Economic Tradeoffs of Substituting Transportation for Inventory in the Department of Defense

- A Case Study of Pipeline Reduction-

By

H. Don Taylor

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APPROVED:

Dr. Roger Waud

Dr. Nancy A. Wentzler

Dr. Brian Reid

Dr. Tom Lutton

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Economic Tradeoffs of Substituting Transportation for Inventory in the Department of Defense: A Case Study of Pipeline Reduction-

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{Abstract}

This thesis identifies the potential net economic gains from substituting less costly transit for relatively costly parts inventory through pipeline reduction. The analysis considers long run steady state economic implications of adjusting the current mix of inventory investments and transportation expenses.

The scope of the analysis is focused on a case study of Department of Defense (DoD) parts inventories within the US. The inventory scope is limited to high cost low priority, non-mission critical, replenishment parts (engines, electronics, assemblies and components, etc.). The study uses baseline data collected over 9 months from over 200 inventory sites on thousands of parts.

Pipeline reductions are achieved by replacing the current 6 day transit time with a conservative 3 day commercial carrier (e.g., UPS, DHL, Emory Air, etc.). Warehouses in the case study automatically lower inventory levels in response to lowered transit times to prevent inventory buildup. These lower inventory levels will generate reductions in inventory investment and associated holding costs. The reductions in these inventory costs are compared to the increases in transportation expenses to generate benefit to cost ratios.

DEDICATION

To Bonnie, Drew, Tekla, and Carly for their joy and support.

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TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

I. Introduction and Background

While there is a clear interest in the Department of Defense (DoD) in the potential tradeoffs between inventory and transportation, there are few quantitative economic estimates of the tradeoffs. This thesis addresses the quantitative gap by providing (1) an analytical measure of the economic tradeoffs between inventory and transportation in the context of a case study, and (2) a sensitivity analysis of associated risk factors.

Data for the analysis were collected over a 9 month period from over 200 DoD domestic inventory locations on thousands of parts[1]. The parts in the study are high dollar value items used in the repair and maintenance of tanks, helicopters, trucks, and armored personnel carriers. The inventories for these parts represent investments for routine training purposes, as contrasted to "go to war inventory".

The levels of investment in these training inventories are set in an environment of tradeoffs. For example, higher inventory leads to higher levels of customer satisfaction[2] by minimizing the chances of a stock out which would delay repair or maintenance activities. At the same time, higher inventories require additional investment. In this environment, higher inventory levels of these parts increase customer satisfaction while increasing both acquisition investments and holding costs. Conversely, lower inventory levels reduce acquisition and holding costs but increase the cost of stockouts. The costs of stockouts can be direct (e.g., direct production losses, downtime, etc.) and indirect (e.g., increased rescheduling, swapping working assets for inoperable assets, customer dissatisfaction, increased personnel movement, etc.) The costs of stockouts are identified fully in Section IV, Risk and Stockout Cost Analysis.

[1] See Appendix E for the thesis data

[2] Customer satisfaction is measured in terms of demand accommodation and is typically expressed as a percentage. A demand accommodation of 100% indicates that all customer needs for inventory are satisfied. A demand accommodation of 80% indicates that 20% of customer requirements are not satisfied and involve some

The relationships between inventory costs, stockout costs and demand accommodations are suggested in the following chart.

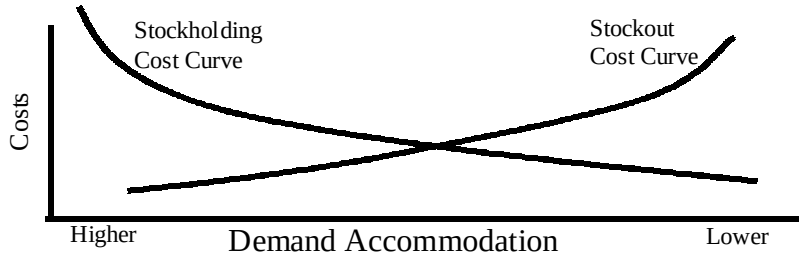

Figure 1: Inventory Holding and Stockout Cost Curves

These relationships illustrate the negative relationship between investment costs and customer satisfaction. The shape of the relationships suggests that inventory costs increase at an increasing rate as demand accommodation targets are increased. In this analysis, however, the specific shape of the curves are less important than the general trend – all other things being equal, lower inventory levels lead to reduced demand accommodation which leads to increased costs due to increased stockouts. Given limited resources, a goal of 80% to 90% accommodations is a typical target at the warehouses and inventories identified in this analysis.

Underlying inventory levels (and their investment costs) is the warehouse manager's utility function. If we assume that the utility function is a function of their incentive structure, then the presumption may be that the stockout penalty exceeds the benefit of reduced inventory levels. This situation will lead to higher stockage levels, all else being equal. This observation is supported by GAO analysis and anecdotal information from the U.S. Army Material Command – the government organization responsible for stockage policy and incentive structures[3].

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amount of delay.

[3] Dr. K. R. Gue, U.S. Navy War College, 14 October 1996

Within the DoD, there is a presumption that improved distribution systems can reduce total inventory costs while improving demand accommodation through pipeline reduction. Pipeline reduction is a specific technique to reduce inventory investments by reducing transportation times to warehouse. The implication is that the stock holding cost curve in the previous figure can be shifted to the left with no impact on the stockout cost curve. Research conducted by the RAND Corporation for the DoD note that there have been substantial reductions in the cost of high-reliability next day carrier operations and that these changes in transportation technology have not been incorporated into the inventory vs. demand accommodation tradeoffs. Rand concluded "*…current DoD distribution process does not take these dramatic cost [of next day transit providers] declines into account."*[4] In Rand's analysis, they noted that "…*certain elements of the distribution process seek to minimize transportation costs by delaying shipments to allow consolidation or by using slower but cheaper transportation. Saving transportation costs is a worthy goal and probably made good sense in an era when transportation costs were high relative to the cost of the materiel being transported, but it may not make sense today. Delaying the shipment of expensive components causes the system to stock more of them. Given the high cost of some components, the cost-effective decision may be to pay the transportation premium and move them rapidly*".

Within the population of warehouses and items used in this analysis, shipments of routine repair and maintenance replenishment stocks of high value items are designed to minimize shipment costs through the selection of slower carriers. Increased transportation time, however, directly and indirectly increases inventory investment costs. Unfortunately, the RAND analysis offers no quantitative measures of the potentially positive payoff from transit and inventory substitutions.

The relationships between transit time and inventory costs are shown in the graph below.

[4] RAND Corporation, Materiel Distribution: Improving Support to Army Operations in Peace and War, John M. Halliday, Nancy Y. Moore; http://www.rand.org:80/publications/IP/IP128/ip128.html

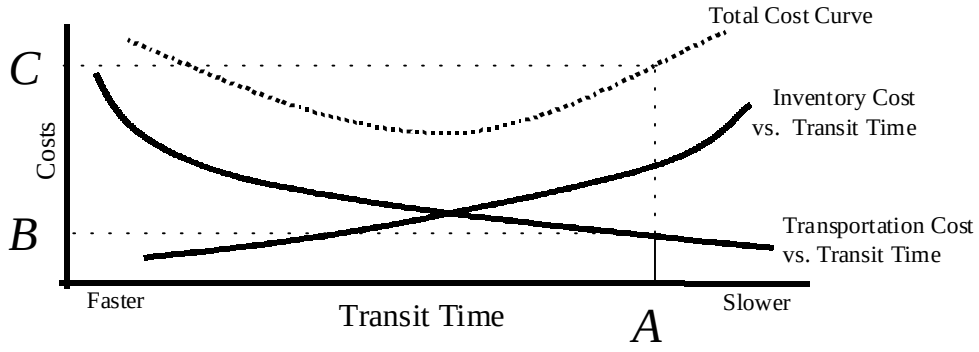

Figure 2: Transportation and Inventory Cost Curves

In this graph, transportation managers opt for relatively slow carries to minimize transit costs, shown as points A and B. The warehouse inventory systems respond to the transit time with higher inventories producing a total cost of C.

Senior DoD leadership has identified the adoption of modern commercial transportation practices to reduce inventories as a key modernization initiative. "Reducing [transit] response times will strengthen overall military readiness through better support for more mobile forces, improved capability for responding to multiple contingencies, and minimizing investment in inventory, facilities, and related infrastructure."[5] In fact, the DoD has begun the planning process to reach a goal of "five-day delivery time for in-stock consumable and reparable items by FY 1997". This thesis uses a more aggressive delivery time of 3 days. This is a conservative goal given the proven ability of next day air carrier to delivery products within two days. In any case, the model used in this analysis will support a variable goal setting process. The results can be assessed for any specified delivery time.

