product is manufactured through a blending process and stored in large tanks at the production site of approximate 15,000 gallons capacity. Product is shipped in stainless steel tankers, specially equipped with a 4 to 5 compartments, valve, meter and pump systems to unload the product. The demand for each product is highly variable and tankers have different compartment sizes in order to accommodate the product mix. When the number of products per shipment exceeds the number of compartments the configuration becomes a capacity constraint. To avoid the risk of cross-contamination, acid and alkaline products are prevented from being loaded in the same vehicle, imposing an additional restriction. In summary, transportation capacity in the bulk system is subject multiple constraints:

- Weight and volume capacity per truck
- Number of compartments
- Product compatibility
- Available working time during the week

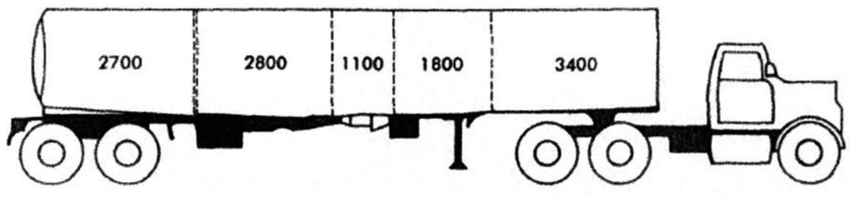


Figure 1. Illustration of a compartmented chemical tanker

At the customer site the product is stored in a dispenser equipment. The dispenser system contains storage tanks for each product, measuring and pumping equipment contained in a closed metallic structure. Dispensers are assets owned by Company A, placed at the customer site as part of the service value proposition.

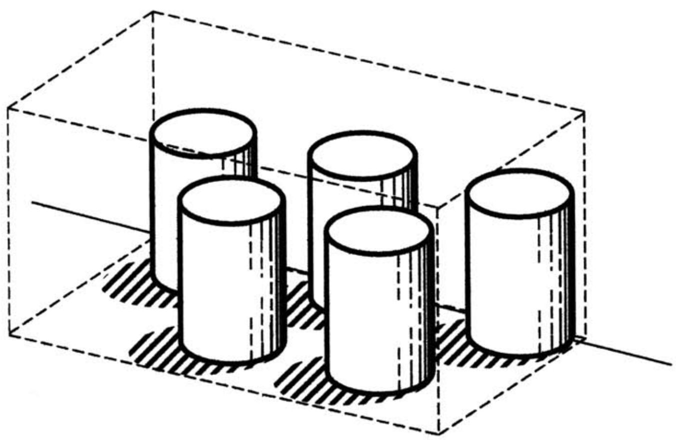


Figure 2. Illustration of a bulk dispenser system

1.6. Packaged Distribution System

The distinctive feature about the packaged distribution system is the use of plastic returnable containers as a handling unit. Returnable containers travel from the production site to the customer and then back for cleaning and reuse defining a closed-loop system, adding a reverse logistic dimension to the distribution process. The number of containers required in the system becomes a key decision at a tactical level[7]. Returnable containers are filled in the plant, prior to dispatch and have minimal storage requirements.

Figure 3. Illustration of a plastic returnable container for chemicals

Transportation of returnable containers requires a 5-Axel flatbed truck, which is a common vehicle type. The only two main constraints for transportation planning of this vehicle are weight capacity and working time per week.

Figure 4. Illustration of a 5-axle flatbed truck

To unload the product at the customer site, each truck is equipped with a mountable forklift, depicted in the next figure.

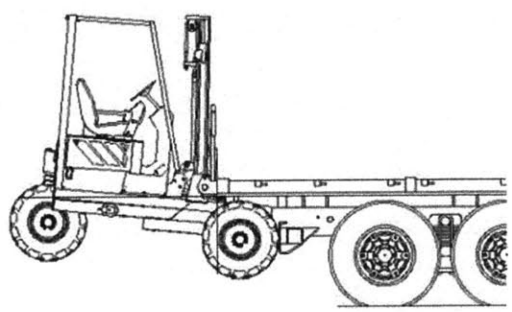


Figure 5. Illustration of a mountable forklift

Another distinctive feature is that a new dispenser system, engineered by Company A, is that eliminates storage tanks at the customer site. Instead the dispenser is designed to hold returnable containers directly. The proposed distribution policy is that customer exchange the same number of empty containers that they receive in a delivery, a one for one distribution policy.

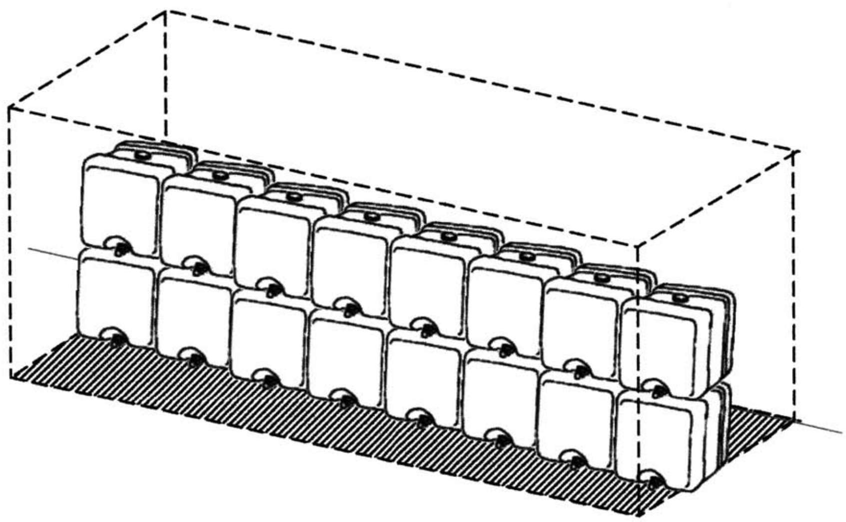


Figure 6. Illustration of a tote dispenser system

1.7. Structure of the Thesis

Chapter 2 reviews the literature on freight distribution and inventory control policies. Chapter 3 develops an analytical model to estimate the variables that influence logistics costs in bulk and packaged distribution systems: traveled distance, vehicle fleet size and number of returnable containers. The analytical model for travel distance estimation is extended to quantify the impact of additional loading restrictions on traveled distance for bulk distribution is

Chapter 4 presents the methodology for data collection and analysis, and defines the proposed distribution strategies to be evaluated. Chapter 5 presents the results of the logistics cost for each distribution strategy scenario. Chapter 6 presents the conclusions of this research.

2. Model Development

2.1. *Logistics Cost Function*

One of the key objectives in analyzing and designing logistics systems is to minimize system-wide costs across the business. The total cost concept consists in identifying all relevant activities to a specific analysis and defines the sum of all incurred cost[8]. Logistics decisions usually have diverse and opposite effects on different logistics activities, such an example is the well known Economic Lot Size problem which illustrates the cost trade-offs between ordering and inventory holding costs depending on the number of items purchased per order.

A logistics cost function (LCF) is a mathematical expression of the sum of relevant costs grouped in categories. It can be defined in relation to time periods or product quantity. This research studies the logistics cost per period of time. The time lend of the time period for analysis is a week, matching the company's operational planning cycle for transportation. The LCF has the form of:

$$C = C_T + C_H + C_S + C_I \qquad (1)$$

Where:

C = Total Cost per period *(USD/week)*

C_T = Transportation Cost per period *(USD/week)*

C_H = Handling Cost per period *(USD/week)*

C_S = Storage Cost per period *(USD/week)*

C_I = Inventory Holding Cost per period *(USD/week)*

In general each cost category has two main components: fixed costs and variable costs. Fixed costs are generally related to the configuration of the system and are stationary in time while variable costs depend on the level of resources required to operate the system.

In the remainder of this section, a discussion of each costs category is presented, the system variables that determine them, and how to estimate these. Finally, the logistics cost function is defined for each scenario.

2.1.1. Transportation Costs

Transportation costs per period for a private fleet are determined by the number of vehicles, and the total distance traveled per period. Fixed costs are defined per vehicle and include equipment lease for trucks and depreciation of trailers, driver salary and benefits, insurance and taxes. Variable costs are defined in relationship to distance and include fuel costs and average maintenance and repair costs.

$$C_T = c_{ft} \cdot M + c_{vt} \cdot D \qquad (2)$$

Where:

C_T = Transportation Cost per period *(USD/week)*

c_{ft} = fixed transportation costs *(USD/(vehicle·week))*

M = number of vehicles

c_{vt} = variable transportation cost *(USD/mile)*

D = Total traveled distance per period *(miles/week)*

2.1.2. Handling Costs

In bulk distribution systems the handling equipment, such as pumps, valves and hoses, is generally part of either the transportation or storage equipment. Therefore the discussion of handling costs is relevant only to the packaged distribution system.

Fixed handling costs are determined by the number of returnable containers and their depreciation cost. Variable costs are determined by labor required to clean and fill the handling units. The number of units filled in a period is assumed to be equal to the same of the number of units dispatched, since containers will be based on planned deliveries.

$$C_H = c_{fh} \cdot R + c_{vh} \cdot Q \qquad (3)$$

Where:

C_H = Handling cost per period *(USD/week)*

C_{fh} = Fixed costs per handling unit *(USD/(container·week))*

R = Number of returnable containers in the system

c_{vh} = Variable handling costs*(USD/gallon)*

Q = Demand per period *(gallons/week)*

2.1.3. Storage Costs

Storage costs are incurred at the origin site and the destination. Storage costs include rent, equipment depreciation, maintenance and overhead.

In this research, storage costs at the origin plant will not be considered, because changes in the local distribution strategy should have no significant effect on costs or resources. Nevertheless, they would be relevant for a evaluating the impact of the change in the distribution policy distribution network.

Storage costs include the cost of the dispenser equipments at customer sites. Fixed costs per customer include the depreciation of the equipment and cleaning costs.

Cleaning costs are incurred in the bulk distribution system when the product is removed from a storage tank at the customer site. Cleaning is requested when a customer wishes to switch to a new product or when, because of seasonal periods of inactivity, the product sediments at the bottom of the tank. Cleaning costs are considered stationary and are expressed as an average fixed cost per dispenser equipment.

In the packaged distribution system, all cleaning costs are accounted in the handling cost category.

Summarizing, the storage are expressed as following:

$$C_S = (c_{fs}) \cdot N \qquad (4)$$

Where:

C_s = Storage cost per period *(USD/week)*

c_{fs} = Fixed storage cost *(USD/dispenser·week)*

N = Number of dispensers

2.1.4. Inventory Holding Costs

Inventory holding costs include the opportunity cost of capital invested in cycle inventory and safety stock at storage locations and in-transit inventory. In this research we will not consider inventory holding costs in our analysis for two reasons: first, local deliveries represent a small fraction of the total distribution volume from the plant; second, transit time and vehicle sizes are similar both packaged and bulk distribution systems. Therefore changes in the local distribution strategy should have no significant effect over the average cycle inventory level or safety stock policies at the plant, nor the inventory in-transit.

2.1.5. Logistics Cost Function

Based on the previous discussion of costs categories, the logistics cost function can be now expressed as a function of different input variables. It is also necessary to identify to which distribution system they refer to. Each system shall be distinguished by superscripts *B*, for Bulk and *P*, for Packaged.

For the bulk distribution system, the LCF can be expressed as:

$$C^B = C_T^B + C_S^B \qquad (5)$$

$$C^B = [c_{ft,B} \cdot M^B + c_{vt,B} \cdot D^B] + [c_{fs,B} \cdot N^B] \qquad (6)$$

For the packaged distribution system, the LCF can be expressed as:

$$C^P = C_T^P + C_H^P + C_S^P \qquad (7)$$

$$C^P = [c_{ft,P} \cdot M^P + c_{d,P} \cdot D^P] + [c_{fh} \cdot R^P + c_{vf} \cdot Q^P] + [c_{fs,P} \cdot N^P] \qquad (8)$$

Where:

$\boldsymbol{S}$ = set of distribution systems; $\boldsymbol{S} = \{B, P\};$

Cost Categories

C^i = Total cost per period for system $i;\ i \in \boldsymbol{S}$

C_T^i = Transportation cost per period for system $i;\ i \in \boldsymbol{S}$

C_S^i = Storage cost per period for system $i;\ i \in \boldsymbol{S}$

C_H^i = Handling cost per period for system $i;\ i \in \boldsymbol{S}$

Cost Parameters

$c_{ft,i}$ = Fixed transportation costs per vehicle for system $i;\ i \in \boldsymbol{S}$

$c_{vt,i}$ = Variable transportation costs for system *i*; $i \in S$ *(USD/mile)*

$c_{fh,i}$ = Fixed handling costs per period for system *i*; $i \in \{P\}$

$c_{vh,i}$ = Variable handling costs per period for system *i*; $i \in \{P\}$

$c_{fs,i}$ = Fixed storage costs per customer for system *i*; $i \in S$

External Variables

Q^i = Total demand per period in system *i*, $i \in S$

Dependent Variables

D^i = Total traveled distance per period in system *i*, $i \in S$

M^i = number of vehicles in system *i*. $i \in S$

R^i = Number of returnable containers in system *i*. $i \in \{P\}$

Decision Variables

N^i = Number of customers allocated to system *i*, $i \in S$

2.2. Determination of Dependent Variables

2.2.1. Traveled Distance

This section presents an analytical approach to estimate the traveled distance distribution systems based on simple formulas based on the area of the distribution zone, the number of customers and their average distance to the depot, without regard to specific customer locations. Next, some useful definitions for the following discussion are presented.

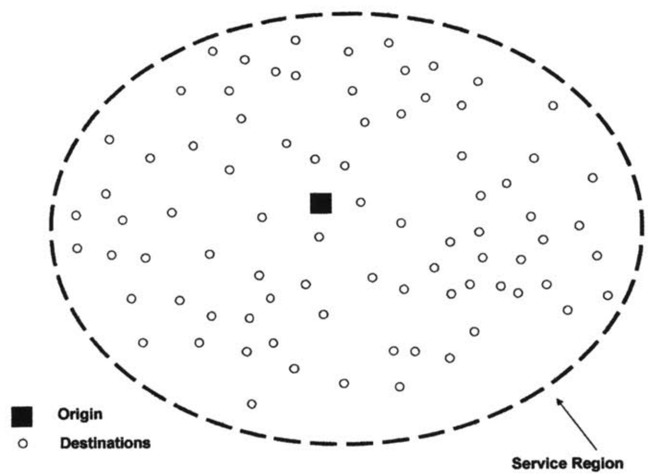


Figure 7. Illustration of a service region

Systems where many customers (destinations) are supplied by a single plant (origin) are classified in the transportation literature as **one-to-many distribution systems**. The **service region** is the geographical area containing the origin and all destinations. A service region can be subdivided in **districts**. A district defines customer groups that provide the basis for load planning[9].

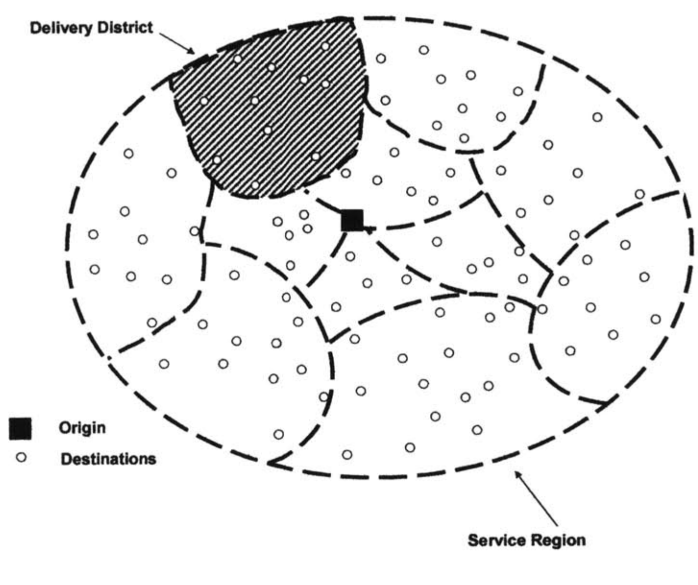


Figure 8. Illustration of Delivery Districts in a Service Region

A fleet of vehicles is assigned to the service region. All vehicles are assumed to be homogeneous with a finite load capacity of v_{max} units of demand. In this research demand is measured in units of volume. The sequence of destinations visited by a vehicle defines a **route**, and it defines a **tour** when it the route starts and ends at the origin.

Consolidation is the process of combining deliveries for different destinations and dates in single vehicle load[10]. In general when many customers with individual demand per period are small compared to vehicle capacity, consolidation is an efficient strategy to reduce the number of vehicle tours and therefore the travel distance. Visiting multiple customers in a single tour is referred to as **peddling**[11].

Peddling tours have three stages: line-haul, local delivery and back-haul. a) In the Line-haul stage the vehicle travels loaded from the origin to the nearest customer in a distribution district b) then travels from the first customer to the last destination in the local delivery stage and finally c) in the back haul stage, returns from the last customer to the origin. The number of customers visited in a peddling tour, *c*, is limited by the vehicle capacity.

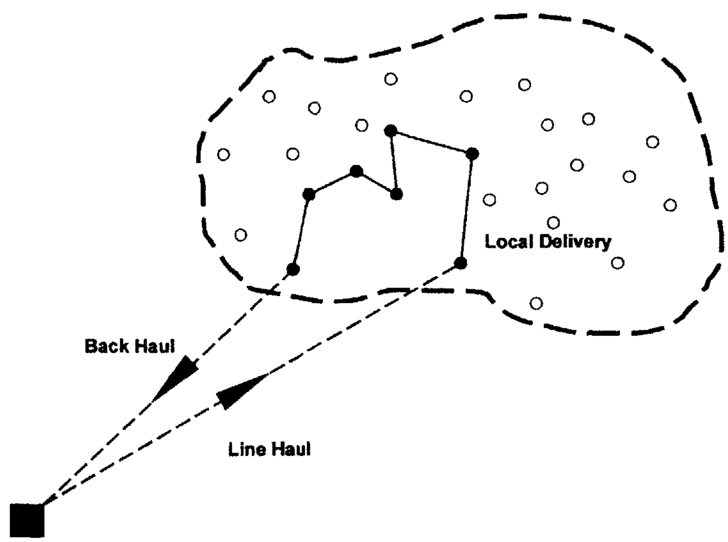


Figure 9. Illustration of peddling route stages

In the case studied in this research, customer demand becomes available and known before the actual delivery. Determining the set of peddling tours to serve customer demand for each period represents a deterministic Capacitated Vehicle Routing Problem (CVRP). In our research the prescriptive solution of the actual stop sequence for routing each trip in every period is not relevant. Only a descriptive solution of the total traveled distance per period is required.

Daganzo[12] obtained analytical expressions for the length of peddling tours, D_t, based on a cluster-first route-second logic just as heuristic algorithms used to solve the detailed version of the problem CVRP problem. The distance of a vehicle tour is defined as the sum of the average round trip distance to the district, estimated as twice the distance from the depot to the center of gravity of the district, r, plus the local delivery distance through c stops, d_l

$$D_t \approx 2 \cdot r + d_l \qquad (9)$$

The length of the local delivery distance, d_l, is equivalent to finding the shortest path through the c stops, and its approximation is based on the analysis of the Traveling Salesman Problem (TSP) studied by Beardwood et al.[13]. Their work exploited the geometrical properties of the problem and obtained an analytical expression for the asymptotic value of the minimum travel distance, D^{TSP}, for visiting n randomly distributed stops, in a region of area A:

$$D^{TSP} = k \cdot \sqrt{nA} \qquad (10)$$

Where k is a constant value independent from n or A, and for straight line distances (L_1 metric) is estimated in 0.765[14]. The robustness of this expression has been documented in the literature even when n is small and for areas of different shapes[15].

Stop density, δ, defined as the ratio between the area of a district and the number of stops, is will be used in the remainder of the formulas introduced in this section:

$\delta = n/A$ *(11)*

Then the average distance per stop, d_s, in a traveling salesman tour is defined as the ratio of the total distance D^{TSP} over the number of stops n.

$$d_s = \frac{D^{TSP}}{n} = k \cdot \frac{\sqrt{nA}}{n} = k \cdot \delta^{-1/2} \qquad (12)$$

Daganzo[16] approximates the length of the local tours as the product of the number of stops, c, times the average distance per stop in the traveling salesman problem over the whole region. This approximation is based in one the basic inequality of the Traveling Salesman Problem, which states that if a region is divided in several disjoint sub regions, the sum of the lengths of the tours of the TSP in each sub region is grater or equal than the optimal distance of a single tour over all n points[17].

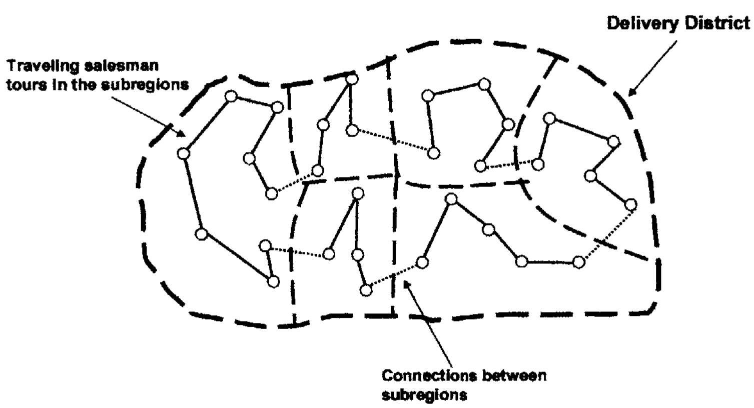


Figure 10. Properties of the traveling distance between the VRP and TSP problem,

Substituting equation (12) in (9) the average distance of a CVRP tour is:

$$D_t = 2 \cdot r + c \cdot k \cdot \delta^{-1/2} \qquad (13)$$

Hall[18] studied distribution problems with variable stops per tour and concluded that the formula still predicts well the travel distance if the average value of c is used, even if there is overlapping between tours. The total distance traveled by all tours in a period serving all n customers in a region is the product of the number of tours, l, and the average travel distance per tour.

$$D = l \cdot Dt = l \cdot (2 \cdot r + c \cdot k \cdot \delta^{-1/2})$$

$$D = 2 \cdot l \cdot r + n \cdot k \cdot \delta^{-1/2} \tag{14}$$

Since the radial distance increases with the number of tours, consolidating demand in the vehicle capacity is key to minimize distance as the delivery district is farther from the depot. The minimum number of tours in a period is an integer number given by the demand per period, Q, and the vehicle capacity, v_{max}

$$l = [Q/v_{max}]^{+} \tag{15}$$

And we can re-write equation *(14)* as:

$$D = 2 \cdot r \cdot [Q/\, v_{max}]^{+} + n \cdot k \cdot \delta^{-1/2} \tag{16}$$

When the product demand per period, Q, and the number of customers, n, vary randomly from period to period, the LCF should be estimated using the expected value of the distance, then

$$E(D) = E(2 \cdot r \cdot [Q/v_{max}]^{+} + n \cdot k \cdot \delta^{-1/2})$$

Where $[x]^{+}$ is a step function that represents the lowest integer number higher than x. Daganzo[19] proposes the use of continuous functions instead of discrete step functions in freight distribution problems, since the latter tend to generate more errors when accumulated in calculations. The expected value of a step function is equivalent to the following continuous formulation:

$$E([x]^{+}) = E(x) + 1/2 \tag{17}$$

The validity of this expression can be verified for uniformly, Poisson and Normal distributed variables through simple spreadsheet simulations. Expression 17 can be re-written as:

$$E(D) = 2 \cdot r \cdot (E(Q)/v_{max} + 1/2) + E(n) \cdot k \cdot \delta^{-1/2} \qquad (18)$$

A region can be decomposed in several delivery districts when customer density varies significantly. The resulting travel distance can be determined by adding the travel distance in each delivery district:

$$E(D) = 2 \cdot \sum_i [r_i \cdot (E(Q_i)/v + 1/2] + k \cdot \sum_i [E(n_i) \cdot \delta_i^{-1/2}] \qquad (19)$$

Where i is the index to identify the delivery district.