These remarks from senior DoD officials show a presumption of *reduced* risk with shortened transit time (i.e., reduced pipeline) and lower inventories. Current government carriers demonstrate substantial variability in delivery times. This variability translates into increased investment to meet target goals of customer demand accommodation. The distribution of delivery times expressed as a percent of

[5] CENTRAL LOGISTICS, Managing Distribution and Inventories, Office of the Executive Secretary (ExecSec) of the Department of Defense (DoD); http://www.dtic.dla.mil:80/execsec/adr95/i_l_.html

total deliveries is shown in the following graph. This figure shows that the modal delivery value is 3 days. As a practical matter, FedEx and UPS have an enormous body of data that supports a 2-day average delivery time. In this study, a 3-day delivery time was assumed to be conservative. This assumption provides some cushion for any unexpected glitches while switching to next day commercial air carriers.

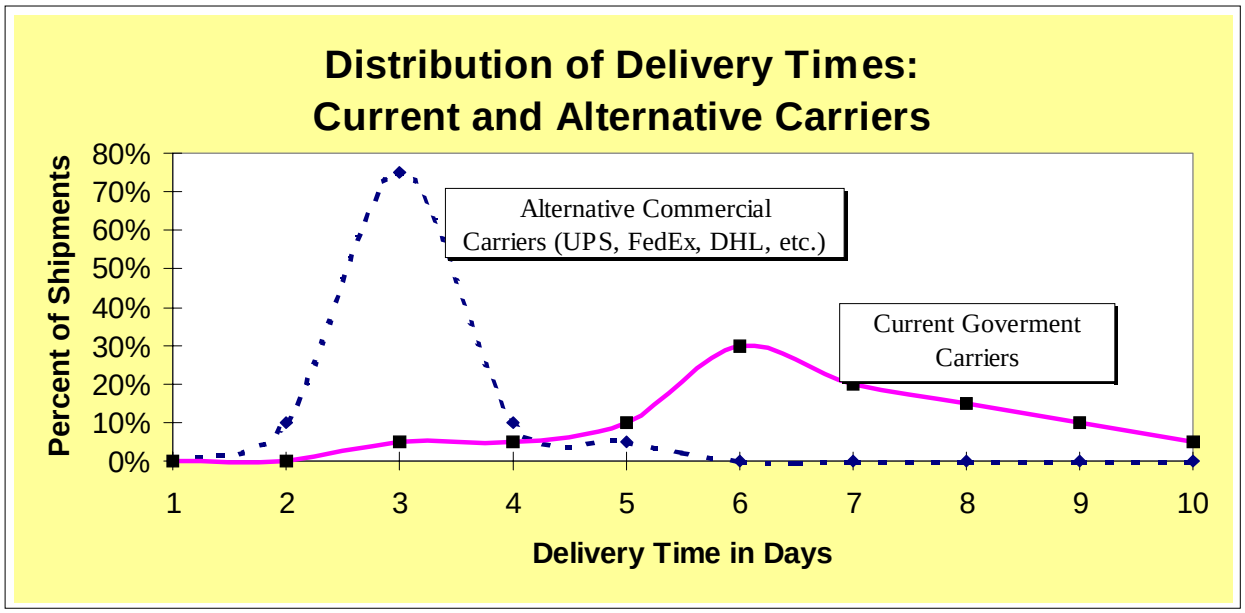

Figure 3: Distribution of Delivery Times

DoD inventory managers in field look at commercial transit reliability with envy. In fact, it is frequently the same next day carriers that are pressed into service when a mission critical "stock out" occurs. Using next day carriers is perceived as reducing variability of delivery times compared to current government carriers.

In academic research, analysis of transportation (or delivery cycle) and inventory availability is well documented. For example, Tyworth identifies the analysis of trade-offs between transportation and inventory elements as basic to logistics planning. He states that "the task is relatively simple when both demand and lead-time elements are known with certainty. By contrast, uncertain sales and lead times creates complex relationships among transportation performance elements, customer service

requirements, and inventory holding costs."[6] The analysis in this thesis does benefit from known and stable demand and supply times. However, as a component of the sensitivity analysis, numerous variables and assumptions are adjusted with an eye on the effect on the thesis conclusions.

Taken to the extreme, the complete substitution of transportation for inventory is typified by Just In Time (JIT) inventory delivery systems. Hammer defines JIT "as an inventory philosophy that attempts to eliminate inventory in order to reduce costs and improve profitability." Limitations of JIT include the lack of an "inventory cushion to fall back on in the event materials or parts are defective or are broken" thus leading to the increased potential of stockouts. Additionally, "transportation delivery systems must be reliable or stockouts will occur."[7] While modern next day air carries are relatively reliable, the demands for these items are variable. JIT is typically suited for stable production line environments, not for military maintenance and repair activities. For these reasons, this thesis is not constructing a JIT paradigm. Rather, transportation expenses are marginally increased to "purchase" reduced inventory costs *due to pipeline reduction.* Pipeline reduction is a specific technique where transportation times to warehouses are reduced to lower inventory levels. Additional inventory reduction techniques include risk pooling and stock transfers. Pipeline reduction is the focus of this analysis because the warehouses in the population respond directly to changes in transit time (pipeline). However, these additional inventory reduction techniques are discussed in detail in Section IV. Risk and Stockout Cost Analysis.

Research in the United Kingdom sponsored by ministerial organizations takes a firm tone towards inventory levels. "Stocks of all types must be considered evil. They consume resources of finance, space, personnel, transportation and require costly protection from damage."[8] A specific technique they recognized to reduce inventories

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[6] Modeling Transportation-Inventory Trade-Offs in a Stochastic Setting, John E. Tyworth, The Pennsylvania State University, The Center for Logistics Research

[7] Just-In-Time (JIT) Inventory Systems, Dr. Hammer, University of Oklahoma State.

http://www.bus.okstate.edu:80/lhammer/costactg/Jit.htm

[8] UK Department of Trade and Industry, Effective manufacture II, Reducing inventories.

is to shorten transit cycles. The potential economic rewards (beyond virtuousness) of reducing inventory through supply cycle management are not identified. Perhaps related to this reverent conviction, there is a commercial product called "INVAL" in the UK that performs analysis on inventory demand and transit times with a goal of reducing inventories. Using the "Pareto Principle", the analysis system claims to have reduced the cost of customer inventories by millions of Pounds. The research for this tradeoff system was developed by the Business School staff at Aston University.[9] The system appears to identify cost driver inventory items and then estimates the potential tradeoffs between inventory and supply. The INVAL approach appears similar to the basic technique used in this study.

The Government Accounting Office (GAO) has identified the improvement of inventory management as a critical component of DoD's response to the National Performance Review (NPR) directive from the Vice President's office. The GAO said that DoD "needs to change its culture with respect to certain areas, such as increasing emphasis on economy and efficiency in inventory and supply management. We have also recommended that DoD pilot test a number of commercial practices in an effort to find ways to improve its operations." The GAO specifically recommended that DoD adopt specific commercial practices such as using low cost next day carriers to reduce inventories and risk.[10]

Within the DoD, the increased use of commercial support alternatives is viewed as critical to achieve desired inventory reductions. For example, the Defense Logistics Agency reduced wholesale medical inventory by 60 percent -- $380 million -- since 1992 by using commercial distribution methods rather than DoD warehouses to distribute medical supplies. The Air Force is credited with taking the lead in substitution of fast transportation for expensive logistics infrastructure. Fast transportation enables the Air Force to replace the traditional caches of just-in-case inventory scattered

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http://www.dti.gov.uk:80/m90s/m9fa35002/m9fa350026.html#3

[9] Epsim Ltd. INVAL - The Inventory Analyser Product Information

[10] GAO Report: DoD Could Save Millions by Reducing Maintenance and Repair Inventories (GAO/NSIAD-93-155, June 7, 1993)

throughout the supply system. The Air Force is expecting $4 billion in savings from the substitution of transit for inventory with reduced risk of stockouts. There appears to be substantial conviction on the part of senior DoD leadership that the substitution of transit for inventory is a net gain: " …in order to free up billions of [inventory] dollars we must now commit to a lean logistics environment [commercial transit practices]"[11].

The cost of inventory is well understood to include onetime acquisition costs and recurring holding costs. Traditionally these recurring expenses are bundled into a single holding cost, which is a fixed percentage of the part's purchase price. The idea is to spread the administration costs over all the lines in stock. It works well for fast-moving parts, but the costs of holding slow-moving items vary widely depending on their physical size, shelf life and maintenance requirements. The optimum investment level is a balance between total holding costs and the cost of stockouts: high downtime costs are incurred if stocks are too low, but holding the spare parts is expensive if the level is too high. Due to a general lack of immediate fiscal restraint and analytical insight, inventory decisions typically have erred on the side of increased inventory investments and holding costs.

In the DoD, inventory of spare and repair parts are stored at multiple locations. The engine for the main battle tank of the Army, for example, is stored at many locations within the United States and other countries around the world. The inventory at each location has a different purpose. The following graph illustrates the distribution of parts in multiple inventory locations.