2.2.2. Travel distance under additional capacity constraints

The previous section studied analytical approximations to the traveled distance of a distribution system, with regard to only one capacity constraint defined in terms of volume. This section considers two additional constraints: maximum number of products per vehicle and the product incompatibility, and studies their effect on travel distance.

Consider the demand per period in a delivery district, Q, and a fleet of vehicles with capacity v_{max}. Let l be the optimal number of vehicle tours to deliver Q and v, the average load per shipment, defined as:

$$v = Q/l, \qquad v \leq v_{max} \qquad (20)$$

The loading efficiency is defined as:

$$e_l = Q/(v_{max} \cdot l) \qquad (21)$$

Equation *(14)* shows that the number of tours l increases the total traveled distance in a period proportionally to the distance to the average distance to the origin.

Additional restrictions to the capacity of the vehicle will reduce the average load by a certain amount ε.

Therefore, to distribute the same load Q, the number of trips should increase for equation (20) to hold.

$$(v + \varepsilon) = Q/(l + k) \qquad \varepsilon \geq 0, k \geq 0 \qquad (22)$$

$$l_c = l + k, \qquad (23)$$

Equation (22) defines the number of tours for vehicles with additional constraints, l_c, as the sum of the number of tours from simple vehicles, l, plus an integer number k representing the extra number of tours imposed by additional constraints

Compartmented Vehicles

Consider the problem of loading quantity of Q, consisting of p different products each of demand q_i, in vehicles of capacity v_{max} with c compartments. If c is less that p, the numbers of compartments become a binding restriction. It will be assumed that compartments are "flexible" so they can accommodate any quantity per compartment as long as the total loaded quantity does not exceed v_{max}.

This problem is a combination a vehicle routing problem and a two-dimensional non-linear knapsack problem, both NP-hard combinatorial problems. A mixed integer linear programming problem would provide the exact allocation of product to each vehicle, but this is far more detail of what is needed, and the actual number of trips would actually be a secondary product of the solution after investing considerable effort.

Consider instead the geometrical formulation of the problem, by plotting all p product quantities, in decreasing order in a bar chart where each product bar has a base of 1 unit and height of q_i units.

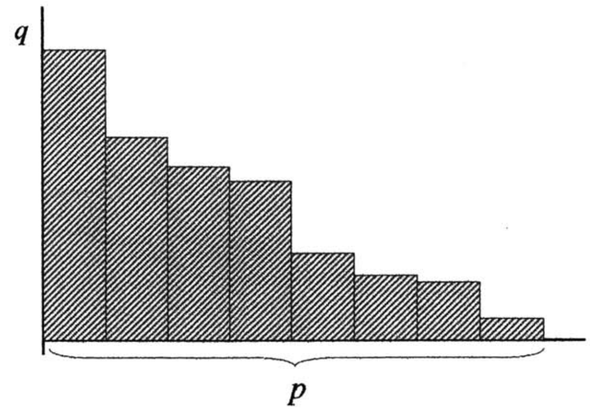
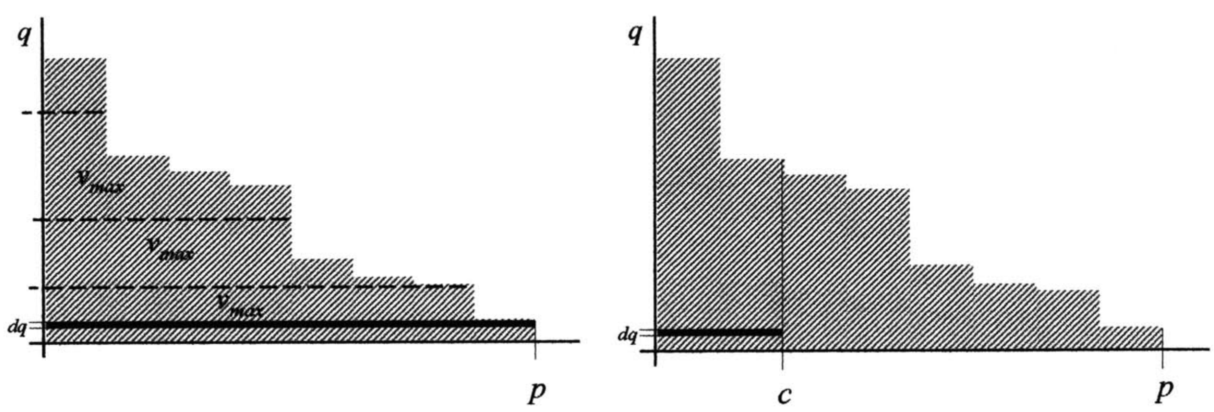


Figure 11. Illustration of the graphical knapsack problem

For vehicles without other restrictions that v_{max} units of capacity, the geometrical problem to determine the number of loads l is equivalent to cover the area of size Q with the minimum number of continuous areas of v_{max} or less units. Figure illustrates this idea with an example. Vehicle capacity can be represented as a horizontal strips of height equal to a differential of quantity dq and width v_{max}/dq. The strip can be cut of sizes p or less and cover an area of v_{max} units.



a) simple vehicles

b) compartmented vehicles

Figure 12. Illustration of the capacity utilization for simple and compartmented vehicles

Vehicles with a fixed number of compartments, c, differ from the previous case in that they can only cover the area Q with strips of width c or less.

A simple heuristic, H_0, is proposed to determine the number of loads that the fleet of compartmented vehicles would have to perform. The heuristic simply separates the p products in the minimum number of groups of c or fewer products. The next figure illustrates the heuristic for the case when p is a multiple of c.

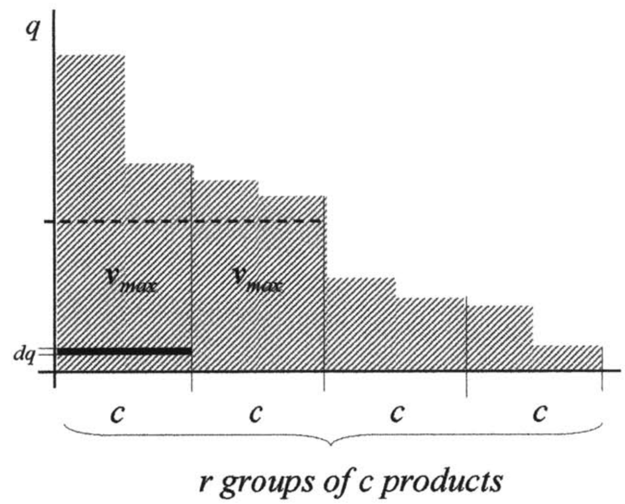


Figure 13. Illustration of the simple bin packing heuristic

In general the number of trips for heuristic H_0, regardless if p is a multiple of c or not, is:

$$l_c = \sum_{i=1}^{r} \left[\left(\sum_{j=c\cdot(i-1)+1}^{c\cdot i} q_i \right) \Big/ v_{\max} \right]^{+} + \left[\left(\sum_{j=c\cdot r+1}^{p} q_i \right) \Big/ v_{\max} \right]^{+} \qquad (24)$$

Where

$r = [p/c]^{-}$, the integer part of (p/c).

This heuristic would appear intuitively appropriate when the demand for all products is identical $(q = Q/p)$, defining a rectangular area. Its behavior was analyzed in several test cases with varying c, p, Q and the individual q_i's.

It was found in all possible cases the maximum difference between the number of trips proposed by heuristic Ho and the minimum number of trips $\underline{[Q/v_{max}]^+}$ is always bounded in $[0, (p/c)^+-1]$, which we refer to as the extra number of trips, k.

The next figure shows the plot of the number of trips performed with regular and compartmented vehicles, l and l_c respectively, versus the total quantity Q.

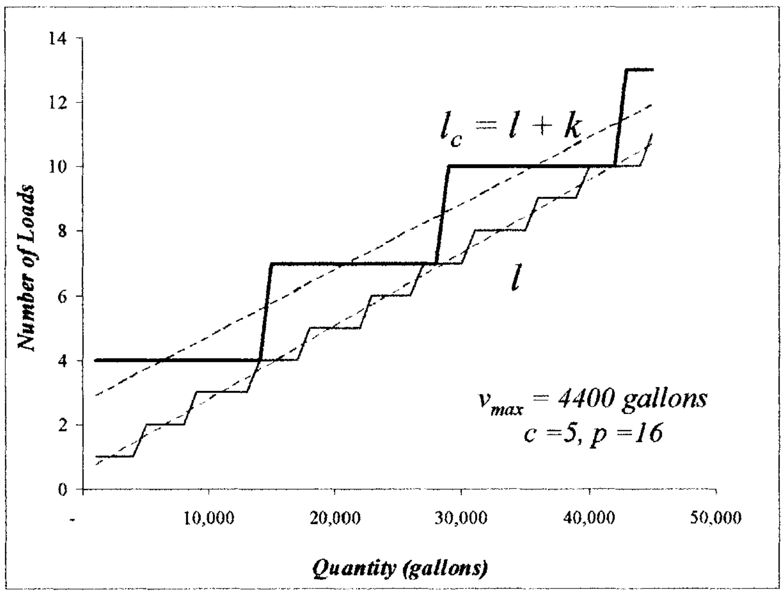


Figure 14. Comparison between the number of minimum number of loads and a the results of a simple heuristic for compartmented vehicles.

A lower bound for the expected number of additional trips with the H0 heuristic $E(k)$ the midpoint of the range:

$$E(k) = ½(E([p/c]^+)-1) \approx ½(E(p)/c + 1/2 - 1) = E(p)/(2c) - 1/4 \qquad (25)$$

Therefore, the distance formula for compartmented trucks can be should be modified:

$$D = 2\cdot(l+k)\cdot r + n\cdot k\cdot \delta^{-1/2} \qquad (26)$$

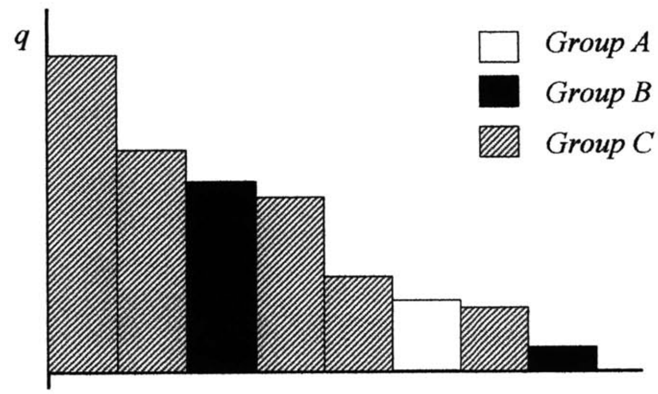
$$E(D) = 2 \cdot E(l+k) \cdot r + E(n) \cdot k \cdot \delta^{-1/2} \quad (27)$$

$$E(D) = 2 \cdot r \cdot [E(Q)/v_{max} + E(p)/(2c) + 1/4] + E(n) \cdot k \cdot \delta^{-1/2} \quad (28)$$

The effect of compartmented vehicles in local distance will cause different products in a customer to be treated as different customers for loading purposes.

Product Incompatibility

Consider now the case when certain products cannot be loaded together in the same vehicle. This restriction is represented by defining different product compatibility groups. In the case under study, products are assigned to three groups. Group A and B are incompatible. A third group C, has general compatibility with groups A and B.



Generalizing the number of additional loads would not be obtained in this effort. Instead an observation is proposed.

Let Q_A, Q_B and Q_C, be the quantity of product to be delivered in a district of each compatibility group. Consider the minimum between quantities Q_A and Q_B. We will refer to $\min(Q_A, Q_B)$ as the incompatible quantity

If $\min(Q_A, Q_B) << Q_C$, then the effect of compatibility is negligible over the number of trips. If two products cannot be loaded in the same trip, they can be assigned to other trips with products from the general compatibility group, without increasing the number of loads. Since this analysis considers a delivery district, it should be possible to deliver both products in different shipments without significantly increasing the local travel distance.

2.2.3. Vehicle Fleet size

The minimum number of vehicles required per period, M, can be estimated based on the amount of required working time per period, T, to cover the total travel distance plus loading at the origin and unloading and service time at destinations, so that the available time of the vehicle fleet is greater or equal than the required amount of work on a single period. Let:

$$T = D/s + l \cdot t_l + n \cdot t_s \qquad (26)$$

Then

$$M \cdot t_w \geq T \qquad (27)$$

Where

T = required working time per week *(hrs/week)*

M = Fleet size *(vehicles)*

t_w = working time per vehicle per week *(hrs/(vehicles·week))*

D = Travel distance per period *(miles/week)*

l = number of shipments per period *(shipments/week)*

n = number of customers visits per period *(stops/week)*

s = average vehicle speed *(miles/hr)*

t_l = loading time per shipment *(hrs/shipment)*

t_s = unloading and service time per stop *(hrs/stop)*

Substituting the travel distance approximation from equation (14), equation (20) can be re-written as:

$$T = (Q/v + 0.5)\cdot[(2\cdot r)/s + t_l] + n\cdot[(k\cdot\delta^{1/2})/s + t_s] \quad (22)$$

Q and n and T are random variables. T is a linear combination of two random variables; its mean and variance can be determined with the following formulas[20]:

$$E[a\cdot X + b\cdot Y] = a\cdot E[X] + b\cdot E[Y] \quad (23)$$

$$Var[a\cdot X + b\cdot Y] = a^2\cdot Var[X] + b^2\cdot Var[Y] + 2\cdot a\cdot b\cdot Cov[X,Y] \quad (24)$$

Substituting equation 22 into the previous definitions:

$$E(T) = (1/v_{max})\cdot[(2\cdot r)/s + t_l]E(Q) + [(k\cdot\delta^{1/2})/s + t_s]E(n) + [(r)/s + t_l/2] \quad (25)$$

$$Var(T) = \{(1/v_{max})\cdot[(2\cdot r)/s + t_l]\}^2 Var(Q) + [(k\cdot\delta^{1/2})/s + t_s]^2 Var(n) +$$

$$2\cdot(1/v_{max})\cdot[(2\cdot r)/s + t_l][(k\cdot\delta^{1/2})/s + t_s]\cdot Cov[Q,n] \quad (26)$$

The fleet size of vehicles should consider the variability of the total required time per week, and should be analyzed considering the probability distribution of T. Given a target a service level, α, the design criteria for M is such that the probability of the required time being higher that M is 1-α:

$$P[T < M\cdot t_w] = \alpha$$

Turnquist and Jordan[21] describe uncertain travel times using a normal distribution in the fleet size determination problem, even when the distribution is non-normal without adding significant error. The remainder of this section follows this approach. The total required time, as the sum of individual travel times will be assumed to be normally distributed:

$$T \sim N(\mu,\sigma) \quad (27)$$

Where

$$\mu = E(T) \quad (28)$$

$$\sigma^2 = Var(T)) \quad (29)$$

For a service regions containing P delivery districts, the mean and variance is determined adding, the individual values for each district

$$\mu = \sum_{i=1}^{P} (E(T_i)) \qquad (30)$$

$$\sigma^2 = \sum_{i=1}^{P} (Var(T_i)) \qquad (31)$$

Finally, M is determined by the normal definition

$$M = \mu + k(\alpha) \cdot \sigma \qquad (32)$$

Where $k(\alpha)$ is the number of standard deviations of a standard normal distribution for a cumulative probability of α.

2.3. Storage and Handling

2.3.1. Pool of Returnable Containers

This section presents the approaches to determine the number of returnable containers required in the system, R.

Returnable containers define a closed loop system passing through different stages:

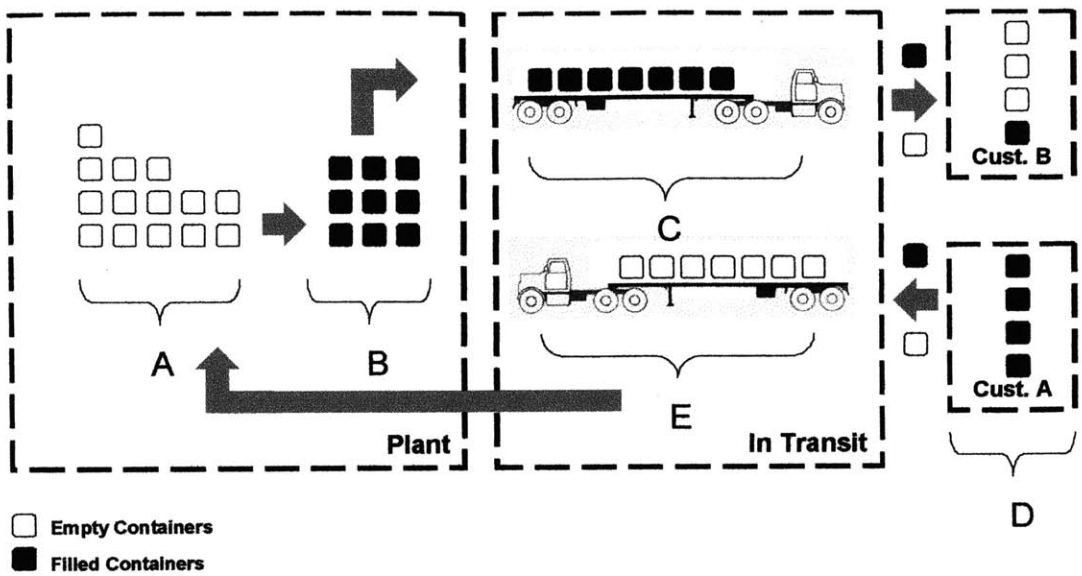
A) empty at the plant until it filled.

B) filled at the plant waiting for dispatch

C) traveling filled on a vehicle to a customer.

D) at a customer site until its contents are consumed.

E) traveling empty on a vehicle back-hauled to the plant.



The number of containers in the system can analyzed considering two separate subsystems:

- Containers in use at the customer site, stage D
- Containers in motion, stages C and E, and at the plant, stages A and B.

The number of containers in stage D, R_{CUST}, is constant; on every shipment customers must return an empty container for every one they receive. R_{CUST}, is the sum of the number of containers allocated to each customer, which should be enough to hold the maximum stock level for all the products they carry.

The sum of all containers in stages A, B, C and E, R_{PLANT}, is also constant. However the number of containers in each stage changes dynamically over time. For the system to operate normally, the number of **empty** containers at the plant, R_A, should always be higher than zero.

Both R_{CUST} and R_{PLANT} become the decision variables of a design problem. The total number of containers in the system R, is expressed as their sum:

$$R = R_{CUST} + R_{PLANT}$$

Inventory control theory studies the coordination between demand and order placement. In the following sections, the inventory control problem associated to each component of the pool of returnable containers is used is presented.

2.3.1.1. Containers allocated to customers

Products stored at the customer site define a single-echelon, multi-product inventory system. This section develops an approach to the number of containers required by customer.

From the customer's perspective, the products they acquire from the company are essential to their production process and relatively low volume. In general items with such characteristics are managed Order-up-to inventory policies, where orders are placed for a quantity enough to bring inventories back to a maximum level S, whenever inventory falls bellow a minimum safety stock level, s. Both continuous and periodic versions of order up to levels are available[22]. Determination of S and s by traditional methods require information about the customer's internal demand for the product, and the definition of inventory policy parameters. Such information is not available for this research.

Assuming that customers order using a continuous review inventory policy (s,S), the order-up-to value, S, will be estimated with the maximum order quantity per product per period. For multiple products, the required storage capacity will be estimated as the sum of the maximum order size in any given period.

Let:

$$R_{CUST} = \sum_{k=1}^{n} \max(q_{i,t}), \forall t \in [1,T]$$

Where

$q_{i,t}$ = order size for product i in period t

$[1,T]$ = is the time horizon of analysis.

2.3.1.2. In Plant and In Transit Stock of Containers

This section studies the inventory control problem of **empty** containers at the plant to determine the total number of stocks at the plant. This analysis assumes that filling and shipping are coordinated process that both operate in a first-in first-out basis and that there is no accumulation of filled containers inventory.

The inventory control system for empty containers at the plant can be classified as a one-for-one, (s-1,s) system. This model is used extensively in the control of high value spare parts inventory, and more recently in quick response systems in the retail industry[23].

When an empty container is drawn from inventory to be filled for a planned delivery, a replenishment process for another empty container is triggered: at the customer site, another container waits to be exchanged and will be received once the vehicle that delivered the first container returns to the plant.

Demand for empty containers the product of two random variables: The number of customers requesting a delivery per period week, and the number of containers in each delivery. The probability of a customer placing an order is different across the service region. These characteristics are common in a compound Poisson process[24].

The replenishment process for empty containers has a random duration defined by the waiting time in the stock of filled containers and the duration of the tour delivering the containers and returning to the plant, which can be any arbitrary distribution.

Feeney and Sheerbrooke[25] generalized Palm's theorem for one-for-one re-supply systems where the demand process follows a compound Poisson distribution and the re-supply time follows a arbitrary distribution. Their work described the number of units in re-supply follow a compound Poisson distribution with a normalized demand by the re-supply time, regardless its distribution.

In the inventory system under study, no backorders are allowed. The containers in re-supply and the stock at plant add to a constant value, and stock outs will be modeled as lost sales. Let

$p(x|\lambda)$ = The density function of the compound Poisson distribution,

λ = Mean demand rate per period

τ = Mean re-supply time

The probability for x containers in re-supply is:

$$h(x) = p(x \mid \lambda\tau) / (\sum_{i=o}^{R_{PLANT}} p(i \mid \lambda\tau), \qquad 0 \le x \le R_{PLANT} \tag{33}$$

R_{PLANT} can be determined based on a fill rate, β, which represents the steady state probability that there are enough empty containers in the system to fill to demand. Let

$$H(x) = \sum_{i=o}^{X} h(i) \tag{34}$$

Then R_{PLANT} is the value that satisfies the equation

$$P\{x \le R_{PLANT}\} = H(R_{PLANT}) = \beta \tag{35}$$

3. Methodology

This section discusses the methodology for the research and is divided in two sections: Data Collection and Data Analysis.

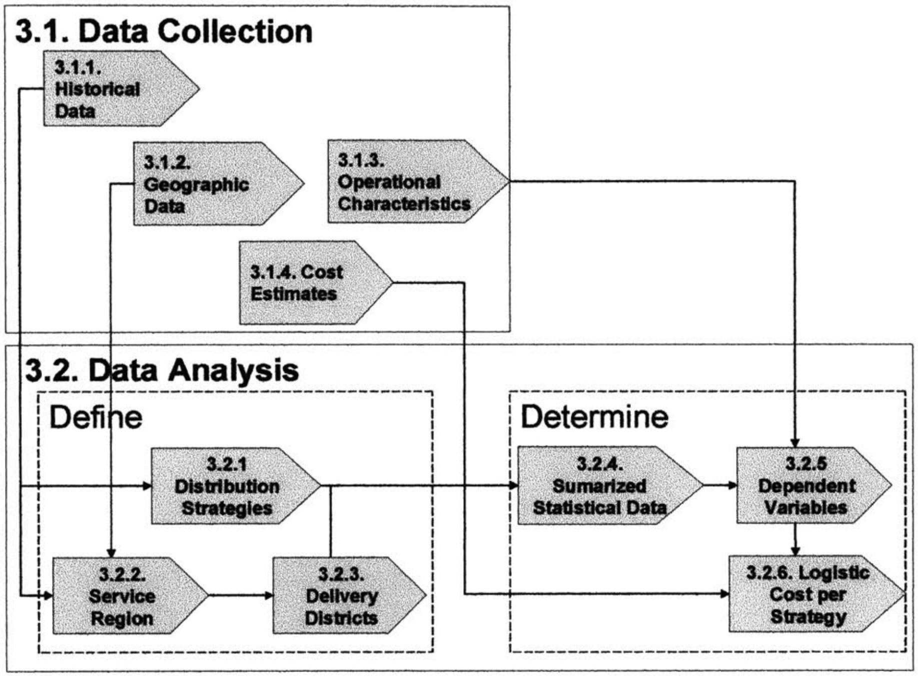


Figure 15. Methodology Overview Diagram

3.1. *Data Collection*

The sources of information for this research are divided in three main categories:

a) Historical sales and shipping data

b) Secondary geographical reference data

c) Operational characteristics for activities and equipment

d) Cost estimates for activities and equipment

Historical demand and shipping was collected to provide insight about customer demand characteristics and the performance of the bulk distribution system. Historical data includes sales orders, deliveries and shipments for year 2002 and was obtained from

Company A's Enterprise Resource Planning (ERP) system reports. Customer and plant location was established using ZIP Code data from their address records. A database model in MS Access was built to store and query historical data. The database was designed so that information could be extracted for any grouping of customers according to demand and geographical criteria.

Secondary geographical reference data included geographical information from the U.S. Census Bureau to complement historical data to aggregate and analyze shipment and demand data geographically. Coordinates and land area information for geographical entities were obtained from the 2000 Gazetteer Place and ZIP Code Tabulation Areas (ZCTA) Files[26]

Operational characteristics and cost estimates were provided by Company A for the resources and processes in each distribution which were used to calculate fixed and variable costs for transportation, storage and handling. Operational characteristics for resources included capacity and useful life. Average speed, available working time per week and fuel consumption was additionally collected for vehicles. Cost estimates included average market price of assets and costs per activity.

3.2. Data Analysis

3.2.1. Definition of Delivery Strategies

Delivery strategies are defined based on the usage of either bulk or packaged distribution systems. Distribution strategies also include the definition of performance measures for the system.

There are four main distribution strategies, based on the allocation of customers and products to each distribution system:

0. Bulk
1. Packaged.
2. Mixed, by customer.
3. Mixed, by product and customer.

Distribution strategies are illustrated in the next figure. Three different customers are depicted, A, B and C, representing, respectively high, medium and low demand.

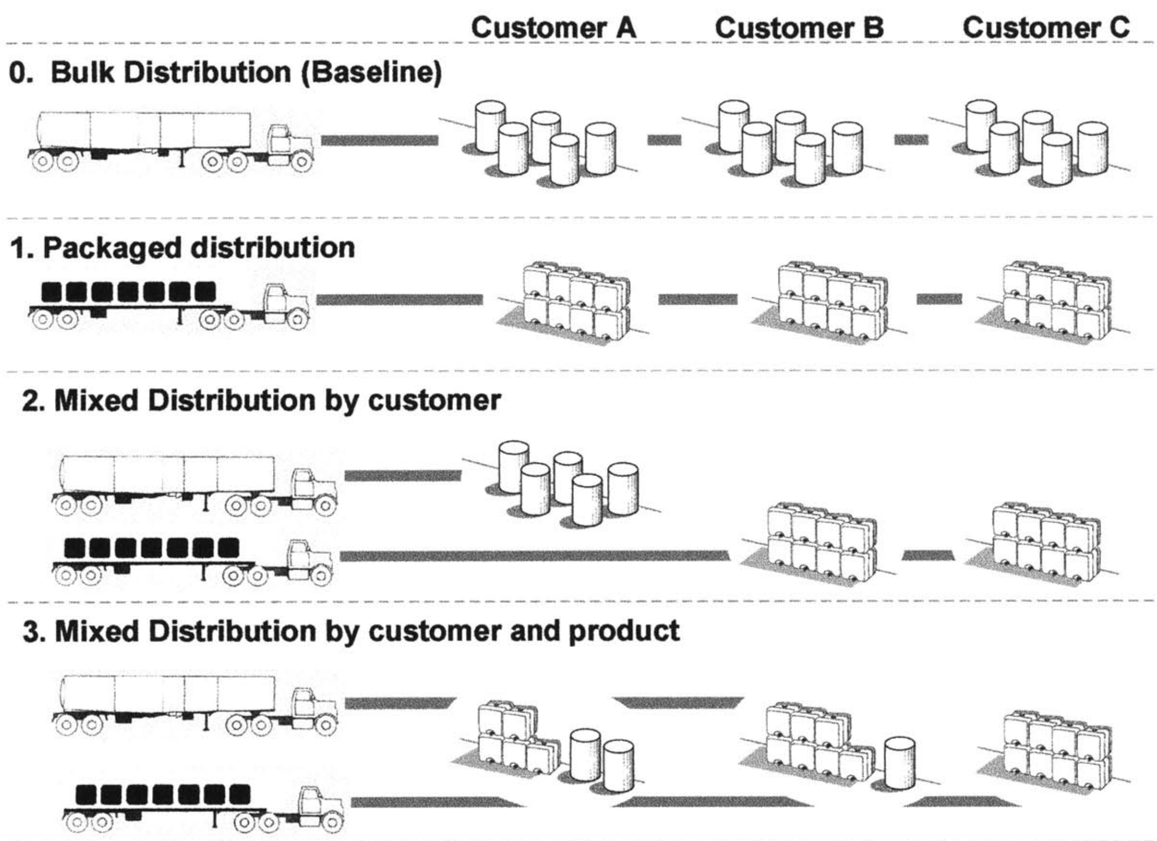


Figure 16. Illustration of Distribution Strategies

Bulk distribution, strategy 0, is the current practice in Company A. It is considered as the baseline for evaluation of other distribution strategies. The results of this strategy will be compared to current performance indicators for validity.

Packaged distribution, strategy 1, considers delivering product to all customers in with returnable containers. It involves replacing the current fleet of tanker vehicles and bulk dispensers to flatbed trucks and tote dispensers.

Mixed distribution by customers, strategy 2, and product considers establishing a threshold value for annual demand per customer to serve those with low demand with a packaged distribution system and customers with high demand with the current bulk system. It involves a mixed fleet of vehicles and dispensers.

Mixed distribution by customer and product, strategy 3, takes a further step in differentiating customer demand. A threshold value is defined for annual customer demand by product. As a guideline, low demand products would be distributed on returnable containers and high demand product in bulk. It is possible to have a single customer served with both systems. In such event a customer would have a dispenser system for returnable containers, and bulk storage tanks would be set up externally.

Both mixed distribution strategies require the allocation of customers and products to either packaged or bulk distribution system. To establish the threshold of demand that separates high from low, a rank and percentile analysis is necessary. Each strategy can include different scenarios at different threshold values of demand.

The decision variables to be for each strategy are two:

- Service level for the vehicle fleet. It is defined as the long run ratio of periods that the current fleet had enough working time to satisfy the weekly demand. Service level is set as 99,9%
- Fill rate for the returnable container inventory. It is defined as the long run average ratio of customer demand that was processed and dispatched at time of request with the circulating stock of returnable containers. Fill rate is set as 99,9%

3.2.2. Definition of the service region

The service region for the Houston plant was determined graphically based on the volume of product delivered to its customers, grouped in geographical areas. Certain areas were served by more than one plant, and the criteria used to determine their primary source of supply is the ratio of product delivered from a plant over the total product delivered to a given area from all plants. A threshold value of 2/3 was defined as the minimum ratio to consider a plant the primary source for a any geographical area.

Customer locations were fairly scattered and there were usually no more than one customer per Zip code area. Demand data was aggregated by County to provide a level of detail for the research.

Only data from the last semester of 2002 was considered assessing the service regions because new distribution centers opened during this period which changed customer allocation to sources of supply.

The service region was manually defined based on the plot of the fraction of deliveries per county from the Houston plant using a GIS application, MS MapPoint 2002.

3.2.3. Definition of delivery districts.

Delivery districts are subdivisions of the service region relevant for delivery load planning. The delivery regions were defined manually in a GIS application based on two criteria: analysis of the historical shipping data patterns and customer clusters around dense urban areas.

Shipping routes and customer locations were plotted using a spreadsheet application, MS Excel. Route and customer location plots revealed areas where shipment stops were concentrated and clusters of customer locations. Once delivery districts were defined, customers would be allocated to a delivery district for analysis purposes.

Next the procedure to determine the coordinates to plot customers and shipment routes is described.

Customer locations in the service region were plotted using their distance from the Houston plant. Distance was calculated using a Euclidian, the straight line distance between two points in the plane. The distance is determined using their Zip code latitude and longitude information and the conversion of distances in degrees to miles in the continental US can be approximated considering the average length of 69 miles per degree of latitude[27]. Therefore the relative location a customer, point *i*, to the origin plant, point *o*, is determined as:

$$(x_{i,o}, y_{i,o}) = (69 \cdot (long_i - long_o), 69 \cdot (lat_i - lat_o))$$

Where,

$x_{i,o}$ = horizontal distance from point *i* to point *o*, in miles.

$y_{i,o}$ = vertical distance from point *i* to the point *o*, in miles.

$long_a$ = longitude of point a, in degrees.

$long_b$ = latitude of point a, in degrees.

Shipments within the service region were studied according to the distance from the origin to the furthest stop, R_{max}, and the mid angle from the route, θ, measured counter-clockwise from the north.

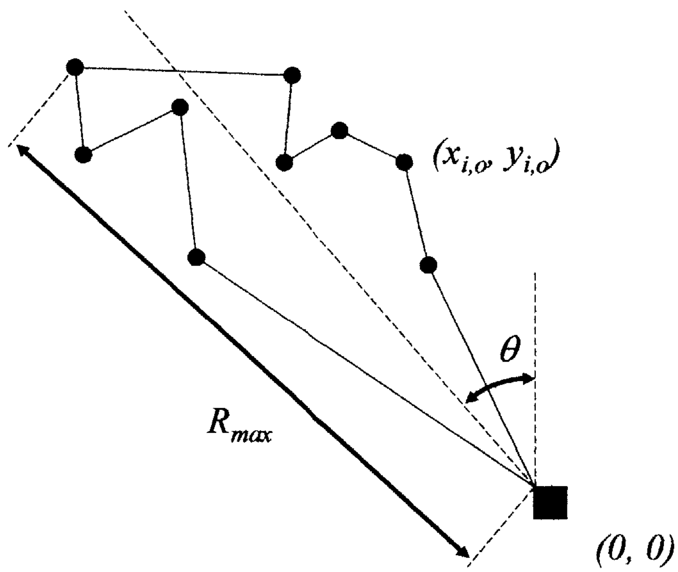


Figure 17. Illustration of shipment angle and range

Where,

n = number of stops in a shipment

i = stop number index, $i \in \{1,..,n\}$

$$Y_{dist} = \sum_{i=1}^{n} y_{io}$$

$$X_{dist} = \sum_{i=1}^{n} x_{io}$$

$$\theta = \tan^{-1}\left(\frac{Y_{dist}}{X_{dist}}\right) - sign(X_{dist}) \cdot \pi / 2, \theta \in \{-\pi, \pi\}$$

$$R_{\max} = \max\left(\sqrt{(y_{io})^2 + (x_{io})^2}\right), i \in \{1,..,n\}$$

$sign(x) = 1$ if $x > 0$; -1 if $x \leq 0$.

To determine the actual routing sequence, each stop individual angle and distance to the origin, θ_i and R_i respectively, is determined.

$$\theta_i = \tan^{-1}\left(\frac{(y_{io})}{(x_{io})}\right) - sign(x_{io}) \cdot \pi / 2$$

$$R_i = \sqrt{(y_{io})^2 + (x_{io})^2}$$

Stops at the right side of the mid angle line are routed going out from the depot; stops at the left side of the mid angle line are routed in reverse order, returning to the depot. This is illustrated in the following figure.

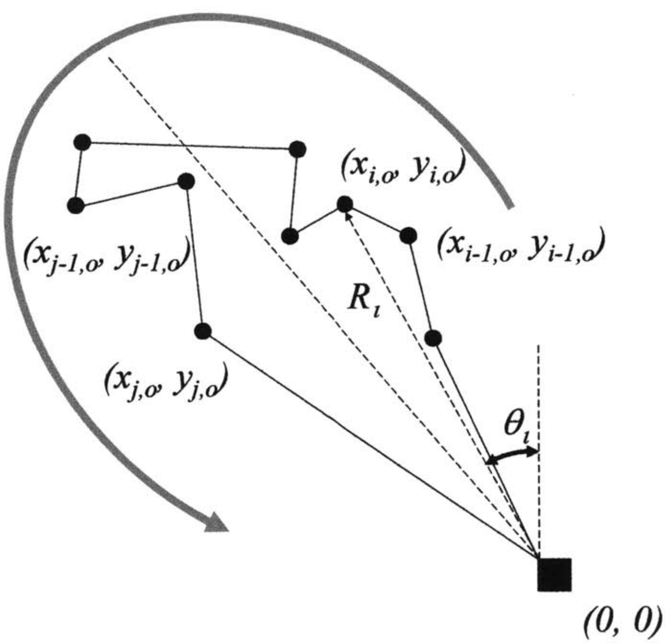


Figure 18. Illustration of Shipment Routing

In other words for all stop indices *i* where $\theta_i \leq \theta$, $R_i \geq R_{i-1}$, and for all indices *j* where $\theta_j \geq \theta$, $R_j \leq R_{j-1}$; j > i. This can be implemented in a spreadsheet using sorting functions once the average angle for each shipment along with the individual stop distances and angles from the depot are determined.

3.2.4. Summarized Statistical Information

The analytical model developed for this research requires summarized statistical information as input to determine the dependent variables to determine the logistics cost for each distribution strategy, i.e. traveled distance, number of vehicles and number of returnable containers.

This activity is composed of three main tasks:

1. Validating assumptions used in the formulation of the analytical model
2. Extracting data for each distribution strategy scenario
3. Calculating key statistical descriptors for the extracted data used as inputs in the analytical model.

Validation of modeling assumptions

a) Small order size compared to vehicle capacity: A percentile analysis of order sizes is presented to verify that order size is small compared to vehicle capacity and to support the assumption that only one visit per customer in necessary per period if there are no additional loading constraints than capacity.

b) Multiple stops per shipment: A histogram of number of stops per shipment will be presented using historical shipment to validate the usage of modeling shipments using a peddling routing scheme.

c) Effect of compartment vehicle capacity in shipment routing: A histogram of the number of visits per customer per week is presented to verify the effect of compartmented vehicle capacity. Despite the validation of small order size to vehicle capacity, compartmented vehicle routing treats each different product requirement at a customer as separate customers, which would increase the probability that customers with multiple products be visited more than once per period.

d) Effect of product compatibility in shipment routing: A histogram of the percentage of the quantity of incompatible product to the quantity of generally compatible product is plotted. A low percentage of incompatible products would support the argument to neglect the effect of product compatibility in the analysis.

e) Correlation of demand and number of customers per period: A scatter plot of customers and total order volume per period is presented to validate the correlation between these two variables. In assessing the variance on total working time per week the covariance of these two variables needs to be included if a positive correlation is found.

f) Probability distribution fitting of external variables: The expressions to estimate the total working time and the required number of containers in circulation are based on the assuming that external variables are distributed according to a particular probability distribution. The next table presents the hypothesis about the behavior of the relevant external random variables. A Chi-squared test for the goodness of fit using a significance level of 95% will be used to test the previous hypothesis:

Hypothesis \ Variables	$Q(i,t)$	$n(i,t)$	$Q'(t)$
H_0, (null)	$Q(i,t)$ follows a Normal distribution	$n(i,t)$ follows a Poisson distribution	$Q'(t)$ follows a Negative Binomial distribution
H_a, (alternative)	$Q(it)$ follows **does not a** Normal distribution	$n(i,t)$ **does not** follow a Poisson distribution	$Q'(t)$ **does not** follow a Negative Binomial distribution

Table 1 Summary of Hypothesis and variables for distribution fitting

Data Extraction

The following is a description of the relevant time series that need to be extracted from the database of historical data using the definition of service region, delivery district and the allocation of customer demand and distribution systems in the definition of distribution strategy scenarios:

$Q(i,t)$ = The total quantity of product ordered in district i in period t, in gallons.

$n(i,t)$ = Number of customer ordering products per period in district i in period t

$p(i,t)$ = The number of products ordered per period.

$Q'(t)$ = The total quantity of product ordered in the service region in period t, expressed as a integer number of returnable containers. To calculate $Q'(t)$, the individual customer demand $q_{k,t}$ is transformed into the individual demand of returnable containers according to their capacity, v_c.

$$q'_{k,t} = [q_{k,t}/v_c]^+$$

$$Q'(t) = \sum_k q'_{k,t}$$

R_{CUST} = the number of containers at the customer site, based on the maximum monthly consumption for each customer. The weekly demand of returnable containers per customer, $q'_{k,t}$, is aggregated into in monthly periods, as $q''_{k,t'}$. The number of returnable containers for each distribution strategy R_{CUST} will be calculated as

$$R_{CUST} = \sum_k \max\left(q''_{k,t'}\right)$$

Where,

i = delivery district index

t = weekly period index, $t \in [1, 52]$

t' = monthly period index, $t' \in [1, 12]$

n = total number of customers in the service region.

k = customer index, $k \in [1, n]$

Determination of key statistical descriptors

From the time series collected in the previous section, the relevant statistical descriptors for each variable are detailed in the next table:

<table>
<tr><th colspan="2">Variable</th><th>Units</th><th>Mean</th><th>Variance</th><th>Covariance</th></tr>
<tr><td>Q(i,t)</td><td>Weekly customer demand per district.</td><td>$\frac{K\ gallons}{week}$</td><td>Q(i)</td><td>Var(Q(i))</td><td rowspan="2">Cov(Q(i),n(i))</td></tr>
<tr><td>n(i,t)</td><td>Number of customer requesting delivery per week per district</td><td>$\frac{customers}{week}$</td><td>n(i)</td><td>Var(n(i))</td></tr>
<tr><td>p(i,t)</td><td>Number of products orders per week per district</td><td>$\frac{products}{week}$</td><td>p(i)</td><td></td><td></td></tr>
<tr><td>Q'(t)</td><td>Weekly customer demand for returnable containers in the service region</td><td>$\frac{totes}{week}$</td><td>Q'(t)</td><td>Var(Q'(t))</td><td></td></tr>
</table>

Table 2. Variables and statistic information to be summarized from historical data

3.2.5. Determination of Dependent Variables

Based on the definition of distribution strategies and the summarized statistical data for the service region and delivery districts a spreadsheet document for each distribution scenario is set up to determine the dependent variables that define the logistic system: traveled distance, number of vehicles and number of containers. The detailed structure and detailed description of the spreadsheet is available in Appendix B.

3.2.6. Determination of Logistic Cost for each Distribution Strategy

A summary worksheet is set up to benchmark all distribution strategy scenarios based on the individual scenario worksheet and unit cost information. This spreadsheet provides a comparison of the total cost per week of each distribution strategy

4. Data and Results

This chapter presents the results following the steps described in the methodology for data analysis. The definition of the service region is presented, the assessment of threshold values for the delivery strategy, and the validation of several assumptions. Finally the results for the different scenarios are presented and summarized. The detailed calculations are available in the Appendix B.

4.1.1. Service Region

A plot of the distribution intensity plant is presented in the following map chart. The dark areas indicate counties where a high fraction of demand is served directly by the Houston Plant. This information along with the updated location of distribution centers were used to define the service region.

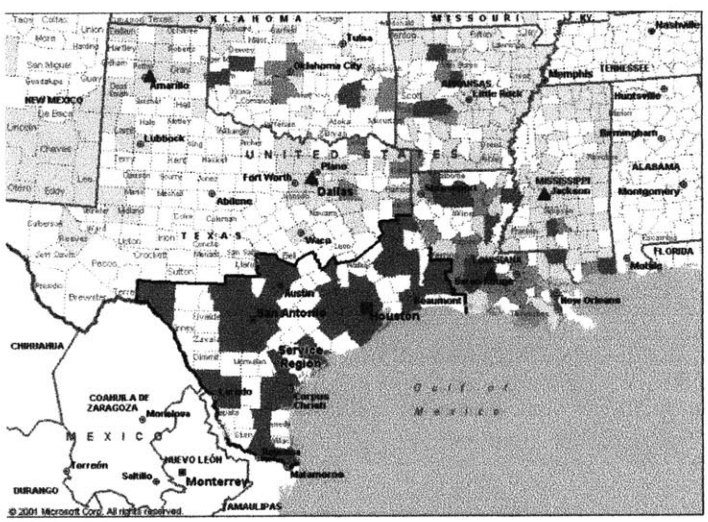


Figure 19. Plot of the fraction of demand by county served directly from the Houston Plant

The service region is defined shown in the next map chart.

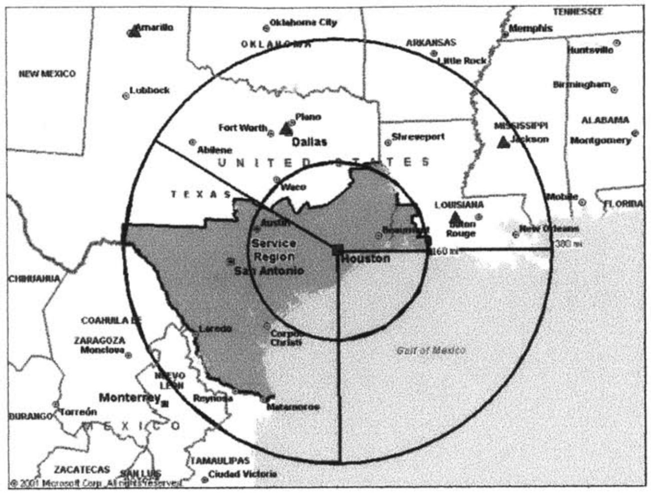


Figure 20. Definition of the service region for the Houston plant

4.1.2. Distribution Strategies

Bulk and Packaged distribution strategies, strategies 0 and 1 respectively, consider directly all customers in the service region. Mixed distribution strategies allocate customers to each distribution system based on the percentile of total order quantity during the year by customer (strategy 3) and by customer and product (strategy 4).