[11] The Navy Public Affairs Library (NAVPALIB), Paul G. Kaminski, Undersecretary of Defense for Acquisition and Technology

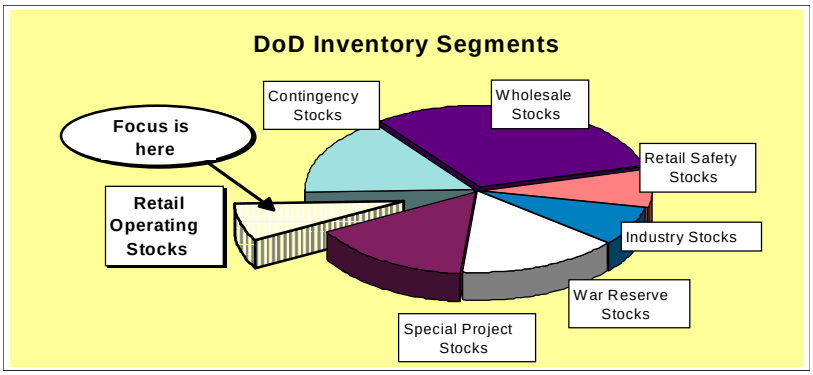


Figure 4: Inventory Locations

Some of these inventories in this figure are reserved only for unexpected contingency operations (e.g., Desert Storm), other inventory is reserved for full-scale mobilization (i.e., a national war). Still other inventories serve a buffer for manufacturer production lead times. For example, inventory designed to support wartime needs is physically separated into "war reserves" stocks. Stock used for lower intensity conflicts are placed into "special project" stocks.

Inventories that support the ongoing recurring needs of day to day operations are called "replenishment" inventories. Replenishment inventories are themselves segmented into "safety stocks" and "operating stocks". These operating stocks serve the purpose of supporting repair and maintenance of military equipment. The focus of this thesis is on reduction of the operating stocks through increases in transportation expenditures.

Of all the inventory segments, only retail operating stock levels can be empirically linked to transportation policy. As practice and policy, the investment in these stocks is driven primarily by two factors: average demand levels and supply cycle times. An increase in either demand or supply times will increase the size of the operating stocks and in turn drive up inventory investments. This practical linkage of transit times and inventory levels supports a quantitative analysis of inventory and transportation substitution.

The *size of the operating stock*, however, has very little impact on weapons system availability or risk of down time (see additional discussion of risk in Section IV: Risk and Stockout Analysis). Weapon system readiness (or availability) is a function of many variables, only one of which is stock level. This analysis looks at the impact of changing the levels of only one of the inventory segments: operating stocks. There are substantial operating inventory levels (and hence investments) associated with routine, non-critical, maintenance. Changes in these stock levels generally have limited effect on military preparedness -– but can have direct and indirect economic impacts due to stockout.

Within DoD (and for the purposes of inventory management) risk is generally defined as the impact of weapon system non-availability and generally referred to as down time. Inventory levels are set such that average expected levels of downtime due to parts non-availability and the costs of inventory are balanced appropriately.[12] This DoD definition of "down time" as the only element of risk is too narrow from an economic perspective. The economic impacts of stockouts can effect the entire spectrum of day-to-day operations and these impacts are discussed in subsequent sections.

Using premium transportation is a well-known and practiced method of reducing "down time" of critical weapon systems due to the lack of parts. As a matter of policy, the DoD authorizes the use of next day air to reduce the time a weapon system is "down". This priority essentially authorizes rapid air-based shipments for any parts that are causing a weapon system to be non-operational. Typically, the dollar costs of these parts, *which are already sent by next day air,* are not substantial in aggregate.

This analysis, however, focuses exclusively on the lower priority day-to-day type inventories and their associated shipments. Theses low priority shipments have the purpose of refilling the inventory from predefined reorder points. There is no production

[12] The economic impact of reducing risk through higher inventory investments leads to forgone expenditures in some other activity. The reduced benefits from this forgone activity is generally considered the opportunity cost of the additional inventory investment.

"waiting" for these shipments. The time required for these shipments, however, drives the bulk of the inventory investment.

For the 9-month sample period, these items represent the highest inventory investment value. To identify these items, a database of shipments was matched with a database of inventory catalog prices. By combining the two databases, I was able to identify the value of the items shipped. The top 100 most expensive parts (defined as total quantity times unit price) were pulled out of the database and scrubbed. Based on this scrub, 9 records were excluded due to data quality issues. The remaining 91 high-value parts form the basis of the study. Consumers ordered $216 million of these inventory items during the 9 months sample period. The following chart shows the distribution of the total value of the demands for the items in the sample population.

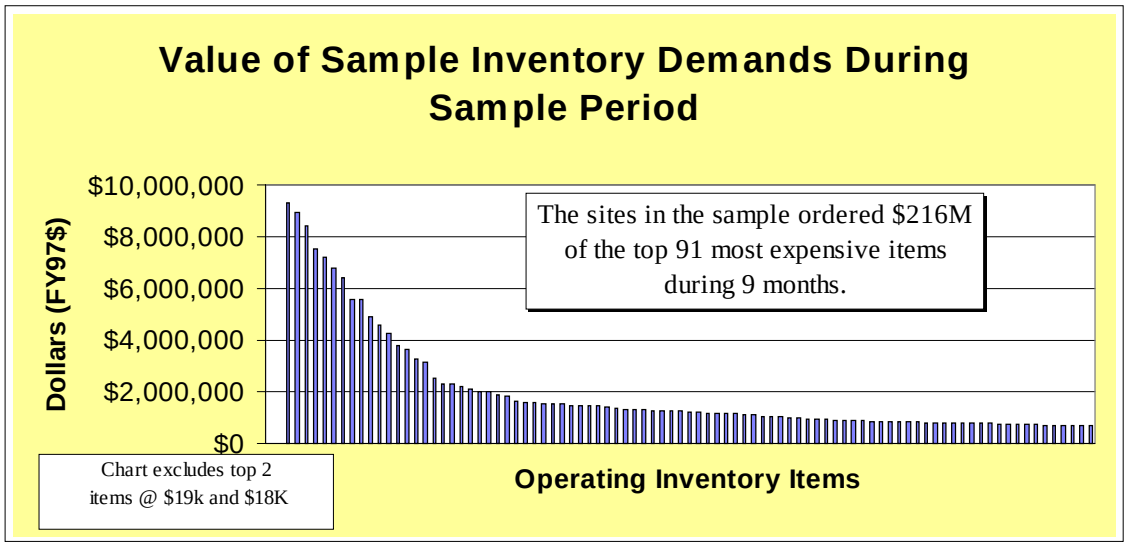


Figure 5: Distribution of Ordered Value

The clustering of high value items on the left side of the axis suggests investment is focused on a minority of the inventory items.[13] The investment

[13] This is a variation of the 80/20 rule: "80% of the investment is contained in 20% of the inventory".

concentration would have been even more apparent if the two most expensive items were included in the graph.

As part of the sensitivity analysis, inventory and transit time risk associated with this inventory are explicitly considered in the Section IV. Risk and Sensitivity.

II. Conceptual Cost Model and Mechanics

This section is organized in two major subsections. The first major subsection defines the conceptual cost model used in the thesis. The second major subsection identifies specific methodologies and their associated parameter values.

II.A Conceptual Cost Model

Research cited in the Introduction illustrates an interest in the economic effects of the transit for inventory substitution. This section lays out the overall cost model design and focuses on the functional relationships in the model. (Specific variable values are discussed in the second major subsection.)

The high level cost model defines total costs (Total_Cost) as the sum of two major elements:

- Recurring Inventory Cost (RIC): This is the recurring cost associated with holding inventories.
- Recurring Transit Cost (RTC): This is the cost of transportation.

These costs sum to the Total_Cost as shown below:

Total_Cost = RIC + RTC

The functional form for these two key variables are defined below.

1. RIC = ((ADD x TD) x UP x (1 + RF))* IHC

where:

ADD = Average Daily Demand. This variable is the average quantity demanded for each item from each storage location.

TD = Transit Days. This variable is the elapsed time in days for the average transit action.

RF = Risk Factor. This variable is a risk adjustment factor accounting for unexpected variations in demand and supply rate, expressed as a percent.

UP = Unit Price. This variable is the unit acquisition price.

IHC = Indirect Holding Costs. This is the sum of all indirect holding costs for borrowing capital, storage, obsolescence, and inventory losses. All of these additional costs are aggregated into a variable called Inventory Holding Costs (IHC). They are generally expressed as a percent of the acquisition price.

2. TC = ADD x TD x UPT

where:

ADD = Average Daily Demand. This variable is the average quantity demanded for each item from each storage location.

TD = Transit Days. This variable is the elapsed time in days for the average transit action.

UPT = Unit Price for Transit. This variable is the total transportation cost for shipping the items to the storage site. This is usually computed on a per pound basis with limitations for minimum cost and maximum size.

Using the elements discussed above, overall cost model is show below.