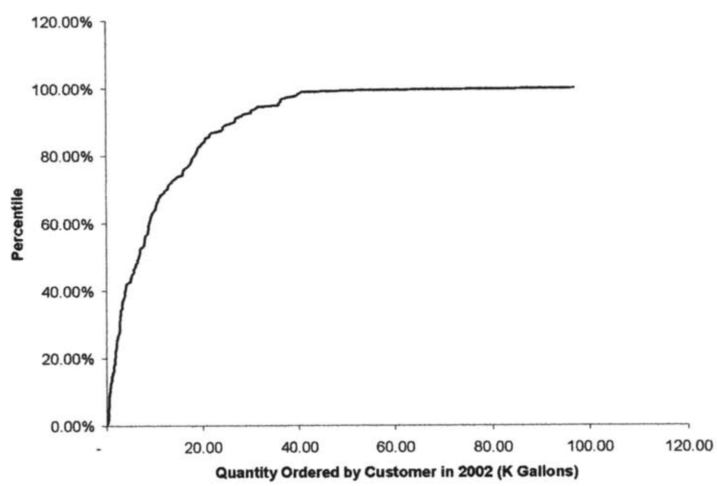


Figure 21. Percentile Analysis for the Quantity Ordered by Customer in 2002

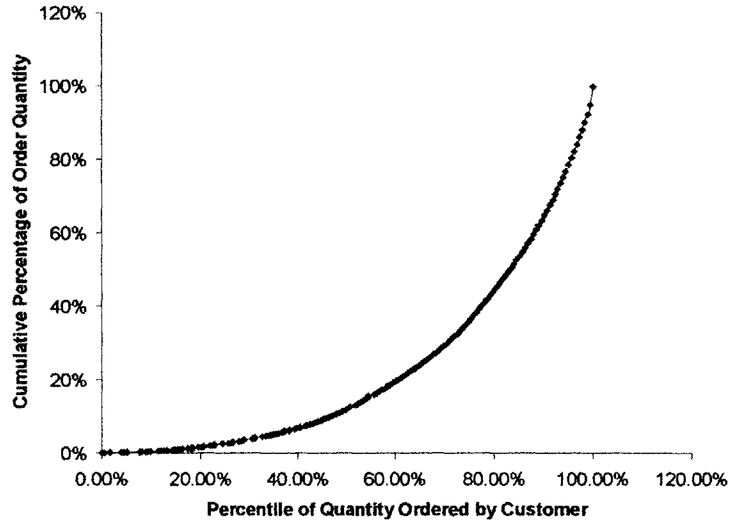


Figure 22. Cumulative Percentage of Quantity Ordered vs. Percentile of Customer Order Quantity in 2002

Mixed distribution by customer, strategy 3, is assessed in the percentile analysis shown in the two previous charts. The analysis reflects a high fragmentation of customer demand; 80% of the customers account roughly for 40% of the total demand, and the remaining 60% is concentrated in the than 40 customers. The scenarios to evaluate the strategy 3 will be based in percentile 50, 80 and 95.

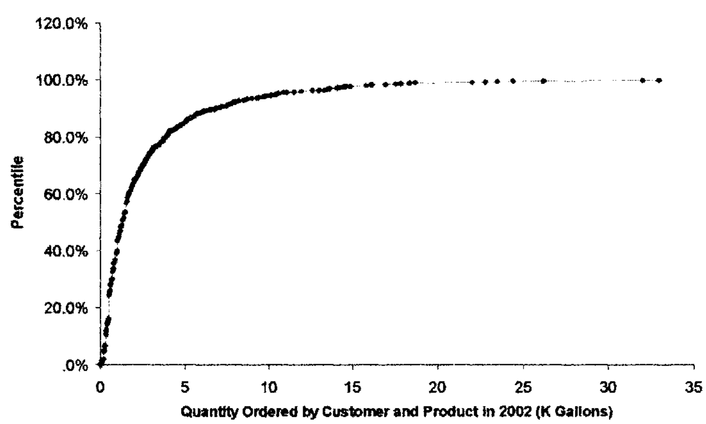


Figure 23. Percentile Analysis for the Quantity Ordered by Customer and Product in 2002

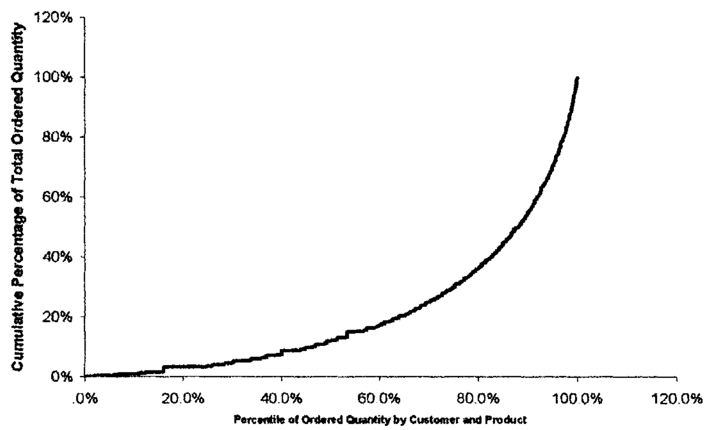


Figure 24. Cumulative Percentage of Quantity Ordered vs. Percentile of Customer Order Quantity by Product in 2002

Analysis of total order quantity in 2002 by customer and product shows very similar behavior than the analysis by customer only. A customer and product segmentation using a mixed strategy by customer and product, strategy 4, would provide a similar allocation of customers. Customers in general use both high and low demand products which mean that using strategy 4 a significant number will be served by both systems, therefore the introduction of additional stops would increase the transportation cost.

The number of customers served by each system vs. the percentile of order quantity for strategy 4 is presented in the next chart. For strategy 4, only a scenario based corresponding to percentile 80 will be evaluated and it will be shown that it produces a higher logistic cost that strategy 3.

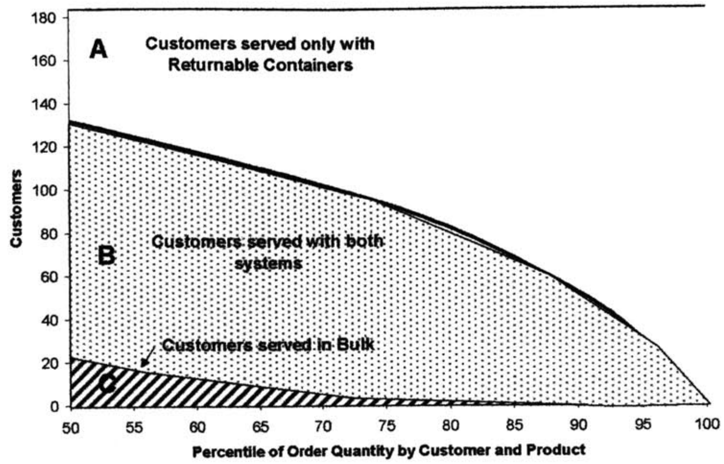


Figure 25. Number of Customers allocated to each Delivery Strategy vs. the Percentile of Order Quantity by Customer and Product

4.1.3. Delivery Districts

Routing patterns for shipments in 2002 according to the number of stops per shipment are presented in Appendix B. The analysis of routing patterns shows clustering of shipment routes on dense urban areas according to the concept of delivery districts.

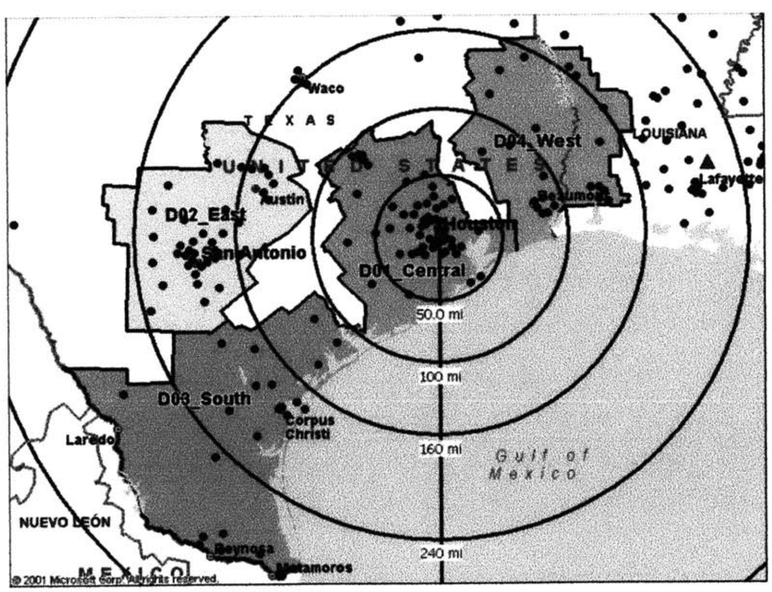


Figure 26. Definition of Delivery Districts for the Service Region

Four delivery districts were defined and are presented in the following map chart:

- D01 (Central)- Houston
- D02 (East) – San Antonio and Austin
- D03(South) – Corpus Christi and McAllen
- D04 (East) - Beaumont

4.1.4. Validation of Modeling Assumptions

Small order size compared to vehicle capacity:

A percentile analysis of The following chart shows the distribution of order sizes per week, and shows that roughly 90% of all orders are bellow 2000 gallons, half of the capacity of bulk tanker vehicles. This supports the assumption of customers requiring only one visit per vehicle when total vehicle capacity is the active constraint.

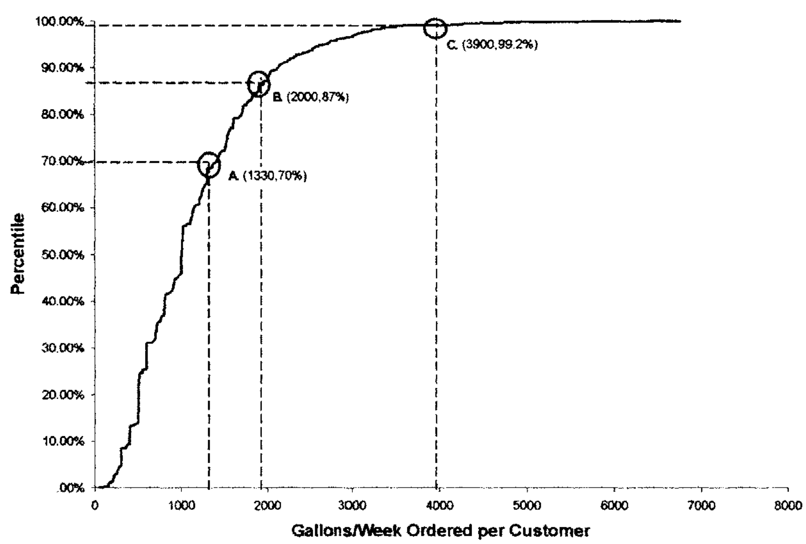


Figure 27. Percentile Analysis of weekly order size by Customer

Multiple stops per shipment

A histogram of the number of stops per shipment in the following figure shows that a significant fraction of shipments contain 3 or more stops, which validates the assumption of peddling routes for analysis of travel distance for the bulk distribution system.

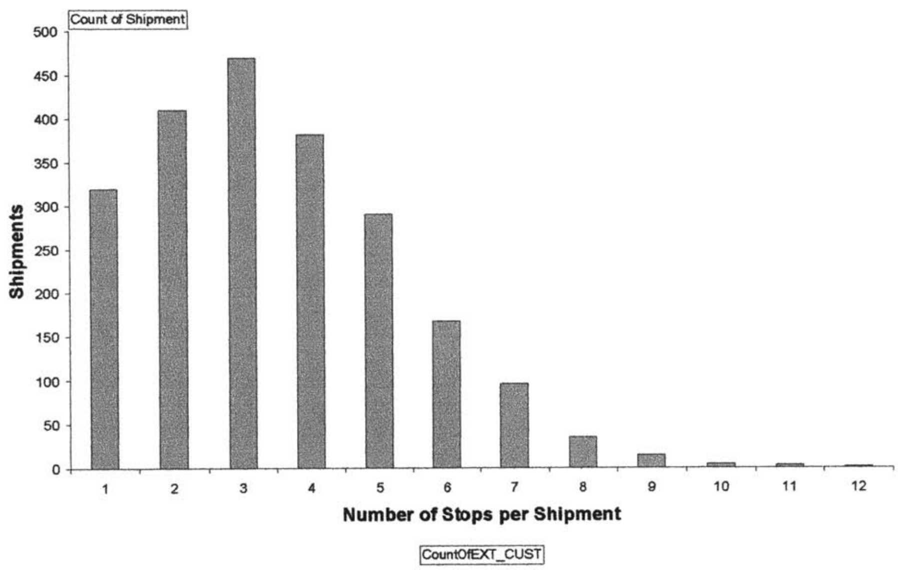


Figure 28. Histogram of the number of stops per shipment

<u>Effect of compartment vehicle capacity in shipment routing</u>

Despite the small size of order quantity to vehicle capacity, customers are visited on average 1.86 times per week with the bulk distribution system, according to the next chart. This finding supports the assumption that compartmented vehicle capacity increases the number of stops per customer per period. The dimensionless constant used in the estimation of local travel distance, *k*, for bulk distribution systems will be adjusted by multiplying the factor suggested in the literature of 0.765, to the square root of the number of stops per customer.

$$k' = k \cdot \sqrt{n_s / n} = 0.765 \cdot \sqrt{1.86} = 1.00$$

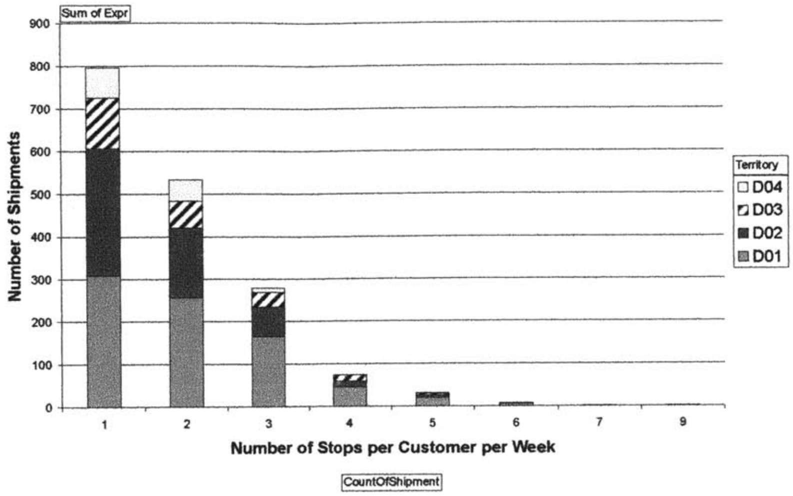


Figure 29. Histogram of the number of visits per customer per week per delivery district

Effect of product compatibility in shipment routing

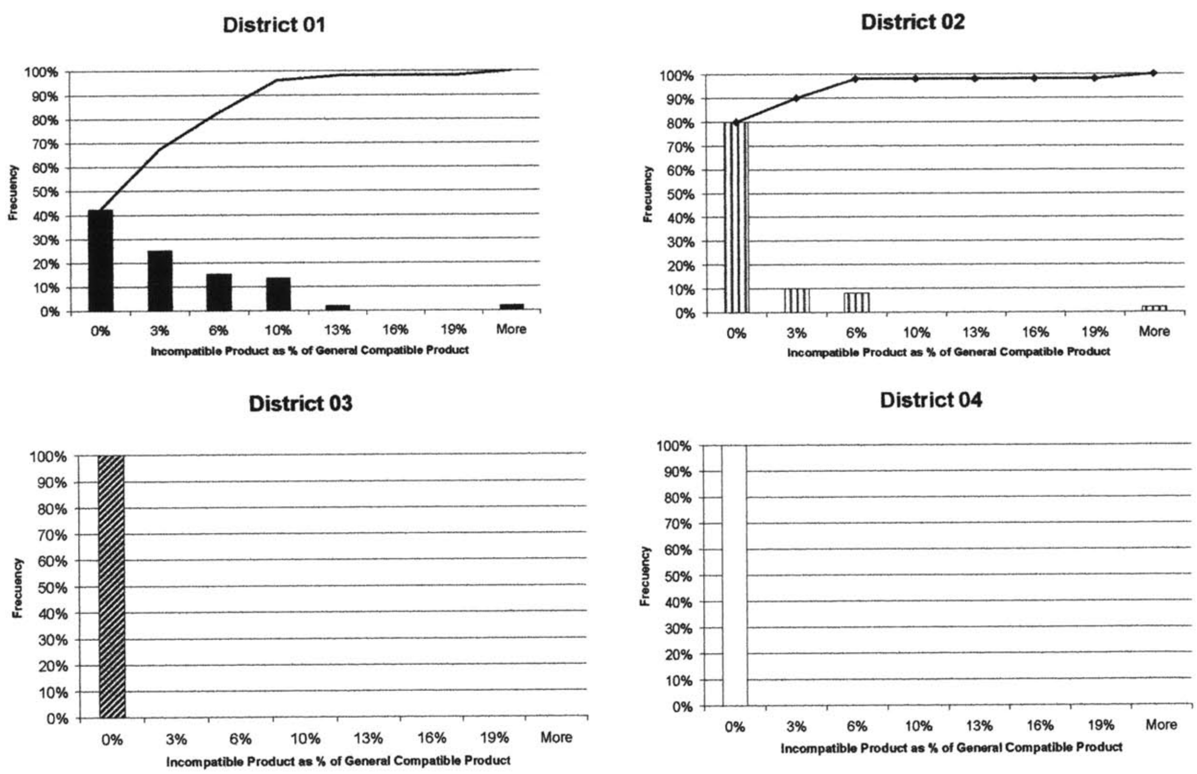


Figure 30. Histogram of quantity of incompatible product as a percentage of the quantity of product with general compatibility per district

Ordering of incompatible products in delivery districts is considerably low as show by the histograms presented in the previous figure. The percentage of weeks were no incompatible products were ordered together was 100% for districts 03 and 04, 80% and 40% for districts 02 and 01 respectively. District 01 presents the highest percentage of weeks were there were incompatible products ordered together. Nevertheless, within district 01 the incompatible quantity was less than 10 % of the quantity of product with general compatibility.

In district 01 where there are usually several shipments per week, such volume of incompatible product can be loaded with products with general compatibility without requiring additional shipments. While there might be an effect on the actual routing of shipments by product compatibility, this is already considered in the assessment the effect of compartmented capacity in traveled distance for bulk tankers. Therefore the effect of product compatibility is neglected from the analysis.

Correlation of demand and number of customers per period

The plot of customers per week and total ordered quantity reveals a significant positive correlation; therefore the term of covariance between both variables should be included in assessing the variability of working time.

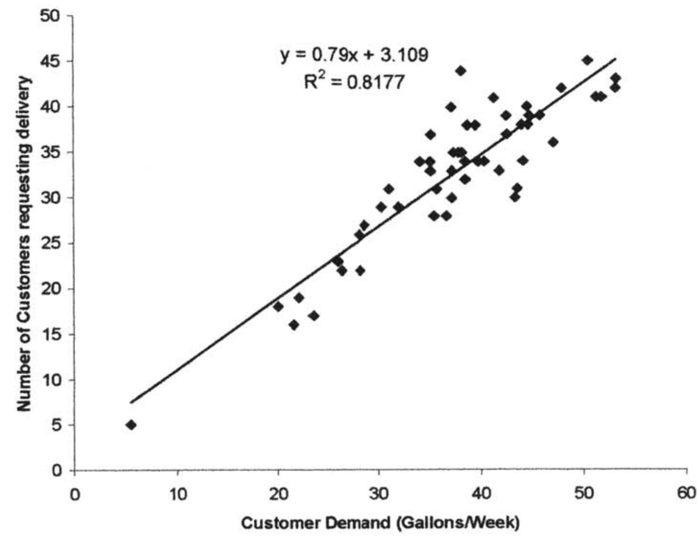
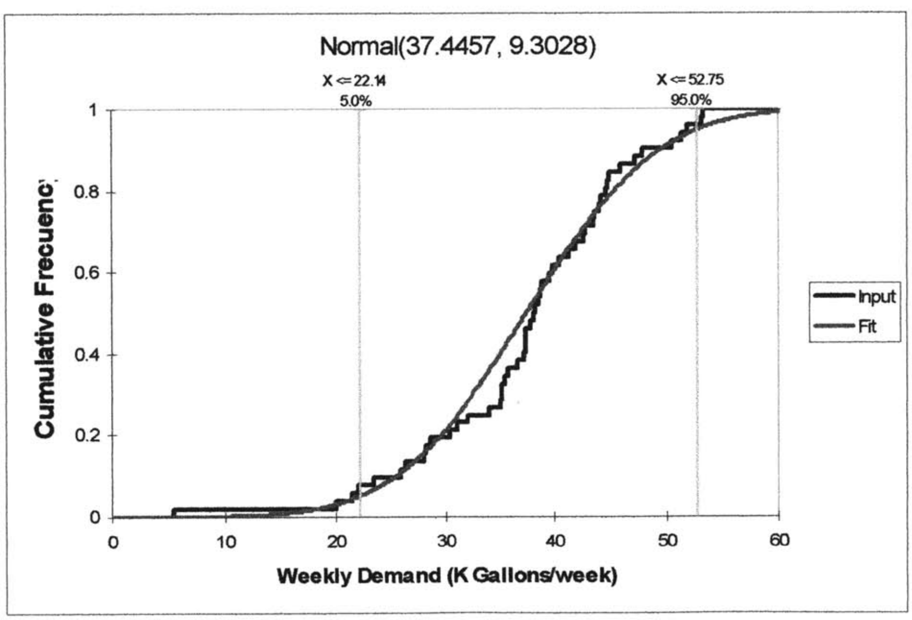


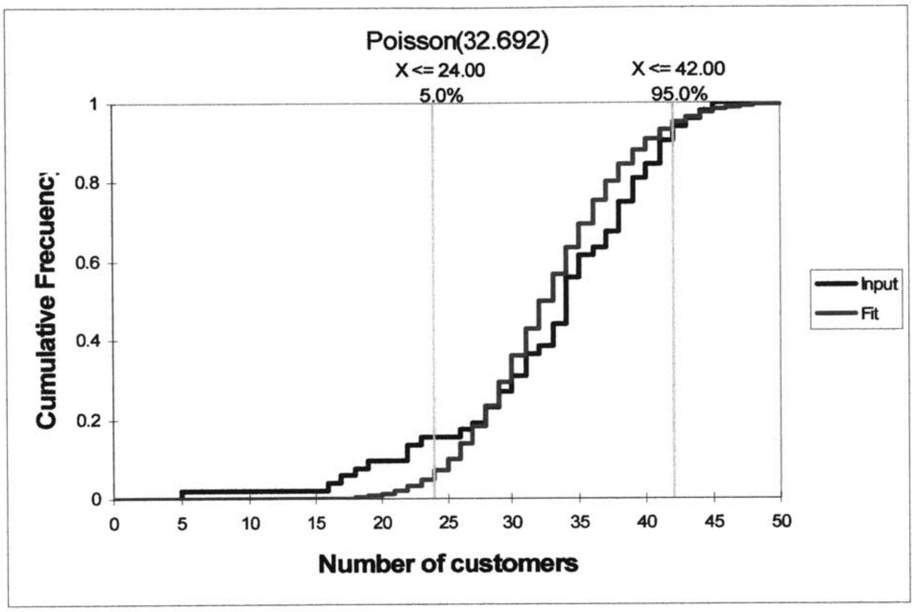
Figure 31. Correlation Analysis of weekly number of customers and demand

Probability distribution fitting of external variables

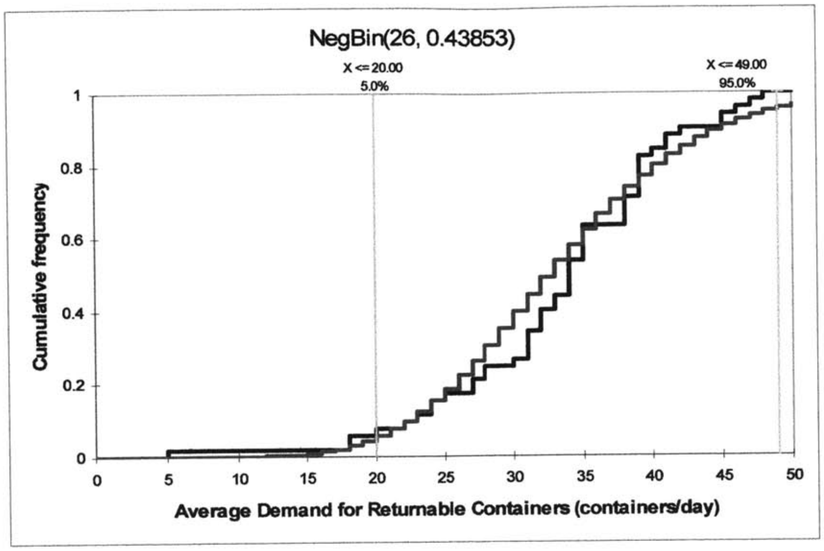
The following figure shows the histogram of customer demand in thousand of gallons per week. The probability of the sample data being generated by a normal distribution (p-value) is 0.4113. The null hypothesis of normally distributed customer demand is accepted.



Next, the cumulative frequency plot of the number of customers requesting product delivery per week is presented. The probability of the sample data being generated by a normal distribution (p-value) is 0.2136. The null hypothesis of Poisson distributed number of customers is accepted.



The cumulative frequency plot of the number of the average daily returnable container demand is presented. The probability of the sample data being generated by a negative binomial distribution (p-value) is 0.1868. The null hypothesis of Negative Binomial distributed number of customers is accepted.



NegBin(26, 0.43853)
X <= 20.00
5.0%
X <= 49.00
95.0%
Cumulative frequency
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
45
50
Average Demand for Returnable Containers (containers/day)

4.1.5. Distribution Strategy Scenario Analysis

I. Transportation Parameters

	key	units	Tanker Truck	Flatbed Truck
max. Capacity	v_{max}	*Thousand gallons*	*4*	*4.4*
avg. Speed	*s*	*miles/hr*	*55*	*55*
# compartments	*c*	*compartments/ vehicle*	*5*	*N/A*
Diesel Fuel Price		*USD/gallon*	*1.75*	
time per stop	t_s	*hr*	*1*	*1*
loading time	t_l	*hr*	*1.5*	*0.5*
workweek	t_w	*hrs/(week·vehicle)*	*60*	*60*
max. driving time/day	t_d	*hrs/day*	*10*	*10*

	key	Tanker Truck	Flatbed Truck
local distance constant	*k'*	*1*	*0.765*
Transportation Service	*SL*	*0.999*	
# of Normal Std. Dev	*k(SL)*	*2.99*	

II. Handling

	units	Value
Delivery days/week	*days/week*	*5*
Production to Delivery	*hrs*	*24*
Handling Fill Rate	*FR*	*0.999*

III. Geographical Information

Plant		XPOS Longitude	YPOS Latitude
4839	*Houston*	*-95.347414*	*29.749278*

District		XPOS Longitude	YPOS Latitude	Distance (r) miles	Area (A) Sq. miles	# of Customers
D01	*Houston*	*-95.81166179*	*29.8037516*	*32.25*	*13,807.04*	*79*
D02	*St. Antonio*	*-98.41529459*	*29.79941133*	*211.71*	*16,571.95*	*48*
D03	*South TX*	*-97.93895677*	*27.51081919*	*236.29*	*19,186.88*	*29*
D04	*East TX*	*-93.97474429*	*30.90789724*	*123.94*	*13,990.00*	*28*

Table 3. Operational Parameter Summary

The previous figure shows the results for the total logistics cost determined for each distribution strategy scenario. It shows that the scenario with the minimum cost is the packaged distribution scenarios, but only slightly lower than the baseline scenario. All other strategies result in higher costs than the baseline.

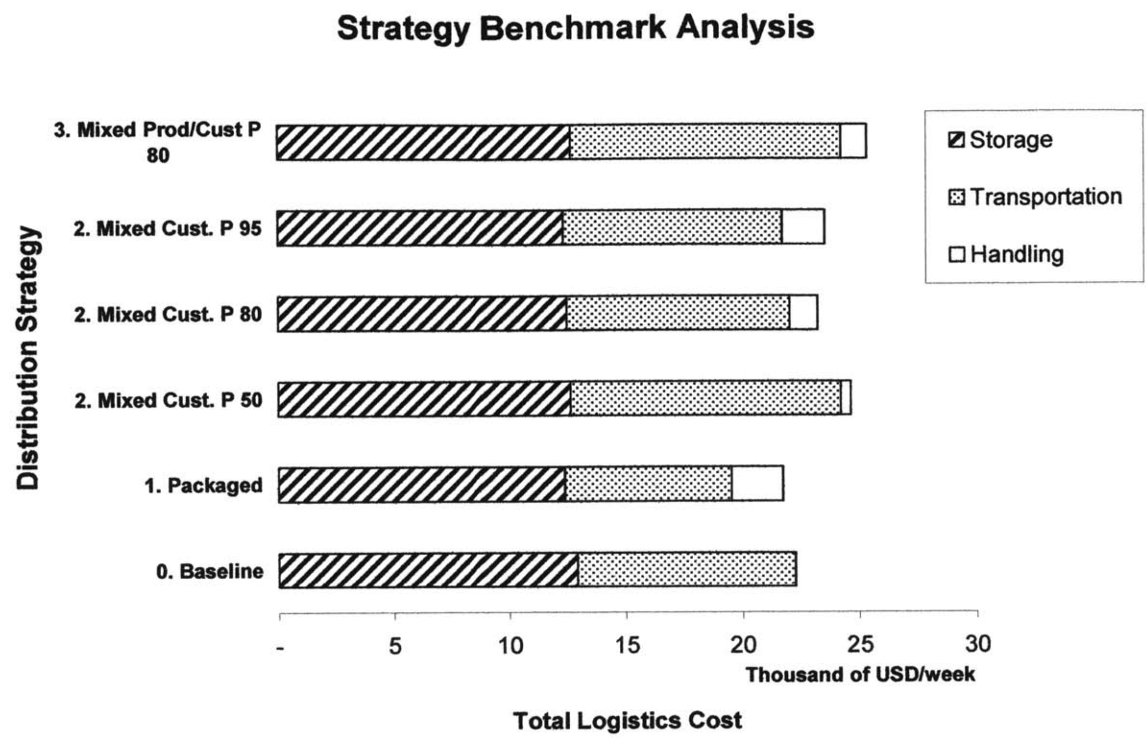


Figure 32. Total Logistics Cost for different distribution strategy scenarios

When comparing the packaged distribution strategy with the baseline, one can notice that despite a reduction of about $1/5^{th}$ in transportation costs, additional handling costs imposed by the inventory of returnable containers have the same order of magnitude. Storage cost in dispenser equipment is similar in all scenarios.

I. Decision Variables and Detailed Costs	Scenario	0. Baseline	1. Packaged	2. Mixed Cust. P 50	2. Mixed Cust. P 80	2. Mixed Cust. P 95	3. Mixed Prod/Cust P 80
a. Bulk							
Average Demand	*K gallons/week*	*37.45*	-	*33.05*	*21.04*	*7.98*	*23.96*
Fraction of Total Demand		*1.00*	-	*0.88*	*0.56*	*0.22*	*0.64*
a.1 Transportation							
Number of Vehicles		*4.00*	-	*3.00*	*2.00*	*1.00*	*3.00*
Traveled Distance	*miles/week*	*4,215.93*	-	*3,664.70*	*2,301.64*	*1,307.16*	*2,962.52*
Fixed Costs	*USD/week*	*7,301.54*	-	*5,476.15*	*3,650.77*	*1,825.38*	*5,476.15*
Variable Costs	*USD/week*	*2,028.19*	-	*1,763.01*	*1,107.27*	*628.85*	*1,425.21*
a.2 Storage							
Number of Dispensers		*184*	-	*92*	*37*	*9*	*3*
Number of Additional Tanks							*139.00*
Fixed Costs	*USD/week*	*12,926.39*	-	*6,463.19*	*2,599.33*	*632.27*	*478.06*
b. Packaged							
Average Demand	*K gallons/week*	-	*37.45*	*4.40*	*16.41*	*28.78*	*13.49*
Fraction of Total Demand		-	*1.00*	*0.12*	*0.44*	*0.78*	*0.36*
b.1 Transportation							
Number of Vehicles		-	*3.00*	*2.00*	*2.00*	*3.00*	*2.00*
Traveled Distance	*miles/week*	-	*3,468.06*	*1,380.72*	*2,379.69*	*3,052.83*	*2,170.55*
Fixed Costs	*USD/week*	-	*5,476.15*	*3,650.77*	*3,650.77*	*5,476.15*	*3,650.77*
Variable Costs	*USD/week*	-	*1,668.41*	*664.23*	*1,144.82*	*1,468.65*	*1,044.21*
b.2 Storage							
Number of Dispensers		-	*184*	*92*	*147*	*174*	*181*
Fixed Costs	*USD/week*	-	*12,384.62*	*6,192.31*	*9,894.23*	*11,711.54*	*12,182.69*
b.3 Handling							
Containers at customer sites		-	*1905*	*433*	*1098*	*1590*	*1052*
Containers in Circulation		-	*102*	*27*	*64*	*92*	*53*
Total Number of Containers		-	*2007*	*460*	*1162*	*1682*	*1105*
Fixed Costs		-	*1,505.25*	*345.00*	*871.50*	*1,261.50*	*828.75*
Variable Costs		-	*708.06*	*83.19*	*310.30*	*544.24*	*255.05*
II. Cost Summary							
a. Cost Summary by Category							
Transportation	*USD/week*	*9,329.73*	*7,144.56*	*11,554.17*	*9,553.63*	*9,399.04*	*11,596.33*
Storage	*USD/week*	*12,926.39*	*12,384.62*	*12,655.50*	*12,493.56*	*12,343.81*	*12,660.76*
Handling	*USD/week*	-	*2,213.31*	*428.19*	*1,181.80*	*1,805.74*	*1,083.80*
Total Cost	***USD/week***	***22,256.12***	***21,742.49***	***24,637.86***	***23,228.98***	***23,548.59***	***25,340.89***
b. Change in Costs over Baseline							
Change in Transportion Costs	*USD/week*	-	*(2,185.17)*	*2,224.43*	*223.89*	*69.31*	*2,266.60*
Change in Storage Costs	*USD/week*	-	*(541.77)*	*(270.89)*	*(432.83)*	*(582.58)*	*(265.63)*
Change in Handling Costs	*USD/week*	-	*2,213.31*	*428.19*	*1,181.80*	*1,805.74*	*1,083.80*
Change in Total Cost	***USD/week***	-	***(513.63)***	***2,381.74***	***972.86***	***1,292.46***	***3,084.76***
Anualized Change in Total Cost	***USD/year***	-	***(26,708.81)***	***123,850.43***	***50,588.79***	***67,208.08***	***160,407.70***

Table 4. Distribution Strategy Scenarios Summary Results

Two important facts are shown in the table. First, the most significant portion of the required inventory of returnable containers is located at customer sites. For strategy number 2, almost 95% of the two thousand returnable containers required are allocated to customer sites, while roughly 5% is required to maintain the pipeline of containers in motion and at the plant.

Second, all mixed distribution strategies also exhibit a higher transportation cost than the baseline, mainly because the combined number of vehicles is always higher or equal.

A comparison between the predicted and actual transportation performance indicators for the Houston plant for 2002 is provided in the following table. Predicted indicators are in accordance with the actual values

Indicator	Units	Calculated	Actual
Number of Vehicles	(vehicles)	4	4
Loading Efficiency	(gallons per load)	8.88	8.48
Milage Efficiency	(gallons delivered/mile)	2,957.46	3,141.61

Table 5. Comparison between predicted and actual transportation indicators for the Houston Plant

5. Conclusions

This research develops a logistics cost model for a distribution system for chemicals from a single plant using bulk and packaged transportation strategies. The purpose of this research is to provide a tool that helps understand the cost trade offs in the operation of a logistics system at a strategic level rather than producing exact results that would useful in operational planning.

An analytical modeling approach was used to determine variables that define the transportation, storage and material handling costs in the system. The model was simple enough to be implemented in a spreadsheet and to evaluate several scenarios without significant additional computational effort.

The transportation system was modeled using results from continuous approximation methods in freight distribution, which employ summaries data and average density of demand and locations rather than detailed information to estimate the traveling distance of vehicle routing problems.

The model was extended to study the effect of additional loading restrictions in bulk distribution based on the geometrical characteristics of the problem, specifically the number of compartments per vehicle and product compatibility.

The material handling component for packaged distribution consisted in a closed loop system of returnable containers with two main components. a) containers allocated to customers which define the transportation capacity and b) containers in transit an at the plant. The design policy for the handling system is a one by one exchange of empty for filled containers for customer deliveries. Therefore, each subsystem is itself is a closed loop system. Both subsystems were analyzed using inventory control policy theory. The number of containers at each customer site define the sum of order up to level of a continuous review inventory control system (s,S) for each product. The number of containers in transit and at the plant is studied as one for one replenishment system, similar to those used in inventory control problems for expensive repair parts, a (s-1,s) inventory control system whose objective is to that the plant never runs out of empty containers.

The baseline for evaluating distribution strategies is the current bulk distribution system. The performance indicators for the transportation system predicted by the model are in accordance with the actual values.

The packaged distribution system and mixed strategies using both systems allocating customers according to their demand were compared to the baseline The packaged distribution offered savings in transportation of approximately 20% over the baseline, but the added handling cost for managing the inventory of returnable containers was approximately of the same order of magnitude; savings over the baseline for the evaluated scenario were estimated in less than 30 K USD per year based on a demand data for 2002.

Mixed strategies resulted in higher cost that the baseline. Transportation efficiency is created by consolidating the scattered and fragmented customer demand. As a reference 80% of the customers account for little over 40% of the total demand. Therefore discriminating strategies limit the potential for load consolidation and add redundancy in the number of transportation assets of both systems. Furthermore, distribution strategies that differentiate product demand by customer result in even higher transportation costs because they increase the required number of stops per period by having customers visited by more than one transportation method.

The results obtained by this research do not provide enough evidence to support a change of the current distribution system on a cost reduction basis. However because the analysis is focused on a single plant and it does not consider further saving opportunities offered by the packaged distribution system in a network that involve the distribution to customers from a plant using several distribution centers.

Further research in this topic should extend the model to incorporate additional transportation to distribution centers and multi-echelon inventories of returnable containers. By extending the model to incorporate a network of distribution centers, the model can also be used to analyze the tradeoffs between transportation costs and depot location.

Appendix A: Unit cost and operational performance data

I. External Variables

Category	Type	Value
Transportation	*Disel Fuel Price*	*1.75 USD/Gallon*

II. Bulk Distribution Costs

Category	Type		Annual		Weekly	
Transportation						
	Fixed Costs	$c_{ft,B}$	*94,920*	*USD/(year*vehicle)*	*1,825.38*	*USD/(week*vehicle)*
	Variable Costs	$c_{vt,B}$	*0.48*	*USD/mile*	*0.48*	*USD/mile*
Storage						
	Fixed Costs	$c_{fs,B}$	*3,653*	*USD/(year*dispenser)*	*70.25*	*USD/(week*dispenser)*
	Special Storage	$c_{xs,B}$	*100*	*USD/(year*tank)*	*1.92*	*USD/(week*tank)*

III. Packaged Distribution Costs

Category	Type		Annual		Weekly	
Transportation						
	Fixed Costs	$c_{ft,P}$	*91,820*	*USD/(year*vehicle)*	*1,765.77*	*USD/(week*vehicle)*
	Variable Costs	$c_{vt,P}$	*0.38*	*USD/mile*	*0.38*	*USD/mile*
Storage						
	Fixed Costs	$c_{fs,P}$	*3,500*	*USD/(year*dispenser)*	*67.31*	*USD/(week*dispenser)*
Handling						
	Fixed Costs	$c_{fh,P}$	*39.00*	*USD/(year*tote)*	*0.75*	*USD/(week*tote)*
	Variable Costs	$c_{vh,P}$	*18.9091*	*USD/1000 gallon*	*18.9091*	*USD/gallons*

Equipment *Five Axle Semi Trailer Bulk Liquid*

I. Characteristics

Tractor			
	Average speed	*55*	*miles/hour*
	Usefull Life	*10*	*years*
	Daily Driving Time	*10*	*hours/day*
	Max Working time	*5*	*hours/day*
	Workweek	*60*	*hrs/week*
	Drivers	*1*	
	Diesel Fuel Price	*1.75*	*USD/gallon*
	Avg. Fuel Consumption	*6*	*miles/gallon*
Bulk Trailer			
	Load Capacity (Weight)	*40,000*	*lbs*
	Load Capacity (Wolume)	*4,000*	*gallons*
	Max. # of compartments	*5*	
	Trailer Purchase Price	*160,000*	*USD*
	Trailer Usefull Life	*10*	*years*

II. Operating Costs Analysis

Fixed Costs				
	Driver			
		Salary	*42,000*	*USD/(year*vehicle)*
		Benefits @ 26% of salary	*10,920*	*USD/(year*vehicle)*
	Tractor			
		Lease	*22,800*	*USD/(year*vehicle)*
		Insurance	*1,000*	*USD/(year*vehicle)*
		Tax	*2,200*	*USD/(year*vehicle)*
	Trailer			
		Depreciation	*16,000*	*USD/(year*vehicle)*
Variable Costs				
		Fuel	*0.29*	*USD/mile*
		Maintenance & Repairs	*0.19*	*USD/mile*

III. Operating Cost Summary

Fixed Operating Costs	*94,920*	*USD/(year*vehicle)*
Variable Operating Costs	*0.48*	*USD/mile*

Notes:

1. Repair costs of 0.19 USD/mile is obtained from repairs expenses in 2002 for 11,500 USD/vehicle @ 14 vehicles and 850,000 miles driven. Repair costs include both tractor and trailer

Equipment *Bulk Dispenser Unit*

I. Characteristics

Dispenser (with 5 tanks)				
	Purchase Price	35,000	*USD/dispenser*
	Usefull Life	10	*years*
	Number of dispensers in the SW region	1,045	*dispensers*
	Total Cleaning Costs in 2002 in SW Region	160,000	*USD*
Additional Tanks (500 / 1500 gallons)			
	Purchase Price & Instalation	1,000	*USD/dispenser*
	Usefull Life	10	*years*

II. Operating Costs Analysis

Fixed Costs				
	Dispenser			
		Depreciation	3,500	*USD/(year*dispenser)*
		Cleaning Costs	153	*USD/(year*dispenser)*
	Additional Tanks			
		Depreciation	100	*USD/(year*dispenser)*

III. Operating Cost Summary

Fixed Operating Costs	3,653	*USD/(year*dispenser)*
Fixed Operatiog Costs	100	*USD/(year*dispenser)*

Notes:

1. Cleaning Costs include transportation and customer site cleaning and disposal of the product.

Equipment *Five Axle Semi Trailer (Flatbed)*

II. Operating Costs Analysis

Fixed Costs				
	Driver			
		Salary	*42,000.00*	*USD/(year*vehicle)*
		Benefits @ 26% of salary	*10,920.00*	*USD/(year*vehicle)*
	Tractor			
		Lease	*22,800.00*	*USD/(year*vehicle)*
		Insurance	*1,000.00*	*USD/(year*vehicle)*
		Tax	*2,200.00*	*USD/(year*vehicle)*
	Trailer			
		Depreciation	*3,500.00*	*USD/(year*vehicle)*
	Forklift			
		Depreciation	*7,000*	*USD/(year*vehicle)*
		Maintenance & Repair	*2,400*	*USD/(year*vehicle)*
Variable Costs				
		Fuel	*0.29*	*USD/mile*
		Maintenance & Repairs	*0.09*	*USD/mile*

III. Operating Cost Summary

Fixed Operating Costs	*91,820*	*USD/(year*vehicle)*
Variable Operating Costs	*0.38*	*USD/mile*

Notes:

Equipment *Tote Dispenser Unit*

I. Characteristics

Tote Dispenser				
	Purchase Price	*35,000*	*USD/dispenser*
	Usefull Life	*10*	*years*
Totes				
	capacity	*275*	*gallons*
	unit price	*78*	*USD/tote*
	usefull life	*2*	*years*

II. Operating Costs Analysis

Fixed Costs				
	Dispenser			
		Depreciation	*3,500*	*USD/(year*dispenser)*
	Containers			
		Depreciation	*39*	*USD/(year*tote)*
Variable Costs				
	Containers			
		Cleaning and Filling	*0.0189*	*USD/ gallon*

III. Operating Cost Summary

Fixed Operating Costs	*3,500*	*USD/(year*dispenser)*
	39	*USD/(year*tote)*
Variable Operating Costs	*18.9091*	*USD/Thousand gallons*

Notes:

1. There are currently 10,000 totes in the system for Tote to Tanker operations

2. One hour 5x275 gal totes can be cleaned and filled, at an estimated expense of 26 USD/hr

Appendix B: Detailed Analysis of Distribution Strategy Scenarios

0. Baseline (Bulk Distribution)

Summary Info

I. Bulk System				
	a. General Info			
		Expected Demand	*Thousand gallons/week*	*37.45*
		Fraction of Total Demand		*1.00*
	b. Transportation			
		Number of Vehicles	*vehicles*	*4.00*
		Expected Travel Distance	*miles/week*	*4,215.93*
		Driving Efficiency	*gallons/mile*	*8.88*
		Loading Efficiency	*gallons/tour*	*2,957.46*
	c. Storage			
		Number of Dispensers	*dispeners*	*184*
II. Packaged System				
	a. General Info			
		Expected Demand	*Thousand gallons/week*	
		Fraction of Total Demand		
	b. Transportation			
		Number of Vehicles	*vehicles*	
		Expected Travel Distance	*miles/week*	
		Driving Efficiency	*gallons/mile*	
		Loading Efficiency	*gallons/tour*	
	c. Storage			
		Number of Dispensers	*dispeners*	
	d. Handling			
		Containers at Customer Sites	*totes*	
		Containers in Ciculation	*totes*	
		Total Number of Containers	*totes*	

Bulk Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(\bar{E}(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)^2		customers/week	(customers/week)^2
D01	21.31	0.57	40.41	1.90	15.25	19.21
D02	9.39	0.25	17.05	1.82	10.40	17.27
D03	4.50	0.12	12.33	2.74	4.46	11.59
D04	2.25	0.06	4.18	1.86	2.58	4.09
Service Region	**37.45**		**73.98**	**1.98**	**32.69**	

II. Traveled Distance

$\bar{E}D) = 2\cdot r\cdot(E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n)\cdot k\cdot\delta$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	$B+C$	$D\cdot(F+G)$	$E(n)\cdot H$	$2\cdot r$	$F+G$	$E(Q)/vmax + 1/2$
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	889.53	430.66	458.87	64.51	6.68	5.83
D02	1,761.30	1,346.08	415.23	423.42	3.18	2.85
D03	1,106.70	814.12	292.58	472.57	1.72	1.62
D04	458.41	268.53	189.87	247.89	1.08	1.06
Service Region	**4,215.93**	**2,859.39**	**1,356.54**		**12.66**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4)\cdot[(2\cdot r)/s + t_l]) + E(n)[(k\cdot{}^{-T/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	$K+L$	ExM	$E(n)xN$	$[(2\cdot r)/s + t_l]$	$[(k\cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	housr/tour	hours/stop
D01	41.44	17.84	23.59	2.67	1.55
D02	47.20	29.24	17.95	9.20	1.73
D03	27.17	17.39	9.78	10.09	2.19
D04	12.54	6.51	6.03	6.01	2.34
Service Region	**128.34**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max})\cdot[(2\cdot r)/s + t_l]\}^2 Var(Q) + [(k\cdot \neg^{-1/2})/s + t_s]^2 Var(n) + 2\cdot(1/v_{max})\cdot[(2\cdot r)/s + tl][(k\cdot d-1/2)/s + ts]\cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max})\cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2\cdot(1/v_{max})\cdot M\cdot N\cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	113.43	18.05	45.98	49.41
D02	264.06	90.17	51.41	122.48
D03	248.28	78.52	55.69	114.07
D04	57.04	9.43	22.40	25.21
Service Region	**682.82**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL)\cdot\neg)$	$E(T)$	$\neg$
hrs/week	hrs/week	hrs/week
206.44	128.34	26.13

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$M = [(E(T)+k\cdot\neg)/t_w]^+$	$M_{min} = E(T)/t_w$	$k\cdot\neg/t_w$
	vehicles	vehicles	vehicles
Service Region	**4.00**	2.14	1.30

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	$E(Q/V)$	$E(Q/(l+k))$
	gallons/mile	gallons/tour
D01	23.95	3,191.18
D02	5.33	2,954.69
D03	4.06	2,611.33
D04	4.91	2,075.67
Service Region	**8.88**	**2,957.46**

1. Packaged Distribution

Summary Info

I. Bulk System			
a. General Info			
	Expected Demand	*Thousand gallons/week*	
	Fraction of Total Demand		
b. Transportation			
	Number of Vehicles	*vehicles*	
	Expected Travel Distance	*miles/week*	
	Driving Efficiency	*gallons/mile*	
	Loading Efficiency	*gallons/tour*	
c. Storage			
	Number of Dispensers	*dispeners*	
II. Packaged System			
a. General Info			
	Expected Demand	*Thousand gallons/week*	*37.45*
	Fraction of Total Demand		*1.00*
b. Transportation			
	Number of Vehicles	*vehicles*	*3.00*
	Expected Travel Distance	*miles/week*	*3,468.06*
	Driving Efficiency	*gallons/mile*	*10.80*
	Loading Efficiency	*gallons/tour*	*3,562.73*
c. Storage			
	Number of Dispensers	*dispeners*	*184*
d. Handling			
	Containers at Customer Sites	*totes*	*1905*
	Containers in Ciculation	*totes*	*102*
	Total Number of Containers	*totes*	*2007*

Packaged Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(\aleph E(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)^2		customers/week	(customers/week)^2
D01	21.31	0.57	40.41	1.90	15.25	19.21
D02	9.39	0.25	17.05	1.82	10.40	17.27
D03	4.50	0.12	12.33	2.74	4.46	11.59
D04	2.25	0.06	4.18	1.86	2.58	4.09
Service Region	**37.45**		**73.98**	**1.98**	**32.69**	

II. Traveled Distance

$\aleph D) = 2 \cdot r \cdot (E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n) \cdot k \cdot \delta^{\aleph}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	B+C	D·(F+G)	E(n)·H	2·r	F+G	E(Q)/vmax + 1/2
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	695.63	344.60	351.03	64.51	5.34	5.34
D02	1,433.28	1,115.63	317.65	423.42	2.63	2.63
D03	943.28	719.45	223.82	472.57	1.52	1.52
D04	395.87	250.62	145.25	247.89	1.01	1.01
Service Region	**3,468.06**	**2,430.30**	**1,037.75**		**10.51**	
	(17.74)					

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4) \cdot [(2 \cdot r)/s + t_l]) + E(n)[(k \cdot \aleph^{1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	K+L	ExM	E(n)xN	$[(2 \cdot r)/s + t_l]$	$[(k \cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	housr/tour	hours/stop
D01	30.57	8.94	21.63	1.67	1.42
D02	37.78	21.60	16.18	8.20	1.56
D03	22.37	13.84	8.53	9.09	1.91
D04	10.28	5.06	5.22	5.01	2.02
Service Region	**101.00**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max}) \cdot [(2 \cdot r)/s + t_l]\}^2 Var(Q) + [(k \cdot \aleph^{1/2})/s + t_s]^2 Var(n) + 2 \cdot (1/v_{max}) \cdot [(2 \cdot r)/s + tl][(k \cdot d - 1/2)/s + ts] \cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max}) \cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2 \cdot (1/v_{max}) \cdot M \cdot N \cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	70.27	5.84	38.66	25.77
D02	190.39	59.20	41.75	89.44
D03	176.52	52.67	42.36	81.48
D04	38.73	5.42	16.78	16.53
Service Region	**475.90**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL) \cdot \aleph)$	$E(T)$	$\aleph$
hrs/week	hrs/week	hrs/week
166.21	101.00	21.82
(19.49)		

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$[(E(T)+k \cdot \aleph)/t_w]^+$	$E(T)/t_w$	$k \cdot \aleph/t_w$
	vehicles	vehicles	vehicles
Service Region	**3.00**	1.68	1.09

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	$E(Q/V)$	$E(Q/lc)$
	gallons/mile	gallons/tour
D01	30.63	3,988.18
D02	6.55	3,565.01
D03	4.77	2,954.93
D04	5.68	2,224.01
Service Region	**10.80**	**3,562.73**
	21.56	20.47

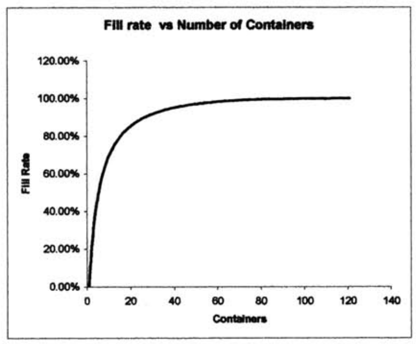
Returnable Containers

	Avg. Demand		Variance	
	E(Q)		Var(Q)	
	containers/week	containers/day	$(containers/week)^2$	$(containers/day)^2$
Service Region	164.37	32.87	1,696.59	339.32

District		B. Production Staging Time	C. Total tour time	D. Loading and unloading	E. Driving breaks	F. net driving time	G. Distance	H. Hauling distance per tour	I. Local Delivery Distance
	= B + C		D + E + F	$t_l + t_u \cdot J$	$(24-t_d) \cdot [G/(s \cdot t_d)]^-$	G/s	H + I	$2 \cdot r$	J·K
	hours	hours	hours	hours/tour	hours/tour	hours/tour	miles/tour	miles/tour	miles/tour
D01	29.72	24.00	5.72	3.35	-	2.37	130.22	64.51	65.71
D02	38.34	24.00	14.34	4.45	-	9.89	543.98	423.42	120.56
D03	52.70	24.00	28.70	3.43	14.00	11.27	619.59	472.57	147.02
D04	34.17	24.00	10.17	3.05	-	7.12	391.55	247.89	143.67
Avg. Service Region	34.91								

	# of Containers at Customers	# of Containers in Plant for SL	Avg. Replenishment time	Normalized Demand	Normalized Variance	Distribution Parameters: Negative Binomial	
	Rcust	R_{PLANT}	□	E(Q)·□	Var(Q)·□	p	r
	containers	containers	days	containers	$(containers)^{2/day}$	=E(Q)/Var(Q)	=E(Q)/(1/p-1)
Service Region	1905	102	1.45	47.82	493.58	0.10	5.13

x	p[x]	P[x]	Fill rate % [x]	x
0	0.00001	0.00001	0.00%	0
1	0.00003	0.00004	17.75%	1
2	0.00008	0.00012	30.52%	2
3	0.00017	0.00029	40.14%	3
4	0.00032	0.00061	47.65%	4
5	0.00053	0.00113	53.67%	5
6	0.00080	0.00194	58.60%	6
7	0.00115	0.00309	62.72%	7
8	0.00158	0.00466	66.20%	8
9	0.00208	0.00674	69.19%	9
10	0.00265	0.00938	71.78%	10
11	0.00329	0.01267	74.04%	11
12	0.00399	0.01667	76.04%	12
13	0.00475	0.02142	77.81%	13
14	0.00556	0.02697	79.40%	14
15	0.00640	0.03337	80.82%	15
16	0.00727	0.04065	82.11%	16
17	0.00816	0.04881	83.28%	17
18	0.00906	0.05787	84.34%	18
19	0.00996	0.06784	85.31%	19
20	0.01086	0.07869	86.20%	20
21	0.01173	0.09043	87.02%	21
22	0.01259	0.10301	87.78%	22
23	0.01341	0.11642	88.48%	23
24	0.01419	0.13061	89.13%	24
25	0.01493	0.14555	89.74%	25
26	0.01563	0.16117	90.30%	26
27	0.01627	0.17745	90.83%	27
28	0.01686	0.19431	91.32%	28
29	0.01740	0.21171	91.78%	29
30	0.01788	0.22959	92.21%	30
31	0.01830	0.24788	92.62%	31
32	0.01866	0.26654	93.00%	32
33	0.01896	0.28550	93.36%	33
34	0.01920	0.30470	93.70%	34
35	0.01939	0.32408	94.02%	35
36	0.01952	0.34360	94.32%	36
37	0.01959	0.36319	94.61%	37
38	0.01962	0.38280	94.88%	38
39	0.01959	0.40240	95.13%	39
40	0.01952	0.42192	95.37%	40
41	0.01940	0.44132	95.60%	41
42	0.01925	0.46057	95.82%	42
43	0.01905	0.47962	96.03%	43
44	0.01882	0.49844	96.22%	44
45	0.01856	0.51700	96.41%	45
46	0.01826	0.53527	96.59%	46
47	0.01794	0.55321	96.76%	47
48	0.01760	0.57081	96.92%	48
49	0.01723	0.58805	97.07%	49
50	0.01685	0.60490	97.21%	50
51	0.01645	0.62135	97.35%	51
52	0.01604	0.63739	97.48%	52
53	0.01561	0.65300	97.61%	53
54	0.01518	0.66817	97.73%	54
55	0.01474	0.68291	97.84%	55
56	0.01429	0.69720	97.95%	56



2. Mixed Distribution by Customer, percentile 50 served with returnable containers

Summary Info

I. Bulk System				
	a. General Info			
		Expected Demand	*gallons/week*	*33.05*
		Fraction of Total Demand		*0.88*
	b. Transportation			
		Number of Vehicles	*vehicles*	*3.00*
		Expected Travel Distance	*miles/week*	*3,664.70*
		Driving Efficiency	*gallons/mile*	*9.02*
		Loading Efficiency	*gallons/tour*	*2,885.71*
	c. Storage			
		Number of Dispensers	*dispeners*	*92*
II. Packaged System				
	a. General Info			
		Expected Demand	*gallons/week*	*4.40*
		Fraction of Total Demand		*0.12*
	b. Transportation			
		Number of Vehicles	*vehicles*	*2.00*
		Expected Travel Distance	*miles/week*	*1,380.72*
		Driving Efficiency	*gallons/mile*	*3.19*
		Loading Efficiency	*gallons/tour*	*1,466.57*
	c. Storage			
		Number of Dispensers	*dispeners*	*92*
	d. Handling			
		Containers at Customer Sites	*totes*	*433*
		Containers in Ciculation	*totes*	*26*
		Total Number of Containers	*totes*	*459*

Bulk Transportation

I. Demand Informantion

District	Avg. Demand $E(Q)$ Thousand gallons/week	Fraction of Demand $E(Q_i)/(\Sigma E(Q_i))$	Variance $Var(Q)$ (Thousand gallons/week)^2	Variance to Mean Ratio VTMR	Avg. Customers $E(n)$ customers/week	Variance $Var(n)$ (customers/week)^2
D01	20.10	0.61	40.60	2.02	13.56	16.49
D02	8.43	0.26	12.54	1.49	8.94	11.62
D03	3.58	0.11	7.86	2.19	2.83	4.42
D04	0.93	0.03	1.56	1.67	0.77	0.73
Service Region	**33.05**		**62.56**	**1.89**	**26.10**	

II. Traveled Distance

$0>D\,) = 2\cdot r \cdot (E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n)\cdot k \cdot \delta^{0>\square}$

District	A. Total Distance B+C miles/week	B. Haul Distance D·(F+G) miles/week	C. Local Distance E(n)·H miles/week	D. Acces distance 2·r miles	E. Total Tours F+G 1/week	F. Regular Tours E(Q)/vmax + 1/2 1/week
D01	842.68	410.02	432.66	64.51	6.36	5.53
D02	1,618.48	1,233.52	384.96	423.42	2.91	2.61
D03	918.04	685.14	232.89	472.57	1.45	1.40
D04	285.51	181.77	103.74	247.89	0.73	0.73
Service Region	**3,664.70**	**2,510.46**	**1,154.25**		**11.45**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4)\cdot[(2\cdot r)/s + t_l]) + E(n)[(k\cdot 0^{-1/2})/s + t_s]$

District	J. Required Working Time K+L hours/week	K. Hauling & Loading Time ExM hours/week	L. Peddling and Unloading Time E(n)xN hours/week	M. Hauling + Loading per tour $[(2\cdot r)/s + t_l]$ hours/tour	N. Peddling and Unloading per stop $[(k\cdot d^{-1/2})/s + t_s]$ hours/stop
D01	38.41	16.99	21.42	2.67	1.58
D02	42.74	26.80	15.94	9.20	1.78
D03	21.69	14.63	7.06	10.09	2.50
D04	7.06	4.40	2.66	6.01	3.45
Service Region	**109.91**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max})\cdot[(2\cdot r)/s + t_l]\}^2\, Var(Q) + [(k\cdot (^{-1/2})/s + t_s]^2\, Var(n) + 2\cdot(1/v_{max})\cdot[(2\cdot r)/s + tl][(k\cdot d\text{-}1/2)/s + ts]\cdot Cov[Q,n]$

District	O. Total Variance $Var(T) = P + Q + R$ (hours/week)^2	P. Hauling & Loading Variance $\{(1/v_{max})\cdot M\}^2\, Var(Q)$ (hours/week)^2	Q. Peddling & Unloading Variance $N^2\, Var(n)$ (hours/week)^2	R. Covariance $2\cdot(1/v_{max})\cdot M\cdot N\cdot Cov[Q,n]$ (hours/week)^2
D01	106.64	18.13	41.17	47.34
D02	191.16	66.30	36.94	87.91
D03	144.90	50.04	27.58	67.28
D04	21.48	3.52	8.70	9.26
Service Region	**464.17**			

Total Worktime for SL (E(T)+k(SL)·( ) hrs/week	Average Worktime E(T) hrs/week	Standard Deviation (hrs/week
174.30	109.91	21.54

IV. Fleet Size

	Total # of Vehicles for SL $M = [(E(T)+k\cdot(\ )/t_w]^+$ vehicles	Min. # of Vehicles $M_{min} = E(T)/t_w$ vehicles	Aditional Vehicles for SL $k\cdot(\ /t_w$ vehicles
Service Region	**3.00**	1.83	1.07

V. Performance Indicators

District	Driving efficiency E(Q/V) gallons/mile	Loading efficiency E(Q/(1+k)) gallons/tour
D01	23.86	3,162.55
D02	5.21	2,893.63
D03	3.90	2,471.96
D04	3.27	1,272.58
Service Region	**9.02**	**2,885.71**

Packaged Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Avg. Customers	Variance	Covariance
	$E(Q)$	$E(Q_i)/(\Diamond E(Q_i))$	$Var(Q)$	$E(n)$	$Var(n)$	$Cov(Q,n)$
	Thousand gallons/week		(Thousand gallons/week)^2	customers/week	(customers/week)^2	(gallons·customers)/week^2
D01	1.21	0.27	1.08	1.71	2.01	1.10
D02	0.96	0.22	1.01	1.46	2.33	1.33
D03	0.91	0.21	1.75	1.63	3.53	2.05
D04	1.32	0.30	1.79	1.81	2.75	2.01
Service Region	**4.40**		**5.64**	**6.62**		

II. Traveled Distance

$\Diamond/D) = 2\cdot r\cdot(E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n)\cdot k\cdot\delta^{\Diamond/\square}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	B+C	$D\cdot(F+G)$	$E(n)\cdot H$	$2\cdot r$	F+G	E(Q)/vmax + 1/2
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	167.54	49.94	117.60	64.51	0.77	0.77
D02	423.47	304.41	119.06	423.42	0.72	0.72
D03	470.01	334.53	135.48	472.57	0.71	0.71
D04	319.70	198.05	121.66	247.89	0.80	0.80
Service Region	**1,380.72**	**886.93**	**493.79**		**3.00**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4)\cdot[(2\cdot r)/s + t_1]) + E(n)[(k\cdot\Diamond^{-1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	K+L	ExM	E(n)xN	$[(2\cdot r)/s + t_1]$	$[(k\cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	hour/tour	hours/stop
D01	5.14	1.29	3.85	1.67	2.25
D02	9.52	5.89	3.63	8.20	2.48
D03	10.53	6.44	4.10	9.09	2.51
D04	8.02	4.00	4.02	5.01	2.22
Service Region	**33.22**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max})\cdot[(2\cdot r)/s + t_1]\}^2\, Var(Q) + [(k\cdot\pi^{-1/2})/s + t_s]^2\, Var(n) + 2\cdot(1/v_{max})\cdot[(2\cdot r)/s + tl][(k\cdot d\text{-}1/2)/s + ts]\cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max})\cdot M\}^2\, Var(Q)$	$N^2\, Var(n)$	$2\cdot(1/v_{max})\cdot M\cdot N\cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	12.22	0.16	10.19	1.88
D02	30.12	3.52	14.35	12.25
D03	50.94	7.47	22.19	21.28
D04	26.08	2.32	13.58	10.18
Service Region	**119.35**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL)\cdot\pi)$	$E(T)$	π
hrs/week	hrs/week	hrs/week
65.87	33.22	10.92

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$[(E(T)+k\cdot\pi)/t_w]^+$	$E(T)/t_w$	$k\cdot\pi/t_w$
	vehicles	vehicles	vehicles
Service Region	**2.00**	0.55	0.54

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	E(Q/V)	E(Q/lc)
	gallons/mile	gallons/tour
D01	7.20	1,558.10
D02	2.27	1,339.87
D03	1.95	1,292.21
D04	4.11	1,646.39
Service Region	**3.19**	**1,466.57**

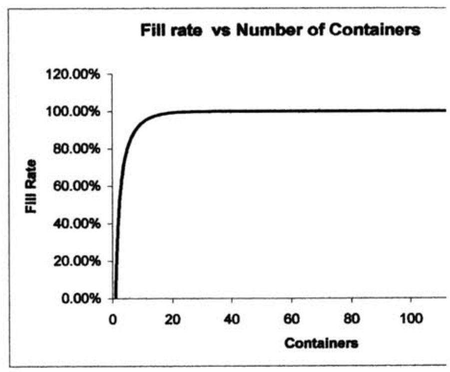
Returnable Containers

	Avg. Demand		Variance	
	E(Q)		Var(Q)	
	containers/week	containers/day	(containers/week)^2	(containers/day)^2
Service Region	20.78	4.16	97.65	19.53

District	A. Replenishment time	B. Production Staging Time	C. Total tour time	D. Loading and unloading	E. Driving breaks	F. net driving time	G. Distance	H. Hauling distance per tour
	= B + C		D + E + F	$t_1 + t_2 \cdot J$	$(24\text{-}td) \cdot [G/(s \cdot t_d)]$-	G/s	H + I	$2 \cdot r$
	hours	hours	hours	hours/tour	hours/tour	hours/tour	miles/tour	miles/tour
D01	30.65	24.00	6.65	2.71	-	3.93	216.42	64.51
D02	51.24	24.00	27.24	2.53	14.00	10.71	589.03	423.42
D03	36.68	24.00	12.68	2.81	-	9.87	543.07	472.57
D04	33.33	24.00	9.33	2.76	-	6.57	361.39	247.89
Avg. Service Region	37.21							