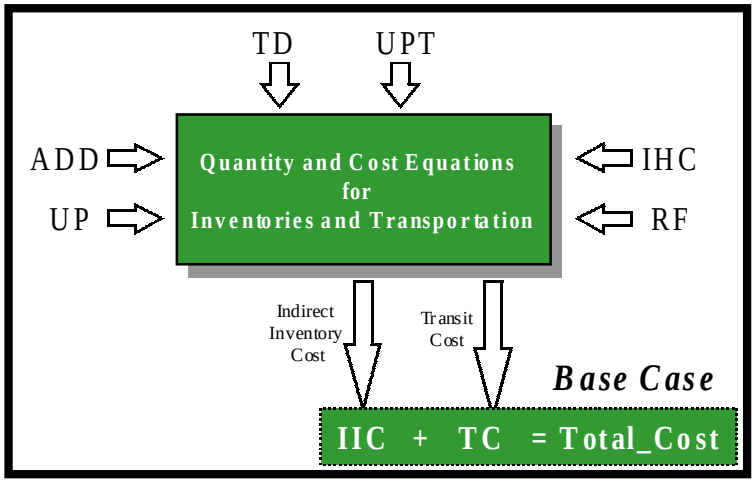


Figure 6: Overall Cost Model Diagram

Using this model with the base case parameters will generate the base case total cost. Changing the Transit Days (TD) variable from the base case to the shorter alternate transit time and re-running the model generates the total costs for the alternate case. Comparing the base and alternate total costs provides a perspective on the potential net cost savings. This concept is illustrated below.

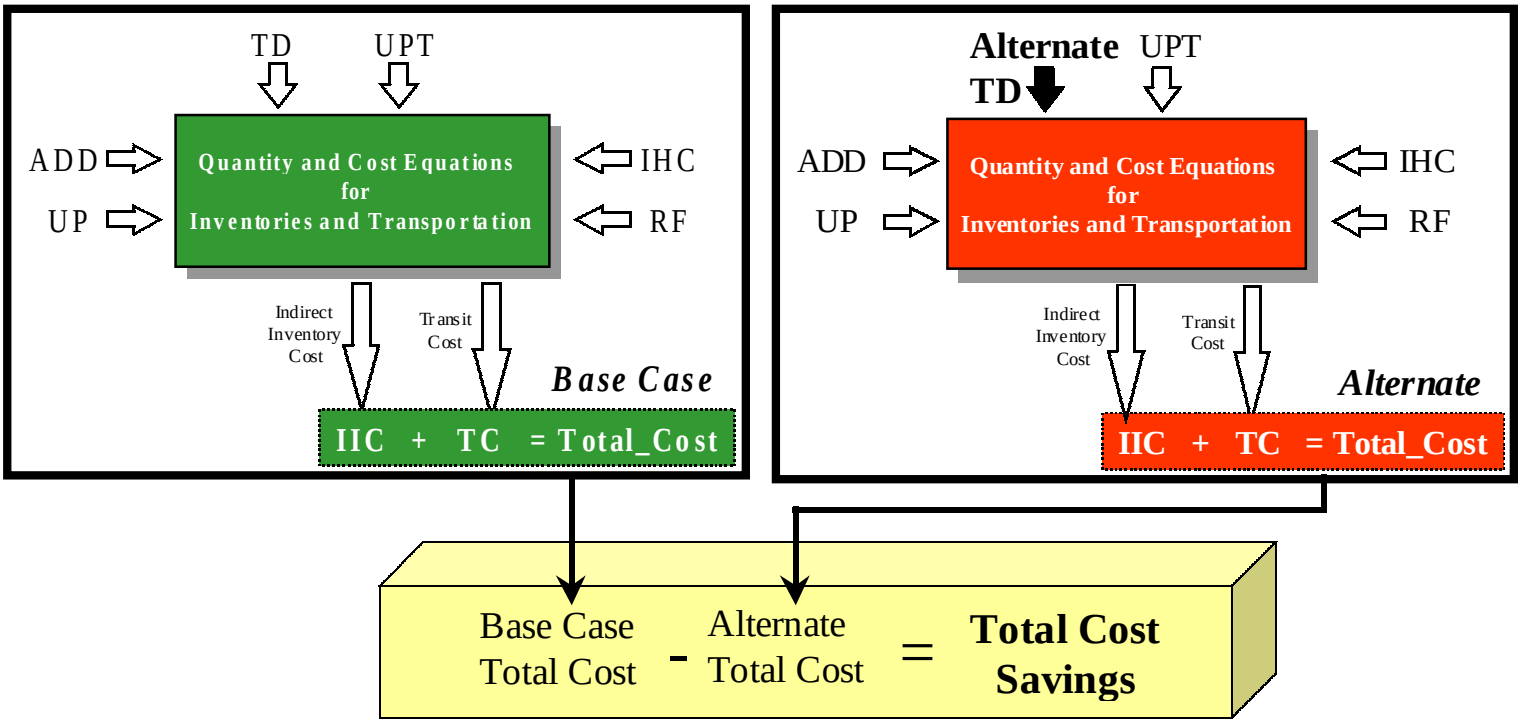


Figure 7: Base and Alternate Total Cost Model

Alternatively, the change in cost between the current and alternate cases can be expressed as a ratio of marginal changes. The sum of marginal savings (benefits) divided by the sum of marginal costs (investments) is a useful technique to express the relationship between benefits and costs. This study uses benefit to cost **ratios** to express the relationship between dollars saved on inventory and dollars expended in transportation.

$$\textbf{Benefits to Cost Ratio} = \frac{\textbf{Recurring Decreased Holding Costs}_{PV}}{\textbf{Recurring Increased Transit Costs}_{PV}}$$

Note that transit and holding costs are flow variables – their costs are recurring. If the ratio of benefits to costs is to be meaningful, these flow variables must be discounted to present terms. After making these adjustments, and all other things being equal, higher benefit ratios make a more compelling case for reducing inventories via rapid transit. This technique is the basic method used to portray the economic consequence of substituting transportation for inventory in this study. This

ratio is frequently applied against an informal benchmark or threshold. For example, improvement programs with expected benefits to cost ratio greater than 10 are frequently selected for additional consideration in the DoD. Of course, the specific threshold varies from situation to situation.

II.B Parameter Values and Model Mechanics

The previous section described the model construct but did not discuss specific parameter values. This section identifies and discusses each parameter value in the context of the procedures that use the parameter value.

There are four basic procedures that together generate the total costs for the base and alternate case. These procedures are identified below.

1. Determine base and alternate transportation times.

2. Estimate base and alternate transit costs.

3. Model the impact of the different transit times on the operating inventory levels.

4. Estimate the direct and indirect economic impacts of the change in inventory levels.

Each of these procedures, and their associated parameter values, are discussed in the following sections.

II.B.1 Determine base and alternate transportation times.

For the study population of sites and inventory items, the current total supply cycle time for low priority stock is measured in weeks. The actual in transit portion of the total supply cycle is approximately one week. These long supply times lead to high inventory levels. A method to reduce transit times is to “out-source” the transit requirement to a third party – such as UPS, for example. Third party carriers can deliver airfreight within 2 to 3 days to most any domestic storage point. These lower supply times will lead to lower inventory levels. The difference in transportation costs between the base case (long supply times and low transportation costs) and alternative case (short supply times and higher transportation costs) is a quantifiable measure of the change in transportation costs.

These reduced transportation times can be fed into a model of the inventory management systems. Modeling the behavior of the inventory management systems under varying supply conditions provides analytically based observations of costs and

benefits. For example, if the inventory systems were "told" that the supply times were reduced from 6 to 3 days, the system would automatically re-compute the item's inventory levels downward. The lower inventory level would lead directly to reductions in inventory investment and reductions in inventory holding costs. The change in inventory investment and holding cost is a quantifiable measure of the benefit of reducing inventories through reduced transit times. If the inventory item were high cost but low weight, then the inventory savings could be many times the increase in transit costs.

There are several components in the ordering and transportation cycle for parts. The process begins with a need for a part and ends when the part is physically ready to be issued from the inventory. This analysis focuses on the segment of the cycle when the part is in physical possession of the shipper[14]. The change in this segment of the cycle is assumed to be relatively small. For example, for low priority requisitions in the United States, in-transit time is an average of 6.8 days out of a total average time of 28.2. Commercial two-day air delivery reduces the in-transit time to two (2) days. There are currently at least four commercial carriers (i.e., UPS, DHL, FedEx and Emory Air) that guarantee delivery anywhere in the US, Hawaii and Alaska excluded, within two days. To be conservative, a three (3) day alternate transit time was selected. This conservative assumption helps make the potential value of investment reallocation in this study worst case, not best case figures. These transit values are shown in the following table.

Table 1: Base and Alternate Ship Times

	The OST Variable (Ship Times)		
LOCATION	Base Case[1]	Alternate[2]	Change[3]
US	6.8	3	3.8

1 Current time is the current average delivery time.

2 Alternate time is the assumed commercial carrier's delivery time.

3 Change time is the delta between Current and Base Case

[14] Average Pipeline Segment Processing Time In Days in Direct Support System Performance Evaluation, Logistics Readiness Sustainment Center.