	# of Containers at Customers	# of Containers in Plant for SL	Avg. Replenishment time	Normalized Demand	Normalized Variance	Distribution Parameters: Negative Binomial	
	Rcust	R_{PLANT}	ξ	$E(Q) \cdot \xi$	$Var(Q) \cdot \xi$	p	r
	containers	containers	days	containers	(containers)$^{2/day}$	=E(Q)/Var(Q)	=E(Q)/(1/p-1)
Service Region	433	26	1.55	6.45	30.28	0.21	1.74

x	p[x]	P[x]	Fill rate % [x]	x
0	0.06744	0.06744	0.00%	0
1	0.09252	0.15996	42.16%	1
2	0.09988	0.25984	61.56%	2
3	0.09809	0.35792	72.60%	3
4	0.09155	0.44947	79.63%	4
5	0.08277	0.53224	84.45%	5
6	0.07322	0.60545	87.91%	6
7	0.06375	0.66920	90.47%	7
8	0.05484	0.72404	92.43%	8
9	0.04673	0.77078	93.94%	9
10	0.03952	0.81029	95.12%	10
11	0.03321	0.84350	96.06%	11
12	0.02776	0.87126	96.81%	12
13	0.02310	0.89436	97.42%	13
14	0.01915	0.91350	97.90%	14
15	0.01582	0.92932	98.30%	15
16	0.01303	0.94235	98.62%	16
17	0.01070	0.95305	98.88%	17
18	0.00877	0.96183	99.09%	18
19	0.00718	0.96900	99.26%	19
20	0.00586	0.97486	99.40%	20
21	0.00477	0.97964	99.51%	21
22	0.00389	0.98352	99.60%	22
23	0.00316	0.98668	99.68%	23
24	0.00256	0.98924	99.74%	24
25	0.00208	0.99132	99.79%	25
26	0.00168	0.99300	99.83%	26
27	0.00136	0.99436	99.86%	27
28	0.00110	0.99546	99.89%	28
29	0.00089	0.99635	99.91%	29
30	0.00072	0.99706	99.93%	30
31	0.00058	0.99764	99.94%	31
32	0.00046	0.99810	99.95%	32
33	0.00037	0.99848	99.96%	33
34	0.00030	0.99878	99.97%	34
35	0.00024	0.99902	99.98%	35
36	0.00019	0.99922	99.98%	36
37	0.00016	0.99937	99.98%	37
38	0.00013	0.99950	99.99%	38
39	0.00010	0.99960	99.99%	39
40	0.00008	0.99968	99.99%	40
41	0.00006	0.99974	99.99%	41
42	0.00005	0.99979	99.99%	42



3. Mixed Distribution by Customer, percentile 80 served with returnable containers

Summary Info

I. Bulk System			
a. General Info			
Expected Demand		*Thousand gallons/week*	*21.04*
Fraction of Total Demand			*0.56*
b. Transportation			
Number of Vehicles		*vehicles*	*2.00*
Expected Travel Distance		*miles/week*	*2,301.64*
Driving Efficiency		*gallons/mile*	*9.14*
Loading Efficiency		*gallons/tour*	*2,766.82*
c. Storage			
Number of Dispensers		*dispeners*	*37*
II. Packaged System			
a. General Info			
Expected Demand		*Thousand gallons/week*	*16.41*
Fraction of Total Demand			*0.44*
b. Transportation			
Number of Vehicles		*vehicles*	*2.00*
Expected Travel Distance		*miles/week*	*2,379.69*
Driving Efficiency		*gallons/mile*	*6.90*
Loading Efficiency		*gallons/tour*	*2,864.11*
c. Storage			
Number of Dispensers		*dispeners*	*147*
d. Handling			
Containers at Customer Sites		*totes*	*1098*
Containers in Ciculation		*totes*	*64*
Total Number of Containers		*totes*	*1162*

Bulk Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	E(Q)	$E(Q_i)/(\Sigma E(Q_i))$	Var(Q)	VTMR	E(n)	Var(n)
	Thousand gallons/week		(Thousand gallons/week)2		customers/week	(customers/week)^2
D01	14.82	0.70	27.13	1.83	9.15	8.21
D02	3.66	0.17	3.72	1.02	3.60	2.48
D03	2.56	0.12	4.63	1.81	1.90	2.28
D04	-	-	-	-	-	-
Service Region	**21.04**		**35.48**	**1.69**	**14.65**	

II. Traveled Distance

$HD) = 2 \cdot r \cdot (E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n) \cdot k \cdot \delta^{H\square}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	B+C	D·(F+G)	E(n)·H	2·r	F+G	E(Q)/vmax + 1/2
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	672.83	317.32	355.51	64.51	4.92	4.20
D02	891.02	646.89	244.12	423.42	1.53	1.42
D03	737.79	546.67	191.13	472.57	1.16	1.14
D04	-	-	-	247.89	-	-
Service Region	**2,301.64**	**1,510.88**	**790.76**		**7.60**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4) \cdot [(2 \cdot r)/s + t_1]) + E(n)[(k \cdot H^{1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	K+L	ExM	E(n)xN	$[(2 \cdot r)/s + t_1]$	$[(k \cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	housr/tour	hours/stop
D01	28.77	13.15	15.62	2.67	1.71
D02	22.09	14.05	8.03	9.20	2.23
D03	17.05	11.67	5.38	10.09	2.83
D04	-	-	-	6.01	1.00
Service Region	**67.91**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max}) \cdot [(2 \cdot r)/s + t_1]\}^2 Var(Q) + [(k \cdot \sigma)^{-1/2})/s + t_s]^2 Var(n) + 2 \cdot (1/v_{max}) \cdot [(2 \cdot r)/s + tl][(k \cdot d-1/2)/s + ts] \cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	Var(T) = P + Q + R	$\{(1/v_{max}) \cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2 \cdot (1/v_{max}) \cdot M \cdot N \cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	65.51	12.11	23.90	29.49
D02	57.41	19.70	12.38	25.33
D03	88.02	29.46	18.24	40.33
D04	-	-	-	-
Service Region	**210.95**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T) + k(SL) \cdot \sigma)$	E(T)	σ
hrs/week	hrs/week	hrs/week
111.32	67.91	14.52

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$M = [(E(T) + k \cdot \sigma)/t_w]^+$	$M_{min} = E(T)/t_w$	$k \cdot \sigma / t_w$
	vehicles	vehicles	vehicles
Service Region	**2.00**	1.13	0.72

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	E(Q/V)	E(Q/(l+k))
	gallons/mile	gallons/tour
D01	22.02	3,011.74
D02	4.11	2,398.87
D03	3.47	2,211.23
D04	-	-
Service Region	**9.14**	**2,766.82**

Packaged Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(\Xi E(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)2		customers/week	(customers/week)^2
D01	6.49	0.40	11.83	1.82	6.12	9.08
D02	5.73	0.35	9.11	1.59	6.81	10.83
D03	1.94	0.12	4.14	2.13	2.56	5.90
D04	2.25	0.14	4.18	1.86	2.58	4.09
Service Region	**16.41**		**29.26**	**1.78**	**18.06**	

II. Traveled Distance

$\Xi 9D) = 2\cdot r\cdot(E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n)\cdot k\cdot \delta^{\Xi 9D}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	$B+C$	$D\cdot(F+G)$	$E(n)\cdot H$	$2\cdot r$	$F+G$	$E(Q)/vmax + 1/2$
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	349.73	127.44	222.29	64.51	1.98	1.98
D02	1,019.89	762.94	256.95	423.42	1.80	1.80
D03	614.19	444.72	169.47	472.57	0.94	0.94
D04	395.87	250.62	145.25	247.89	1.01	1.01
Service Region	**2,379.69**	**1,585.73**	**793.96**		**5.73**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4)\cdot[(2\cdot r)/s + t_I]) + E(n)[(k\cdot \Xi^{1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	$K+L$	ExM	$E(n)xN$	$[(2\cdot r)/s + t_I]$	$[(k\cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	hours/tour	hours/stop
D01	13.46	3.30	10.16	1.67	1.66
D02	26.25	14.77	11.48	8.20	1.69
D03	14.20	8.56	5.64	9.09	2.20
D04	10.28	5.06	5.22	5.01	2.02
Service Region	**64.19**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max})\cdot[(2\cdot r)/s + t_I]\}^2 Var(Q) + [(k\cdot 8^{-1/2})/s + t_s]^2 Var(n) + 2\cdot(1/v_{max})\cdot[(2\cdot r)/s + tl][(k\cdot d\text{-}1/2)/s + ts]\cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max})\cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2\cdot(1/v_{max})\cdot M\cdot N\cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	37.87	1.71	25.06	11.10
D02	116.62	31.63	30.78	54.21
D03	83.50	17.67	28.67	37.15
D04	38.73	5.42	16.78	16.53
Service Region	**276.72**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL)\cdot 8)$	$E(T)$	8
hrs/week	hrs/week	hrs/week
113.91	64.19	16.63

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$[(E(T)+k\cdot 8)/t_w]^+$	$E(T)/t_w$	$k\cdot 8/t_w$
	vehicles	vehicles	vehicles
Service Region	**2.00**	1.07	0.83

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	$E(Q/V)$	$E(Q/lc)$
	gallons/mile	gallons/tour
D01	18.56	3,286.42
D02	5.62	3,179.03
D03	3.16	2,062.24
D04	5.68	2,224.01
Service Region	**6.90**	**2,864.11**

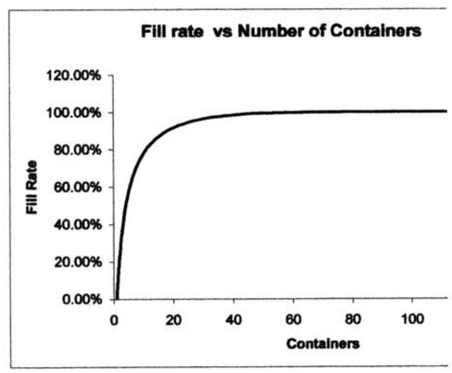
Returnable Containers

	Avg. Demand		Variance	
	$E(Q)$		$Var(Q)$	
	containers/week	containers/day	(containers/week)^2	(containers/day)^2
Service Region	72.92	14.58	548.62	109.72

District	A. Replenishment time	B. Production Staging Time	C. Total tour time	D. Loading and unloading	E. Driving breaks	F. net driving time	G. Distance	H. Hauling distance per tour
	$= B + C$		$D + E + F$	$t_1 + t_2 \cdot J$	$(24\text{-}td) \cdot [G/(s \cdot t_d)]\text{-}$	G/s	$H + I$	$2 \cdot r$
	hours	hours	hours	hours/tour	hours/tour	hours/tour	miles/tour	miles/tour
D01	30.81	24.00	6.81	3.60	-	3.22	177.02	64.51
D02	52.57	24.00	28.57	4.28	14.00	10.29	566.03	423.42
D03	53.08	24.00	29.08	3.22	14.00	11.87	652.65	472.57
D04	34.17	24.00	10.17	3.05	-	7.12	391.55	247.89
Avg. Service Region	41.50							

	# of Containers at Customers	# of Containers in Plant for SL	Avg. Replenishment time	Normalized Demand	Normalized Variance	Distribution Parameters: Negative Binomial	
	Rcust	R_{PLANT}	8	$E(Q) \cdot 8$	$Var(Q) \cdot 8$	p	r
	containers	containers	days	containers	(containers)$^{2/day}$	$=E(Q)/Var(Q)$	$=E(Q)/(1/p-1)$
Service Region	1098	64	1.73	25.22	189.74	0.13	3.87

x	p[x]	P[x]	Fill rate % [x]	x
0	0.00041	0.00041	0.00%	0
1	0.00137	0.00178	22.98%	1
2	0.00289	0.00467	38.10%	2
3	0.00490	0.00958	48.79%	3
4	0.00730	0.01687	56.75%	4
5	0.00996	0.02683	62.89%	5
6	0.01276	0.03959	67.78%	6
7	0.01559	0.05518	71.75%	7
8	0.01836	0.07354	75.03%	8
9	0.02099	0.09453	77.79%	9
10	0.02342	0.11794	80.15%	10
11	0.02559	0.14353	82.17%	11
12	0.02749	0.17103	83.93%	12
13	0.02909	0.20012	85.46%	13
14	0.03039	0.23051	86.82%	14
15	0.03139	0.26190	88.02%	15
16	0.03209	0.29399	89.08%	16
17	0.03252	0.32650	90.04%	17
18	0.03268	0.35918	90.90%	18
19	0.03261	0.39180	91.68%	19
20	0.03233	0.42413	92.38%	20
21	0.03186	0.45599	93.01%	21
22	0.03122	0.48721	93.59%	22
23	0.03045	0.51766	94.12%	23
24	0.02955	0.54721	94.60%	24
25	0.02856	0.57577	95.04%	25
26	0.02750	0.60327	95.44%	26
27	0.02637	0.62964	95.81%	27
28	0.02521	0.65485	96.15%	28
29	0.02402	0.67887	96.46%	29
30	0.02281	0.70168	96.75%	30
31	0.02161	0.72329	97.01%	31
32	0.02042	0.74371	97.25%	32
33	0.01924	0.76295	97.48%	33
34	0.01809	0.78104	97.68%	34
35	0.01697	0.79801	97.87%	35
36	0.01589	0.81389	98.05%	36
37	0.01484	0.82873	98.21%	37
38	0.01384	0.84257	98.36%	38
39	0.01288	0.85545	98.49%	39
40	0.01197	0.86742	98.62%	40
41	0.01110	0.87852	98.74%	41
42	0.01028	0.88881	98.84%	42
43	0.00951	0.89832	98.94%	43
44	0.00878	0.90711	99.03%	44
45	0.00810	0.91521	99.11%	45
46	0.00746	0.92267	99.19%	46
47	0.00687	0.92954	99.26%	47
48	0.00631	0.93585	99.33%	48
49	0.00579	0.94164	99.39%	49
50	0.00531	0.94694	99.44%	50
51	0.00486	0.95181	99.49%	51
52	0.00445	0.95625	99.53%	52
53	0.00406	0.96032	99.58%	53
54	0.00371	0.96403	99.61%	54
55	0.00339	0.96742	99.65%	55
56	0.00309	0.97050	99.68%	56



4. Mixed Distribution by Customer, percentile 95 served with returnable containers

Summary Info

I. Bulk System			
a. General Info			
Expected Demand		*Thousand gallons/week*	*7.98*
Fraction of Total Demand			*0.22*
b. Transportation			
Number of Vehicles		*vehicles*	*1.00*
Expected Travel Distance		*miles/week*	*1,307.16*
Driving Efficiency		*gallons/mile*	*6.11*
Loading Efficiency		*gallons/tour*	*2,112.43*
c. Storage			
Number of Dispensers		*dispeners*	*9*
II. Packaged System			
a. General Info			
Expected Demand		*Thousand gallons/week*	*28.78*
Fraction of Total Demand			*0.78*
b. Transportation			
Number of Vehicles		*vehicles*	*3.00*
Expected Travel Distance		*miles/week*	*3,052.83*
Driving Efficiency		*gallons/mile*	*9.43*
Loading Efficiency		*gallons/tour*	*3,369.71*
c. Storage			
Number of Dispensers		*dispeners*	*174*
d. Handling			
Containers at Customer Sites		*totes*	*1590*
Containers in Ciculation		*totes*	*92*
Total Number of Containers		*totes*	*1682*

Bulk Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(\Sigma E(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)2		customers/week	(customers/week)^2
D01	5.43	0.68	11.54	2.12	2.88	2.06
D02	1.76	0.22	1.64	0.93	1.29	0.52
D03	0.78	0.10	0.91	1.16	0.48	0.25
D04	-	-	-	-	-	-
Service Region	**7.98**		**14.09**	**1.77**	**4.65**	

II. Traveled Distance

$\Pi\_D) = 2 \cdot r \cdot (E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n) \cdot k \cdot \delta^{\Pi(\cdot)}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	$B+C$	$D \cdot (F+G)$	$E(n) \cdot H$	$2 \cdot r$	$F+G$	$E(Q)/vmax + 1/2$
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	337.66	138.09	199.57	64.51	2.14	1.86
D02	544.56	398.44	146.12	423.42	0.94	0.94
D03	424.94	328.90	96.04	472.57	0.70	0.70
D04	-	-	-	247.89	-	-
Service Region	**1,307.16**	**865.43**	**441.74**		**3.78**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4) \cdot [(2 \cdot r)/s + t_1]) + E(n)[(k \cdot \Pi^{1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	$K+L$	ExM	$E(n)xN$	$[(2 \cdot r)/s + t_1]$	$[(k \cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	housr/tour	hours/stop
D01	12.24	5.72	6.51	2.67	2.26
D02	12.60	8.66	3.95	9.20	3.06
D03	9.25	7.02	2.23	10.09	4.63
D04	-	-	-	6.01	1.00
Service Region	**34.09**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max}) \cdot [(2 \cdot r)/s + t_1]\}^2 Var(Q) + [(k \cdot 8^{-1/2})/s + t_s]^2 Var(n) + 2 \cdot (1/v_{max}) \cdot [(2 \cdot r)/s + tl][(k \cdot d\text{-}1/2)/s + ts] \cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max}) \cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2 \cdot (1/v_{max}) \cdot M \cdot N \cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	27.99	5.15	10.53	12.31
D02	24.16	8.65	4.90	10.61
D03	20.77	5.80	5.46	9.51
D04	-	-	-	-
Service Region	**72.92**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL) \cdot 8)$	$E(T)$	8
hrs/week	hrs/week	hrs/week
59.61	34.09	8.54

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$M = [(E(T)+k \cdot 8)/t_w]^+$	$M_{min} = E(T)/t_w$	$k \cdot 8 / t_w$
	vehicles	vehicles	vehicles
Service Region	**1.00**	0.57	0.43

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	$E(Q/V)$	$E(Q/(l+k))$
	gallons/mile	gallons/tour
D01	16.09	2,537.57
D02	3.24	1,874.57
D03	1.84	1,126.32
D04	-	-
Service Region	**6.11**	**2,112.43**

Packaged Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(-E(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)2		customers/week	(customers/week)^2
D01	15.19	0.53	20.62	1.36	12.06	12.49
D02	7.63	0.27	13.08	1.71	9.12	15.36
D03	3.71	0.13	10.28	2.77	3.98	10.69
D04	2.25	0.08	4.18	1.86	2.58	4.09
Service Region	**28.78**		**48.17**	**1.67**	**27.73**	

II. Traveled Distance

$-\square D) = 2 \cdot r \cdot (E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n) \cdot k \cdot \delta^{-\square\square}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	$B+C$	$D \cdot (F+G)$	$E(n) \cdot H$	$2 \cdot r$	$F+G$	$E(Q)/vmax + 1/2$
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	567.07	254.94	312.14	64.51	3.95	3.95
D02	1,243.21	945.88	297.33	423.42	2.23	2.23
D03	846.68	635.26	211.42	472.57	1.34	1.34
D04	395.87	250.62	145.25	247.89	1.01	1.01
Service Region	**3,052.83**	**2,086.70**	**966.14**		**8.54**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4) \cdot [(2 \cdot r)/s + t_l]) + E(n)[(k \cdot \neg^{-1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	$K+L$	ExM	E(n)xN	$[(2 \cdot r)/s + t_l]$	$[(k \cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	housr/tour	hours/stop
D01	24.34	6.61	17.73	1.67	1.47
D02	32.84	18.31	14.52	8.20	1.59
D03	20.05	12.22	7.82	9.09	1.97
D04	10.28	5.06	5.22	5.01	2.02
Service Region	**87.51**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max}) \cdot [(2 \cdot r)/s + t_l]\}^2 Var(Q) + [(k \cdot \square^{1/2})/s + t_s]^2 Var(n) + 2 \cdot (1/v_{max}) \cdot [(2 \cdot r)/s + tl][(k \cdot d\text{-}1/2)/s + ts] \cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max}) \cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2 \cdot (1/v_{max}) \cdot M \cdot N \cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	45.11	2.98	27.01	15.12
D02	158.97	45.41	38.98	74.58
D03	159.36	43.91	41.29	74.16
D04	38.73	5.42	16.78	16.53
Service Region	**402.17**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL) \cdot \square)$	$E(T)$	$\square$
hrs/week	hrs/week	hrs/week
147.45	87.51	20.05

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$[(E(T)+k \cdot \square)/t_w]^+$	$E(T)/t_w$	$k \cdot \square/t_w$
	vehicles	vehicles	vehicles
Service Region	**3.00**	1.46	1.00

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	$E(Q/V)$	$E(Q/lc)$
	gallons/mile	gallons/tour
D01	26.79	3,843.34
D02	6.14	3,415.17
D03	4.39	2,763.41
D04	5.68	2,224.01
Service Region	**9.43**	**3,369.71**

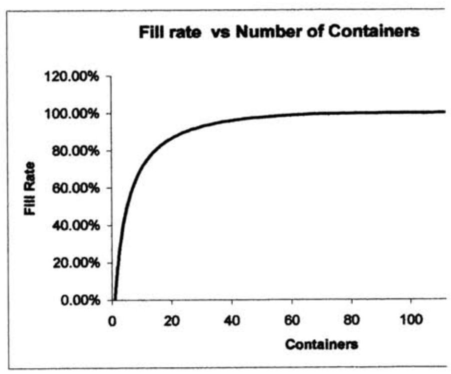
Returnable Containers

	Avg. Demand		Variance	
	E(Q)		Var(Q)	
	containers/week	containers/day	(containers/week)²	(containers/day)²
Service Region	127.08	25.42	1,174.70	234.94

District	A. Replenishment time	B. Production Staging Time	C. Total tour time	D. Loading and unloading	E. Driving breaks	F. net driving time	G. Distance	H. Hauling distance per tour
	= B + C		D + E + F	$t_1 + t_2 \cdot J$	$(24\text{-}td) \cdot [G/(s \cdot t_d)]$-	G/s	H + I	2·r
	hours	hours	hours	hours/tour	hours/tour	hours/tour	miles/tour	miles/tour
D01	30.16	24.00	6.16	3.55	-	2.61	143.48	64.51
D02	52.70	24.00	28.70	4.58	14.00	10.12	556.52	423.42
D03	52.91	24.00	28.91	3.46	14.00	11.45	629.85	472.57
D04	34.17	24.00	10.17	3.05	-	7.12	391.55	247.89
Avg. Service Region	39.38							

	# of Containers at Customers	# of Containers in Plant for SL	Avg. Replenishment time	Normalized Demand	Normalized Variance	Distribution Parameters: Negative Binomial	
	Rcust	R_{PLANT}	□	E(Q)·□	Var(Q)·□	p	r
	containers	containers	days	containers	(containers)²/day	=E(Q)/Var(Q)	=E(Q)/(1/p-1)
Service Region	1590	92	1.64	41.71	385.54	0.11	5.06

x	p[x]	P[x]	Fill rate % [x]	x
0	0.00001	0.00001	0.00%	0
1	0.00006	0.00007	18.14%	1
2	0.00016	0.00023	31.14%	2
3	0.00033	0.00056	40.90%	3
4	0.00060	0.00116	48.50%	4
5	0.00096	0.00212	54.58%	5
6	0.00144	0.00357	59.56%	6
7	0.00203	0.00560	63.70%	7
8	0.00273	0.00833	67.21%	8
9	0.00354	0.01187	70.21%	9
10	0.00443	0.01630	72.80%	10
11	0.00541	0.02171	75.07%	11
12	0.00646	0.02817	77.07%	12
13	0.00756	0.03573	78.84%	13
14	0.00870	0.04443	80.43%	14
15	0.00985	0.05429	81.85%	15
16	0.01102	0.06530	83.13%	16
17	0.01217	0.07748	84.29%	17
18	0.01330	0.09078	85.35%	18
19	0.01440	0.10518	86.31%	19
20	0.01545	0.12063	87.19%	20
21	0.01644	0.13707	88.01%	21
22	0.01737	0.15444	88.75%	22
23	0.01822	0.17266	89.45%	23
24	0.01900	0.19165	90.09%	24
25	0.01969	0.21135	90.68%	25
26	0.02031	0.23165	91.23%	26
27	0.02083	0.25249	91.75%	27
28	0.02127	0.27376	92.23%	28
29	0.02162	0.29538	92.68%	29
30	0.02189	0.31728	93.10%	30
31	0.02208	0.33936	93.49%	31
32	0.02219	0.36155	93.86%	32
33	0.02223	0.38378	94.21%	33
34	0.02219	0.40596	94.53%	34
35	0.02208	0.42805	94.84%	35
36	0.02191	0.44996	95.13%	36
37	0.02169	0.47165	95.40%	37
38	0.02141	0.49306	95.66%	38
39	0.02108	0.51413	95.90%	39
40	0.02071	0.53484	96.13%	40
41	0.02029	0.55513	96.34%	41
42	0.01985	0.57498	96.55%	42
43	0.01937	0.59435	96.74%	43
44	0.01887	0.61322	96.92%	44
45	0.01835	0.63157	97.10%	45
46	0.01781	0.64937	97.26%	46
47	0.01725	0.66663	97.41%	47
48	0.01669	0.68331	97.56%	48
49	0.01611	0.69942	97.70%	49
50	0.01554	0.71496	97.83%	50
51	0.01496	0.72992	97.95%	51
52	0.01438	0.74430	98.07%	52
53	0.01381	0.75811	98.18%	53
54	0.01324	0.77135	98.28%	54
55	0.01268	0.78403	98.38%	55
56	0.01213	0.79616	98.48%	56