II.B.2 Estimate base and alternate transit costs.

The current or base case transportation expenditures were estimated by calculating an average cost per ton based on recent transportation cost data. Transportation cost data was first extracted from the published sources. Unfortunately, this data does not provide an exact cost for each type of item in the operating inventory. The published data provide only the total costs and tonnage transported during a period within commodity groups.[15] To calculate an estimated average transportation cost for moving the items in this study, the cost and tonnage data were combine to create an overall average cost per ton. These three commodity groups were: vehicles and parts, machinery and parts, and electrical equipment. The averaging process created a composite transportation cost of $0.06 per pound. The components of the average and its calculation are detailed below:

Table 2: Base Case Transportation Costs Per Quarter

Surface Transportation Activity			
Commodity	LBS Transported	Cost	Cost Per LBS
Vehicles and Parts	145,960,000	$6,133,150	$0.04
Machinery and Parts	22,220,000	$618,690	$0.03
Electrical Equipment	2,000,000	$203,260	$0.10
		Average:	$0.06

This transportation cost factor was multiplied against the inventory weight and pipeline days to estimate the base case transit costs. A limitation of this averaging approach is that it assumes the distribution of commodities will be constant in the future. This is not likely to be the case as requirements change over time, and these requirements drive the distribution of commodities. The effect of different commodities will change the expected baseline transportation costs. Within the relevant of range of potential transportation costs (a high of $.10 to a low of $.03), the impacts of baseline

[15] Military Traffic Management Command's (MTMC) Traffic Management Progress Report, Fourth Quarter, RCS DD-M(Q).

transportation cost deltas between averaged costs and actual costs actual will be minor.

Estimating the cost of premium transportation was slightly more complicated. For points in the US, United Parcel Post 2nd Day Air commercial rates were used for shipments of less than 150 pounds[16]. The US rate data for UPS two (2) day air (UPS 2nd Day Air) reflect rates paid by commercial shippers and do not reflect government discounts. Were the DoD to negotiate rates with UPS, it is likely that DoD's substantial volume would result in lower rates than used in this study. The rates are applicable only to boxes from 1 to 150 lbs[17] shipped within the continental United States (Hawaii and Alaska excluded). UPS will not accept any box weighing in excess of 150 lbs.

Table 3: UPS Domestic Transit Rates

UPS Domestic Rates	
WEIGHT (Lbs)	**COST PER POUND**
1	$6.00
2 - 70	$1.32
71 - 150	$1.05

Table 3 indicates the upper weight limit for single boxes shipped via UPS. This 150 lb limit is designed to protect UPS employees who do not have heavy lifting equipment at their disposal.

Obviously, the DoD will ship items in excess of 150 lbs. For that reason, it was necessary to obtain rate information from a carrier that handles items in excess of 150 lbs. For heavier items, rate information was collected from Emory for the shipment of items that weigh in excess of 150 lbs. Emory uses different rates depending on the

[16] UPS Rate Chart, Effective February 7, 1994

[17] If dimensional weight (LxWxH/166) of a package measuring over one cubic foot exceeds the actual weight, the dimensional weight is used to compute cost by UPS. Assuming the packing box fits the shipped item, the dimensional weight and the shipped weight are normally quite close. Additional charges may apply (e.g., hazardous materials, Saturday pickup, insurance, confirmation) which have not been taken into account but which do not appear to be sufficiently large to effect the analysis.

point of origin and destination of the shipment within US. For example, for shipments from 151 to 1,000 pounds, rates vary depending on point of origin and delivery from $0.64 to $0.85 per pound, for an average rate of $0.75 per lb. Similarly, for shipments in excess of 1,000 lbs, rates vary depending on point of origin and delivery from $0.62 to $0.83 per pound, for an average rate of $0.73. The following average rates per pound have been utilized in this analysis:

Table 4: Emory Air Corp. Domestic Transit Rates

Emory Air Rates	
WEIGHT (Lbs)	**COST PER POUND**
151 - 1,000	$0.75
1,000 Plus	$0.73

These cost rates were applied against the total weight of the inventory to be shipped. Where required, a minimum cost of $35 was set for light items.

It is interesting to note that the base case cost per pound is an order of magnitude less than the alternate case: $.06 vs. $6.0. Despite this substantial increase in per pound prices, the inventory savings more than offset the effect of increased transit costs for high-value low-weight items.

II.B.3 Estimate the impact of the different transit times on the operating inventory levels.

The impacts of shortened transit times are felt in (and reflected by) the inventory management systems. The inventory management systems translate these changes in transit time into changes in inventory levels. Accurately modeling the behavior of inventory management systems is **critical** to estimating the impacts of rapid transit on inventory levels.

In the 1950s and 1960s, maintaining inventory levels to support tanks, armored personnel vehicles, trucks and other vehicles required a considerable amount of data

gathering and a large number of tedious manual calculations. Inventory management systems were introduced in the late 1960s to help automate supply management functions performed manually by solders. *The logic contained in the automation, however, did not address the* ***economic*** *impacts of inventory decisions.*

The inventory management systems calculate the inventory level for each part using a complicated group of interrelated variables and calculations. These procedures are based on operations research and inventory theory. These variables and calculations are reproduced here to ensure reproducibility and to demonstrate that the study's inventory model is faithful to the actual inventory mechanics.

The inventory level is termed the **Requisition Objective Quantity (RO_q).** The ROq is the number of items which should be held in the inventory based on the inputs to the inventory management system. The RO_q is calculated by combining two terms: inventory levels driven by transit times (called the Order Shipment Time Quantity (OST_q)) and inventory levels driven by set safety levels (called Safety Level Quantity (SL_q)). This relationship is expressed below.

$$\mathbf{RO_q = OST_q + SL_q}$$

The OST_q and SL_q quantities are set by the calculations shown and described below.

The OST_q variable represents the amount of inventory needed to meet demands given the demands and transit times. This is expressed below.

$$\mathbf{OST_q = OST_{days} \times ADD}$$

Where:

Order to Ship Time Days (OST_{days}) is the elapsed transit time between the start date of the transportation process and the date of receipt. Within the inventory software, this time is calculated as the difference between the time when an item is given to the transport system and when it is received. The difference is called Order to Ship Time (OST). The inventory software calculates OST each time an item is received into the inventory and then takes a simple average of the last six values of the calculated OST. The approach in this study is to average the OST

over a 9 month period. This approach to calculating OST will provide a very good proxy for the value calculated by each site's actual inventory software.

Average Daily Demand (ADD) is the sum of low priority demands for each item from each location in the sample population over time. For this analysis, the term Average Daily Demand is calculated by taking the total period demand divided by the number of days in the period (244 days). The result of this calculation was an estimate of each location's ADD that would have been calculated by the inventory management system at each location in the study. The ADD was a critical component of the analysis. The ADD was the basis for estimating: (1) the estimated inventory size due to the transportation times; and (2) the tonnage to be moved which drives the transport costs.

The SL_q variable represents the amount of inventory needed to account for unexpected delays in transit times or unexpected demand spikes. The safety level quantity is essentially the "risk premium" used to adjust for variability in supply and demand rates. This is expressed below.

$$\mathbf{SL_q = Risk\ Adjustment\ Factor \times SL_{days} \times OST_q}$$

The two new terms of this equation are discussed below.

Risk Adjustment Factor is a proportion of normal demand held in addition to normal stocks to account for unexpected variation in demand rates, supply time, delivery processing, etc. Based on inventory cost analyses research, DoD estimates that 11% of normal inventory should be held for unexpected changes in supply and demand rates[18]. There are two reasons to question this factor. First, UPS, Fed/Ex, and DHL have far less variability of delivery time than current government carriers (see Figure 1). As a practical matter, there is very little variability in delivery times of modern commercial carriers. Based on a review of the data the variability of current ground carriers is much more

[18] The value of this factor was developed by at the DoD's Inventory Research Office (IRO) after an analysis of inventory demand and supply patterns.

substantial. There is an argument, then, that the risk factor could be *reduced* in the alternative case.

Safety Level Days (SL_{days}) is the number of days for which supply stocks should be held to account for unexpected delays in transit time. This figure is a constant of five (5) days for all domestic inventory sites and a constant of fifteen (15) days for all overseas inventory sites. This term is also exogenous to the model and is proscribed by DoD policy. The impacts of varying this term on the results are identified in the Risk and Sensitivity section.

Analysis of these equations indicates that there are three principle drivers in this model: (1) time to receive the item **(OST_{days})**, (2) demand frequency for the item (ADD), and (3) risk factors. The relationship between these inventory-input parameters, and the model inventory level output, is linear and positive. As the values of any of the three parameters (i.e., time, demand, and risk) increase, the inventory management systems increase the inventory level.

This system of equations makes clear that changes in ROq (inventory levels) are driven by changes in OST_{days}, if ADD and risk are held constant. In running the model, the OST_{days} term was set equal to the possible change in OST_{days} (6.8 days minus 3 days = 3.8 days) which would occur if UPS (for example) were to move the item. After changing OST_{days} and holding ADD and risk constant, any observed change in both $OST_{q\ and}$ SL_q are attributed to the change in OST_{days} terms. This process is done for each item ordered from each inventory location over 9 months of data.

In an assessment of risk impacts, all of the risk and "fixed" factors were also changed to observe the economic impact on inventories and costs.

II.B.4 Estimate of the economic impacts of the change in inventory levels.

To asses the direct economic implications of the new inventory levels, the change in the OST_q and SL_q terms are expressed in their economic valuations and are represented below.

economic value of inventory reductions = Σ operating inventory reduction values + Σ safety level reduction values

When inventory levels fall, there is also the potential for reductions in longer-term annual holding and storage costs (i.e., flow variables). These costs have four components:

- borrowing costs of capital,
- storage costs,
- obsolescence, and
- inventory losses.

The investment of capital represents the cost to the government of borrowing money to finance expenditures – this is the cost of capital term. For this thesis, the value has been set at 10%. This amount represents the annual proscribed investment charge used by the DoD to finance inventories[19] for the purposes of analysis. This amount appears to overstate the actual cost of federal borrowing. The impact of this higher funds rate is to put an upward bias on the potential savings from reducing inventory. This term could be reduced to the current federal funds interest rates (e.g., 6% to 7%) to asses the impact of changing the assumptions on the results of the analysis.

Storage costs are estimated to be approximately 1% of acquisition price based on published analysis from the Inventory Research Office[20]. This term represents the assumed variable costs for warehouse space, personnel, and local storage operation

[19] This factor is based on cost analysis performed by the DoD Inventory Research Office published in Instruction 4140.39 Guidance for Inventory Cost Analysis

[20] This factor is based on cost analysis performed by the DoD Inventory Research Office, published in DoD Instruction 4140.45 Rates for Inventory Analysis

expenses. This term may be much too low relative to current commercial practices. The sensitivity effects of using much higher rates of inventory holding costs are assessed later in this analysis. The final components of these costs are the losses due to obsolescence and inventory shrinkage. Based on published analysis from the Inventory Research Office, these obsolescence and shrinkage costs are estimated to be 5% of purchase costs.[21] These can be expressed as follows:

Recurring Costs = Σ ((10% + 1% + 5%) x (operating inventory reduction values + safety level reduction values))

The estimated values of these factors may have been based on out of date inventory cost research. They do not appear to be consistent with current commercial practices of inventory evaluation. Current ranges for these factors start with 20% and move up to 45%. A sensitivity analysis was performed to assess the impact of changes in costs of funds and holding costs upon the results. The sources for commercial holding costs and the sensitivity results are discussed in Section IV. Analysis of Sensitivity and Risk. In any case, variations of these estimates are not expected to have a significant impact on the final observations of the analysis, provided that the factor estimates are the same in the baseline and the alternative analysis.

When performing an analysis of flow costs, it is typical to express their value in Present Value (PV) terms. Discounting the value of the flow allows for comparison with other one time and flow variables. In this analysis, the discount rate is assumed to be 10% to match the implicit cost of borrowing funds used in the inventory financing term. The time period is set to 10 years as a proxy of the DoD inventory-planning horizon for investment of expensive inventory parts. Combining the short run change in inventory investment with the longer run change in recurring holding costs generates the following total cost expression.

Total economic value of inventory reductions = Σ operating inventory reduction values + Σ safety level reduction values + Σ (PV)recurring holding costs

[21] Inventory Valuation Factors from the U.S. Department of the Army, Memorandum, Inventory Data Call,

As discussed in the Cost Model section, the relationship between cost increases and decrease can be expressed as a ratio of changes as shown below.

$$\textit{Benefit Ratio} = \frac{\Delta\ \textit{Holding Costs}}{\Delta\ \textit{Transportation Expenditures}}$$

III. Results

The numerical results are organized into four sections:

A) base case,

B) alternative case,

C) differences between the base and alternative case, and

D) benefit to cost ratios.

These are discussed below.

III.A Base Case

Using sample data and the procedures discussed in the previous section, the estimated base case inventory value is just under 10 million dollars. The average item inventory investment was approximately 100,000 dollars. Within the sample population, the highest individual inventory value was 600,000 dollars for an aircraft engine and the least was 300 dollars for an engine alternator. These values were, however, widely distributed as shown in the following graph.

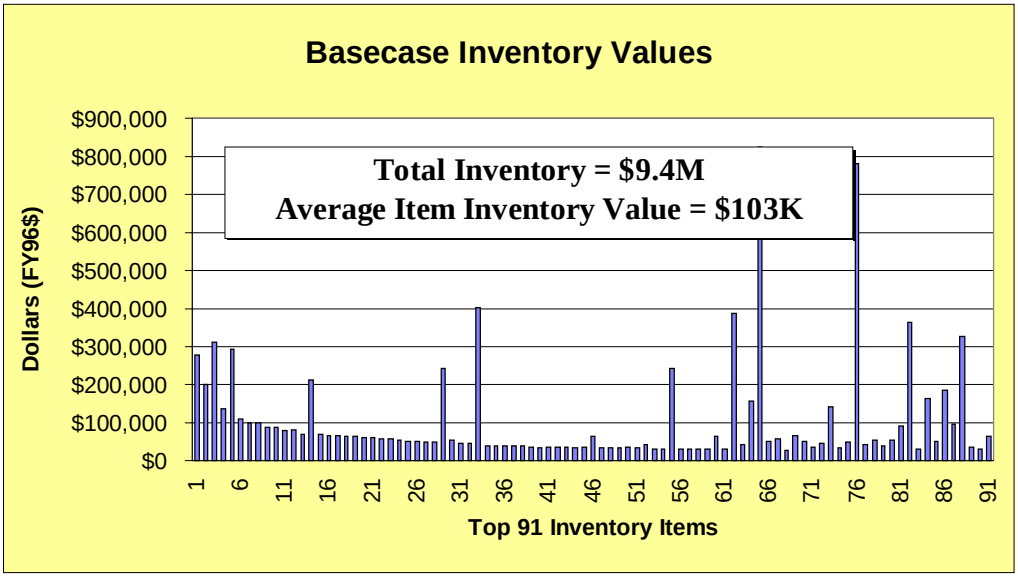


Figure 8: Base Case Inventory Values

In addition to the basic inventory investment, there were annual holding costs of approximately 1.5 million dollars. This amount represents the recurring cost of borrowing, warehousing, loss, obsolesce, etc. The average annual holding cost per item was 16,000 dollars. This information is shown in the following graph.

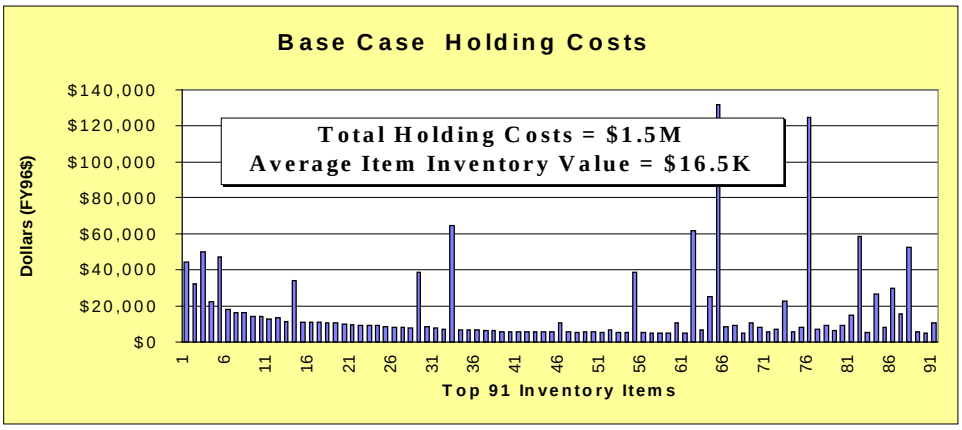


Figure 9: Base Case Recurring Holding Costs

The high degree of visually apparent covariance between the inventory costs and the inventory holding costs is the result of using percent factors in the holding cost calculations. Given this approach of factoring holding costs as a percent of investment, these results are obvious. Prior to comparing the inventory and holding costs, however, the holding costs need to be discounted into the present term.

Given the base case transportation cost factor of $.06 per pound, the base case transit costs are expected to be much lower than inventory and holding costs. The results did not disappoint. The total base case transit costs were five thousand dollars. The average item required approximately fifty dollars in transportation costs during the sample period. The following graph shows these results for each item.