5. Mixed Distribution by Customer and product , percentile 80 served with returnable containers

Summary Info

I. Bulk System			
a. General Info			
	Expected Demand	*Thousand gallons/week*	*23.96*
	Fraction of Total Demand		*0.64*
b. Transportation			
	Number of Vehicles	*vehicles*	*3.00*
	Expected Travel Distance	*miles/week*	*2,962.52*
	Driving Efficiency	*gallons/mile*	*8.09*
	Loading Efficiency	*gallons/tour*	*2,775.64*
c. Storage			
	Number of Dispensers	*dispeners*	*3*
	Additional Tanks	*tanks*	*139*
II. Packaged System			
a. General Info			
	Expected Demand	*Thousand gallons/week*	*13.49*
	Fraction of Total Demand		*0.36*
b. Transportation			
	Number of Vehicles	*vehicles*	*2.00*
	Expected Travel Distance	*miles/week*	*2,170.55*
	Driving Efficiency	*gallons/mile*	*6.21*
	Loading Efficiency	*gallons/tour*	*2,662.74*
c. Storage			
	Number of Dispensers	*dispeners*	*181*
d. Handling			
	Containers at Customer Sites	*totes*	*1052*
	Containers in Ciculation	*totes*	*53*
	Total Number of Containers	*totes*	*1105*

Bulk Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(\sum E(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)2		customers/week	(customers/week)^2
D01	14.75	0.62	24.55	1.66	11.48	12.73
D02	5.75	0.24	6.95	1.21	6.85	8.25
D03	2.83	0.12	4.66	1.65	2.62	3.69
D04	0.63	0.03	0.89	1.42	0.62	0.71
Service Region	**23.96**		**37.05**	**1.55**	**21.56**	

II. Traveled Distance

$E(D) = 2\cdot r\cdot(E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n)\cdot k\cdot \delta^{-1/2}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	B+C	D·(F+G)	E(n)·H	2·r	F+G	E(Q)/vmax + 1/2
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	701.60	303.46	398.14	64.51	4.70	4.19
D02	1,210.35	873.52	336.83	423.42	2.06	1.94
D03	794.96	570.95	224.01	472.57	1.21	1.21
D04	255.61	162.82	92.79	247.89	0.66	0.66
Service Region	**2,962.52**	**1,910.76**	**1,051.77**		**8.63**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4)\cdot[(2\cdot r)/s + t_l]) + E(n)[(k\cdot \delta^{-1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	K+L	ExM	E(n)xN	$[(2\cdot r)/s + t_l]$	$[(k\cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	hours/tour	hours/stop
D01	31.29	12.57	18.72	2.67	1.63
D02	31.95	18.98	12.97	9.20	1.89
D03	18.88	12.19	6.69	10.09	2.56
D04	6.25	3.95	2.30	6.01	3.74
Service Region	**88.37**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max})\cdot[(2\cdot r)/s + t_l]\}^2 Var(Q) + [(k\cdot \Xi^{1/2})/s + t_s]^2 Var(n) + 2\cdot(1/v_{max})\cdot[(2\cdot r)/s + tl][(k\cdot d\text{-}1/2)/s + ts]\cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max})\cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2\cdot(1/v_{max})\cdot M\cdot N\cdot Cov[Q,n]$
	(hours/week)^2	(hours/week)^2	(hours/week)^2	(hours/week)^2
D01	79.14	10.96	33.83	34.35
D02	123.38	36.73	29.61	57.04
D03	102.64	29.66	24.15	48.83
D04	20.12	2.01	9.97	8.14
Service Region	**325.28**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL)\cdot \Xi)$	$E(T)$	Ξ
hrs/week	hrs/week	hrs/week
142.28	88.37	18.04

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$M = [(E(T)+k\cdot \Xi)/t_w]^+$	$M_{min} = E(T)/t_w$	$k\cdot \Xi/t_w$
	vehicles	vehicles	vehicles
Service Region	**3.00**	1.47	0.90

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	E(Q/V)	E(Q/(l+k))
	gallons/mile	gallons/tour
D01	21.02	3,135.03
D02	4.75	2,788.16
D03	3.56	2,344.61
D04	2.45	955.17
Service Region	**8.09**	**2,775.64**

Packaged Transportation

I. Demand Informantion

District	Avg. Demand	Fraction of Demand	Variance	Variance to Mean Ratio	Avg. Customers	Variance
	$E(Q)$	$E(Q_i)/(\square E(Q_i))$	$Var(Q)$	VTMR	$E(n)$	$Var(n)$
	Thousand gallons/week		(Thousand gallons/week)2		customers/week	(customers/week)2
D01	6.56	0.49	6.00	0.91	9.77	11.04
D02	3.64	0.27	4.79	1.31	6.00	11.73
D03	1.67	0.12	3.25	1.95	3.21	7.19
D04	1.62	0.12	2.32	1.43	2.31	3.63
Service Region	**13.49**		**16.35**	**1.21**	**21.29**	

II. Traveled Distance

$\square\ D) = 2 \cdot r \cdot (E(Q)/v_{max} + E(p)/(2c) + 1/4) + E(n) \cdot k \cdot \delta^{\square\square}$

District	A. Total Distance	B. Haul Distance	C. Local Distance	D. Acces distance	E. Total Tours	F. Regular Tours
	$B+C$	$D \cdot (F+G)$	$E(n) \cdot H$	$2 \cdot r$	$F+G$	$E(Q)/vmax + 1/2$
	miles/week	miles/week	miles/week	miles	1/week	1/week
D01	409.38	128.42	280.96	64.51	1.99	1.99
D02	803.33	562.10	241.23	423.42	1.33	1.33
D03	605.11	415.21	189.90	472.57	0.88	0.88
D04	352.73	215.28	137.45	247.89	0.87	0.87
Service Region	**2,170.55**	**1,321.01**	**849.54**		**5.07**	

III.a Total Transportation Working Time

$E(T) = (E(Q)/v_{max} + E(p)/2c + 1/4) \cdot [(2 \cdot r)/s + t_1]) + E(n)[(k \cdot \square^{1/2})/s + t_s]$

District	J. Required Working Time	K. Hauling & Loading Time	L. Peddling and Unloading Time	M. Hauling + Loading per tour	N. Peddling and Unloading per stop
	$K+L$	ExM	$E(n)xN$	$[(2 \cdot r)/s + t_1]$	$[(k \cdot d^{-1/2})/s + t_s]$
	hours/week	hours/week	hours/week	hours/tour	hours/stop
D01	18.21	3.33	14.88	1.67	1.52
D02	21.27	10.88	10.39	8.20	1.73
D03	14.65	7.99	6.66	9.09	2.08
D04	9.16	4.35	4.81	5.01	2.08
Service Region	**63.29**				

III.b Transportation Working Time Variance

$Var(T) = \{(1/v_{max}) \cdot [(2 \cdot r)/s + t_1]\}^2 Var(Q) + [(k \cdot H^{1/2})/s + t_s]^2 Var(n) + 2 \cdot (1/v_{max}) \cdot [(2 \cdot r)/s + tl][(k \cdot d\text{-}1/2)/s + ts] \cdot Cov[Q,n]$

District	O. Total Variance	P. Hauling & Loading Variance	Q. Peddling & Unloading Variance	R. Covariance
	$Var(T) = P + Q + R$	$\{(1/v_{max}) \cdot M\}^2 Var(Q)$	$N^2 Var(n)$	$2 \cdot (1/v_{max}) \cdot M \cdot N \cdot Cov[Q,n]$
	$(hours/week)^2$	$(hours/week)^2$	$(hours/week)^2$	$(hours/week)^2$
D01	33.59	0.87	25.61	7.11
D02	90.32	16.62	35.13	38.57
D03	80.17	13.87	30.96	35.34
D04	30.76	3.00	15.75	12.01
Service Region	**234.84**			

Total Worktime for SL	Average Worktime	Standard Deviation
$(E(T)+k(SL) \cdot H)$	$E(T)$	H
hrs/week	hrs/week	hrs/week
109.09	63.29	15.32

IV. Fleet Size

	Total # of Vehicles for SL	Min. # of Vehicles	Aditional Vehicles for SL
	$[(E(T)+k \cdot H)/t_w]^+$	$E(T)/t_w$	$k \cdot H/t_w$
	vehicles	vehicles	vehicles
Service Region	**2.00**	1.05	0.76

V. Performance Indicators

District	Driving efficiency	Loading efficiency
	$E(Q/V)$	$E(Q/lc)$
	gallons/mile	gallons/tour
D01	16.02	3,294.95
D02	4.53	2,742.77
D03	2.75	1,896.08
D04	4.60	1,866.73
Service Region	**6.21**	**2,662.74**

Returnable Containers

I. Demand Informantion

	Avg. Demand		Variance	
	E(Q)		Var(Q)	
	containers/week	containers/day	$(containers/week)^2$	$(containers/day)^2$
Service Region	62.71	12.54230769	337.62	67.52

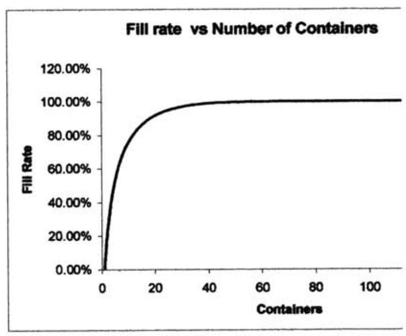
II. Average Replenishment Time

District	A. Replenishment time	B. Production Staging Time	C. Total tour time	D. Loading and unloading	E. Driving breaks	F. net driving time	G. Distance	H. Hauling distance per tour
	$= B + C$		$D + E + F$	$t_l + t_u \cdot J$	$(24-td) \cdot [G/(s \cdot t_d)]-$	G/s	$H + I$	$2 \cdot r$
	hours	hours	hours	hours/tour	hours/tour	hours/tour	miles/tour	miles/tour
D01	33.15	24.00	9.15	5.41	-	3.74	205.63	64.51
D02	54.02	24.00	30.02	5.02	14.00	11.00	605.14	423.42
D03	54.68	24.00	30.68	4.16	14.00	12.52	688.70	472.57
D04	34.54	24.00	10.54	3.16	-	7.38	406.16	247.89
Avg. Service Region	41.61							

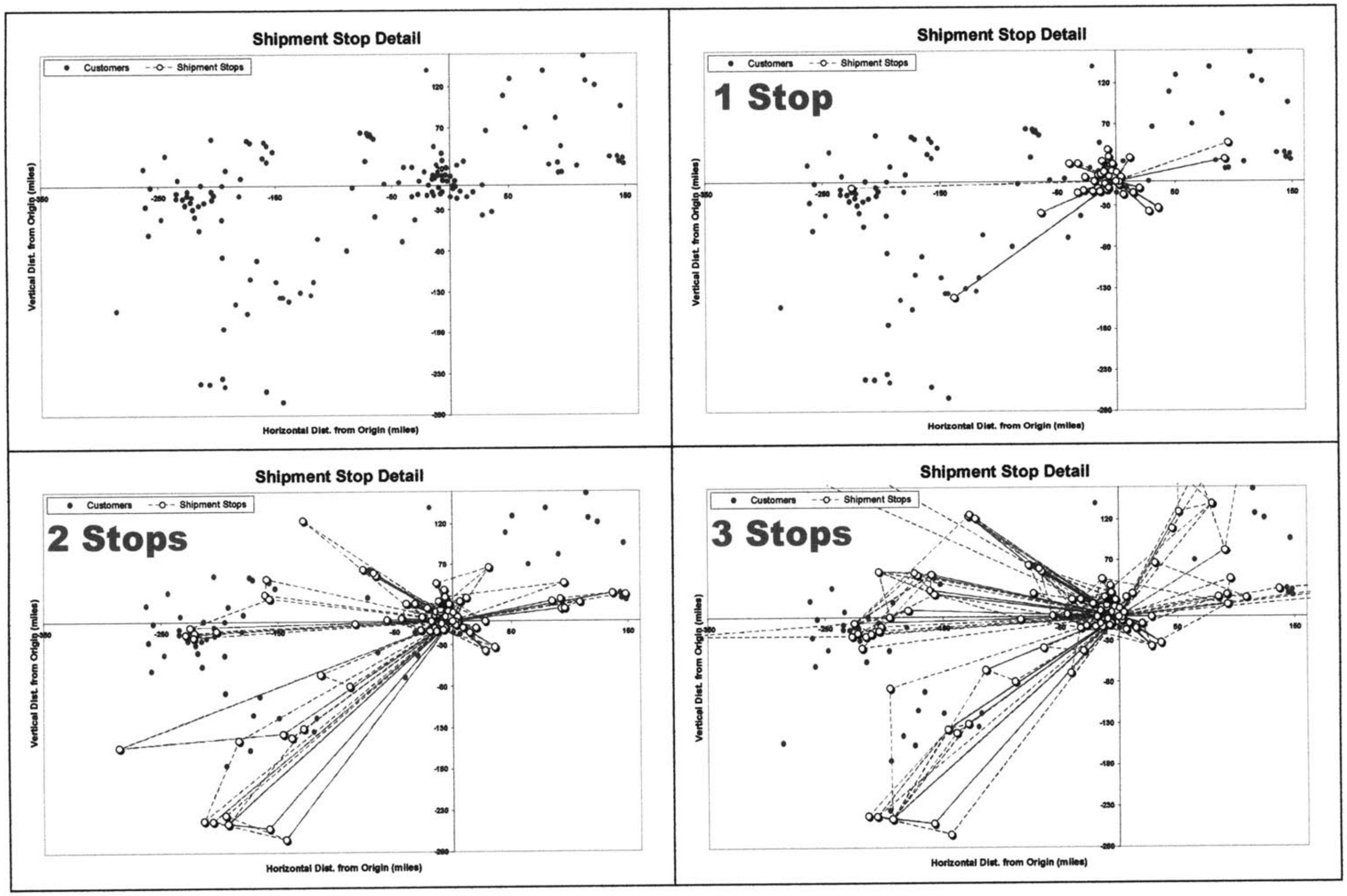
III. Calculation of number of containers

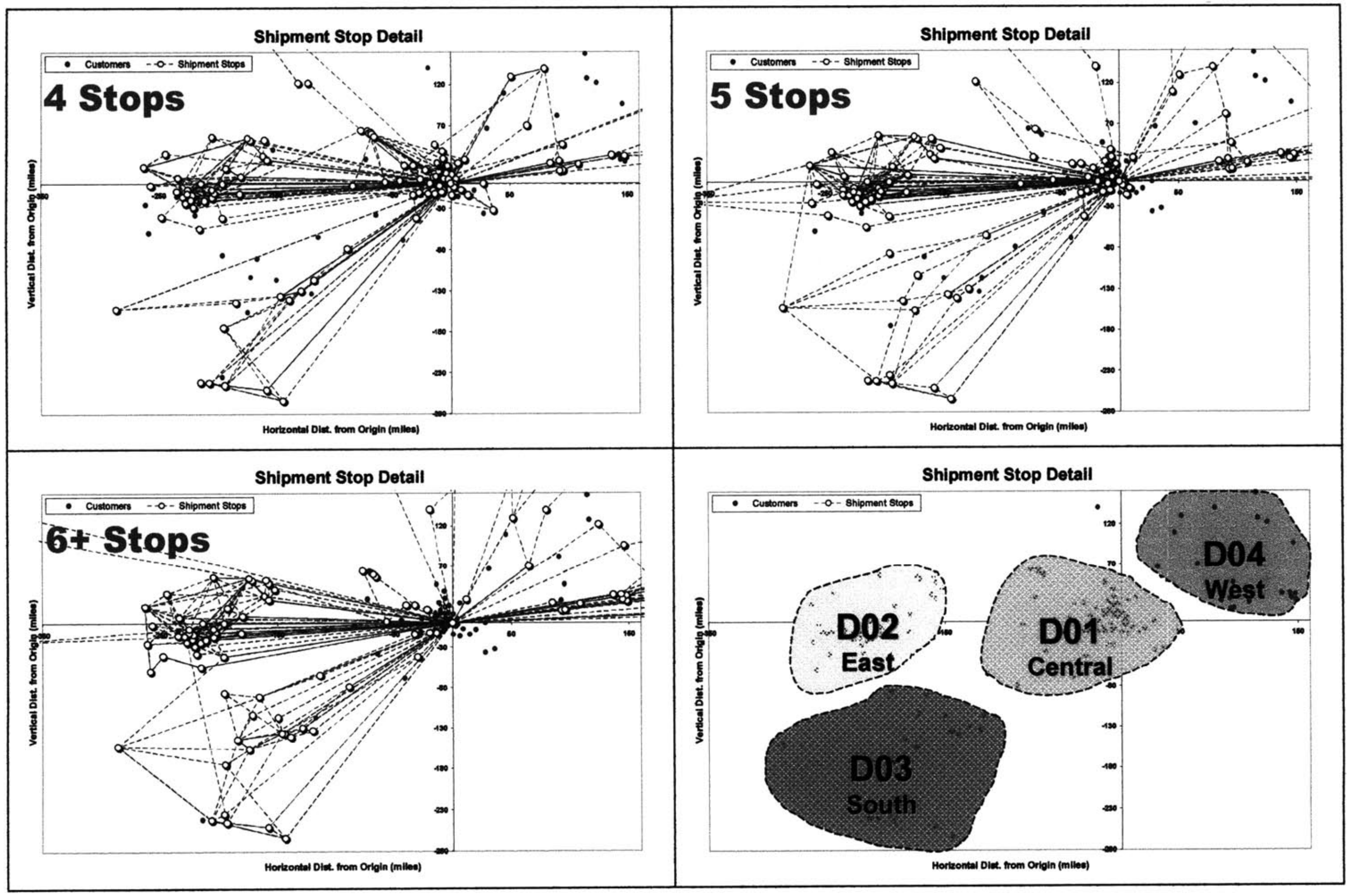
	# of Containers at Customers	# of Containers in Plant for SL	Avg. Replenishment time	Normalized Demand	Normalized Variance	Distribution Parameters: Negative Binomial	
	Rcust	R_{PLANT}	Π	$E(Q) \cdot \Pi$	$Var(Q) \cdot \Pi$	p	r
	containers	containers	days	containers	$(containers)^{2/day}$	$=E(Q)/Var(Q)$	$=E(Q)/(1/p-1)$
Service Region	1052	53	1.73	21.74	117.07	0.19	4.96

x	p[x]	P[x]	Fill rate % [x]	x
0	0.00024	0.00024	0.00%	0
1	0.00095	0.00119	19.85%	1
2	0.00232	0.00351	33.96%	2
3	0.00438	0.00788	44.49%	3
4	0.00709	0.01498	52.65%	4
5	0.01035	0.02533	59.14%	5
6	0.01399	0.03931	64.42%	6
7	0.01783	0.05715	68.79%	7
8	0.02171	0.07886	72.47%	8
9	0.02546	0.10432	75.60%	9
10	0.02894	0.13325	78.28%	10
11	0.03205	0.16530	80.61%	11
12	0.03470	0.20000	82.65%	12
13	0.03687	0.23687	84.44%	13
14	0.03851	0.27538	86.02%	14
15	0.03964	0.31502	87.42%	15
16	0.04026	0.35528	88.67%	16
17	0.04042	0.39570	89.78%	17
18	0.04015	0.43586	90.79%	18
19	0.03951	0.47537	91.69%	19
20	0.03854	0.51391	92.50%	20
21	0.03730	0.55121	93.23%	21
22	0.03584	0.58705	93.89%	22
23	0.03421	0.62126	94.49%	23
24	0.03245	0.65371	95.04%	24
25	0.03061	0.68432	95.53%	25
26	0.02872	0.71304	95.97%	26
27	0.02682	0.73986	96.38%	27
28	0.02492	0.76478	96.74%	28
29	0.02306	0.78785	97.07%	29
30	0.02126	0.80911	97.37%	30
31	0.01952	0.82863	97.64%	31
32	0.01786	0.84649	97.89%	32
33	0.01629	0.86278	98.11%	33
34	0.01481	0.87759	98.31%	34
35	0.01342	0.89102	98.49%	35
36	0.01213	0.90315	98.66%	36
37	0.01094	0.91409	98.80%	37
38	0.00983	0.92392	98.94%	38
39	0.00882	0.93274	99.05%	39
40	0.00789	0.94063	99.16%	40
41	0.00705	0.94768	99.26%	41
42	0.00628	0.95396	99.34%	42
43	0.00558	0.95954	99.42%	43
44	0.00496	0.96450	99.49%	44
45	0.00439	0.96889	99.55%	45
46	0.00388	0.97277	99.60%	46
47	0.00343	0.97620	99.65%	47
48	0.00302	0.97922	99.69%	48
49	0.00266	0.98188	99.73%	49
50	0.00234	0.98422	99.76%	50
51	0.00205	0.98627	99.79%	51
52	0.00180	0.98807	99.82%	52
53	0.00157	0.98964	99.84%	53
54	0.00137	0.99101	99.86%	54
55	0.00120	0.99221	99.88%	55
56	0.00105	0.99326	99.89%	56



Appendix C: Analysis of Routing Patterns in the Service Region




Shipment Stop Detail
Customers
Shipment Stops
4 Stops
Vertical Dist. from Origin (miles)
Horizontal Dist. from Origin (miles)
Shipment Stop Detail
Customers
Shipment Stops
5 Stops
Vertical Dist. from Origin (miles)
Horizontal Dist. from Origin (miles)
Shipment Stop Detail
Customers
Shipment Stops
6+ Stops
Vertical Dist. from Origin (miles)
Horizontal Dist. from Origin (miles)
Shipment Stop Detail
Customers
Shipment Stops
D04
West
D02
East
D01
Central
D03
South
Vertical Dist. from Origin (miles)
Horizontal Dist. from Origin (miles)

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