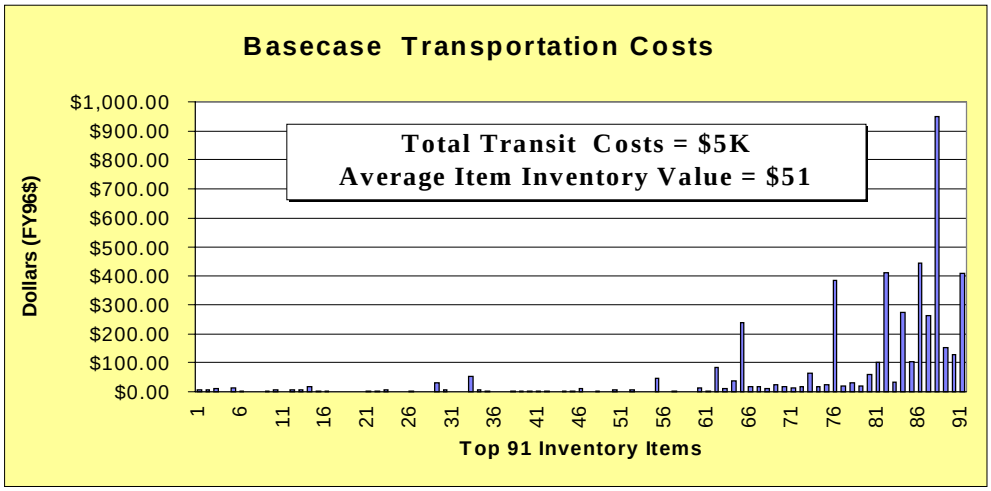


Figure 10: Base Case Recurring Transportation Costs

The clustering of items with higher transportation costs to the right of this graph is the result of the data sort sequence which placed the items with the highest cost to benefit rates on the right, and the least on the left. Items with higher cost to benefit rate generally have the highest weight, and this drives the higher transportation costs. Prior to comparing these costs to one-time benefits, like inventory changes, they need be discounted into the present term.

The composite picture of inventory, holding and transit cost is shown below.

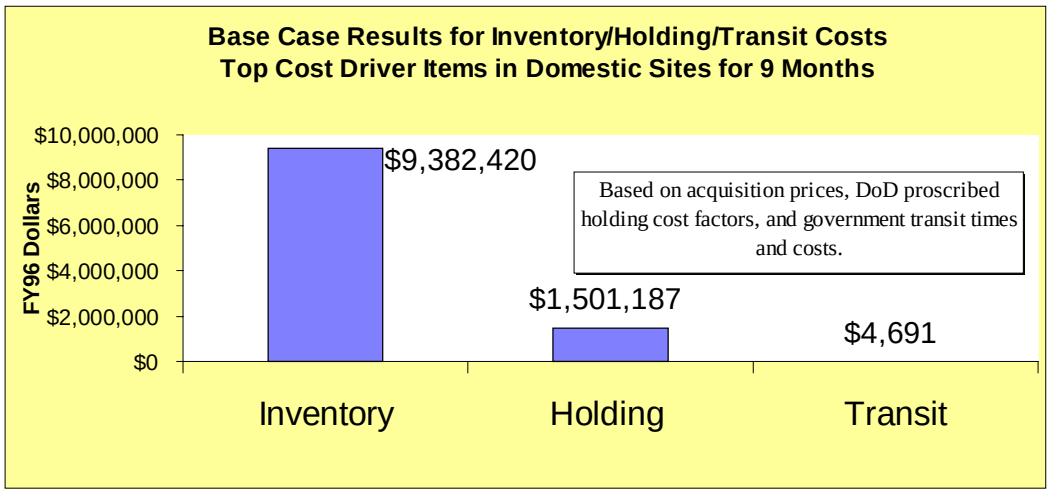


Figure 11: Base Case Composite Cost Picture

The holding and transit costs are computed as recurring values. The effects of discounting these values are discussed in subsequent sections.

III.B Alternative Case

Using rapid transit drives down the inventory levels. This in turn reduces the inventory value and the associated holding costs; however, transportation costs increase. The numerical results are presented below.

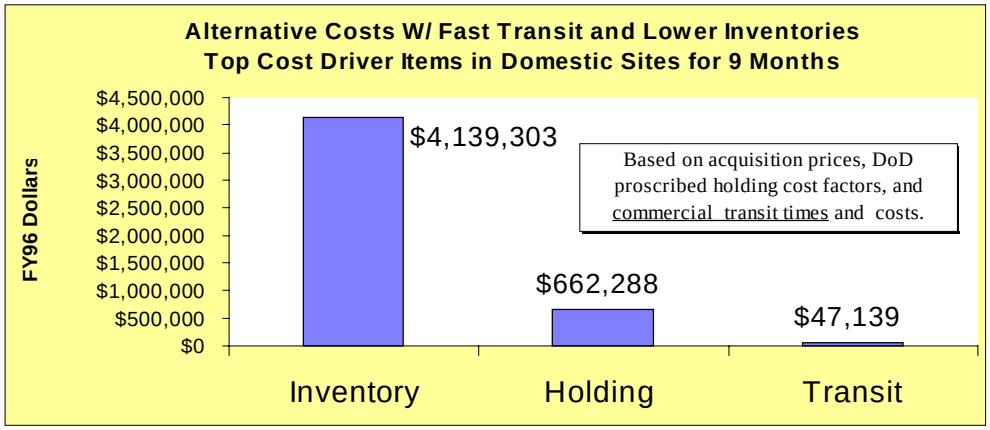


Figure 12: Alternate Case Composite Cost Picture

The distribution of values for each type of cost is very similar to the base case distributions and is not presented here.

III.C Base vs. Alternative Case Results

The changes in inventory, holding and transportation costs are shown in the following graph. Note that all recurring costs are expressed in present terms (see the methodology section for additional information on discounting streams). The long-term savings that accrue from reduced holding cost approximately equals the initial change in inventory. One time Inventory changes are not factored into the cost benefit analysis.

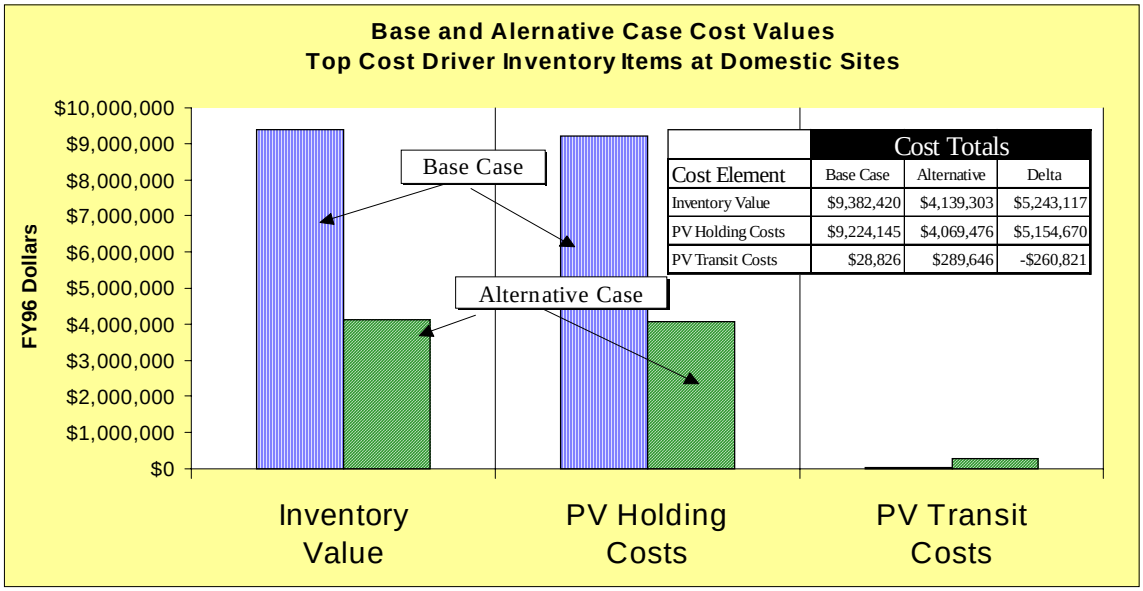


Figure 13: Base and Alternative Cost Values

This figure shows the substantial changes in cost values for inventory, holding and transit costs. The top 10 inventory items with the largest net reduction in total costs (inventory, holding and transportation) are shown below.

Table 5: Top 10 Inventory Items With Net Cost Reductions

Item Part Number	Item Name	Acquisition Price
1270013083019	TURRET,SENSOR-SIGHT	$200,160
1270011775497	TRANSCEIVER,UNIT	$72,948
1055012404957	STABL REF PKG SRP	$153,607
1260012936337	THERMAL IMAGING SEN	$287,676
1240012939706	THERMAL RECEIVER WI	$87,191
6675011828813	INERTIAL MEASUREMEN	$159,460
5855013283540	IMAGE INTENSIFIER,N	$2,666
5855011514191	IMAGE INTENSIFIER,N	$3,013
5855012329440	NIGHT SENSOR ASSEMB	$184,046
1270011873439	OPTICAL RELAY COLUM	$80,333

A review of these cost-driving parts indicates that they are all high cost electronic components. Relative to mechanical components, however, their weights are lower. This characteristic of high cost and low weight makes them ideal candidates for inventory reduction.

The degree of change between the base and alternate case costs can also be expressed on a percent basis. Calculating the results on a percent basis supports the potential extrapolation of the results of this analysis to other similar situations. The percent changes are shown below.

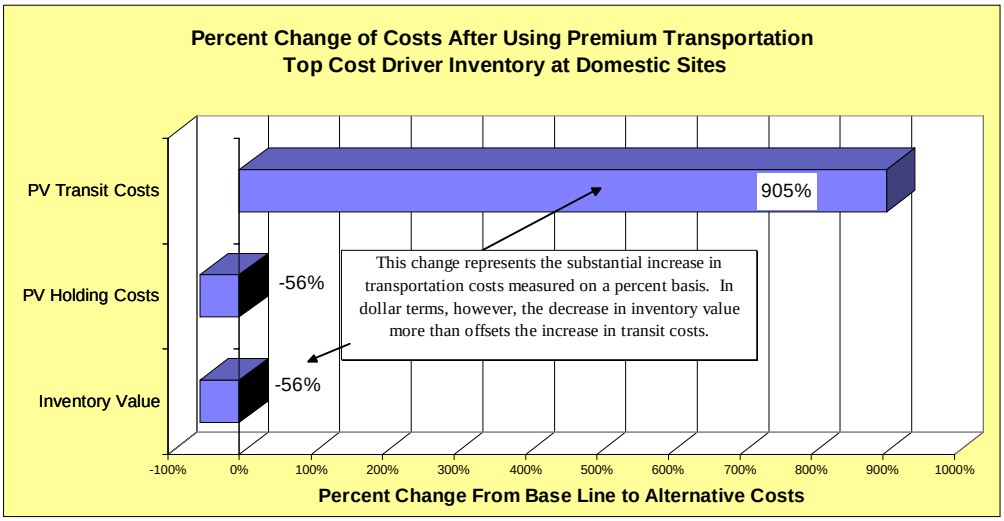


Figure 14: Percent Change in Costs Due to Reduction in

Inventory Levels

Note that the large percentage change in transportation costs is misleading. While the change is substantial as a percent of the base values, the absolute dollar value is not similarly significant. The following graph puts the absolute dollar values in perspective.

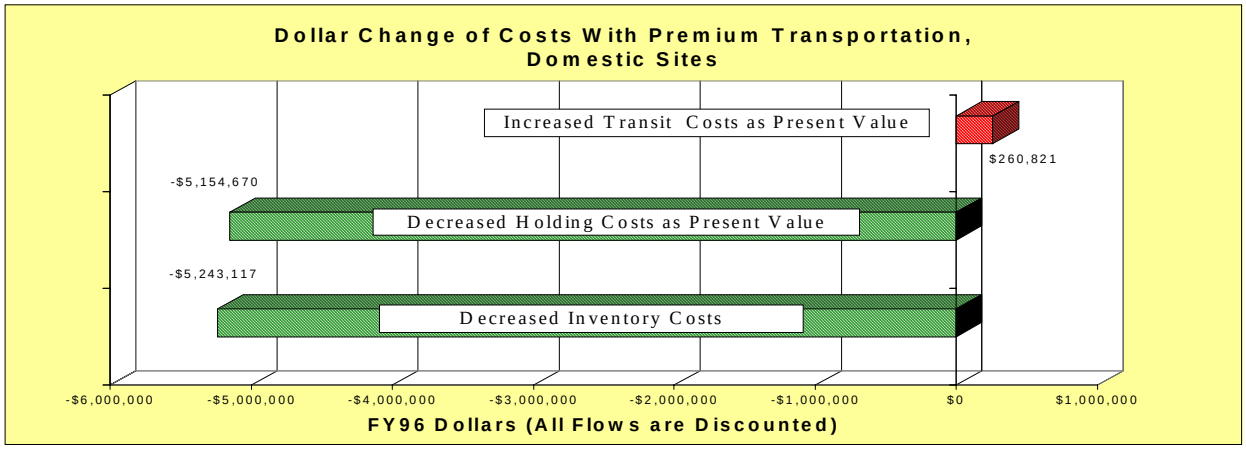


Figure 15: Absolute Dollar Change of Cost Elements

III.D Benefit to Cost Ratios

As discussed in the methods section, a benefit to cost ratio can provide substantial insight in understanding the relative impacts of changes in costs and the potentials of substitution. Taken as a group, the population's long term benefit to cost ratio is 20 to 1. These values are shown in the following graph.

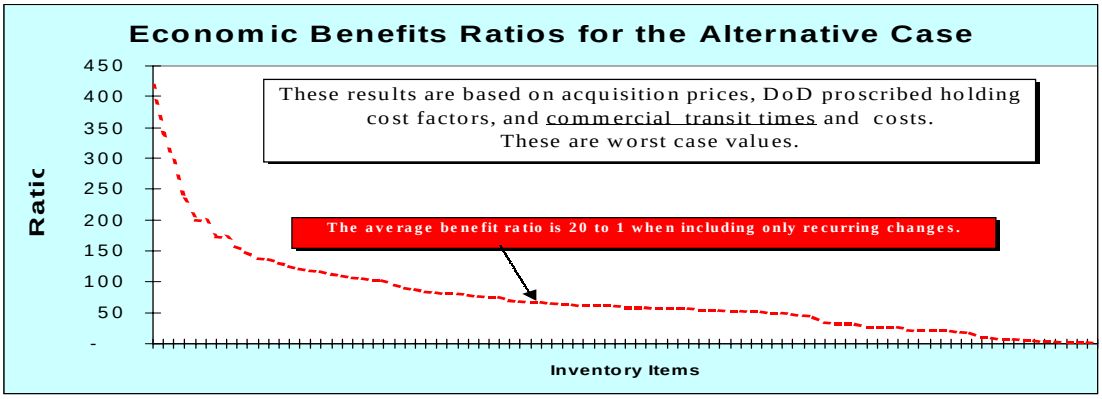


Figure 16: Benefit to Cost Ratios: Worst Case Alternative Numbers

The individual benefit to cost ratios vary from 100's to 1 down to 2 to 1. In all cases the ratio was positive. This result is in part due to the population selection of only high value parts with substantial demands. If low value parts were included in the analysis, it is most likely that the benefit ratios would be less than 1 to 1 – suggesting that next day transit for these items is not cost effective.

An alternative method to compute the benefit ratios uses prices computed as *net of refunds.* Under certain conditions, DoD has a policy of issuing refunds to organizations that turn in excess parts inventories. This policy is designed to reduce the occurrence of one group "dumping" an item while another group is procuring the same item. If prices are reduced to reflect the effect of refunds, then the benefit of inventory reductions is reduced.[22] Under this condition, less than 10 inventory items have benefit ratios less than 1 to 1. These items are all found on the far left of Figure 14 above. Under these pricing assumptions, it would not be cost effective to reduce inventory via reduced transit times for these parts.

[22] See Appendix: C: Price Adjustments for Refunds for additional discussion of this topic.

IV. Risk and Stockout Cost Analysis

The results of this analysis are clearly dependent upon the increased risk of stockout due to reduced inventory levels, and the potential effects of risk pooling and inventory shifts. The economic consequences of stockouts can be aggregated into general categories. The typical stockout risk category is operational – here the stockout itself leads to a loss of production or training with an economic loss to the military. A stockout has operational consequences if lack of a spare part leads to costs over and above the cost of obtaining a spare. The direct economic cost of a stockout has several sources:

- Extended downtime or reduced output leading directly to lost military training,
- Penalty clauses for late delivery,
- Cost of overtime to make up lost training or production,
- Lower process efficiency or higher raw material costs,
- Costs of swapping out unusable for working equipment,
- Costs of rescheduling effected training exercises,
- Costs of increased military and civilian personnel movement, and
- Poor product quality, leading to returns and rework.

All of these stockout costs could be born by the users (ultimately the U.S. taxpayer).

Stockouts can have economic consequences beyond the direct impacts noted above. For example, if the stockout of a safety-related item injures or kills military trainees or civilian maintenance personnel, then this is an increase in safety risk. The economic cost of this safety violation could be measured in direct costs (e.g., medical, lost wages, etc) and indirect costs (e.g., mental anguish, impact on defense preparedness). Stockouts can also be non-operational – that is, the effect of the stockout is limited to the cost of repair or the cost of obtaining a replacement part. This economic cost can be measured directly as the marginal costs incurred in any

unplanned repair or purchase. Lastly, there are stockouts that can have direct impacts on environmental standards or regulation. These costs can be measured as the direct costs of remediation and the indirect costs of additional oversight or cost transfers in the case of environmental externalities.

Inventory stocks have an essential purpose to insure that the various costs of stockouts detailed above are held to acceptable levels. To accommodate the risk of stockouts, inventory investments can be grouped into safety, normal cycle, excess and stockout costs. The following chart illustrates the roles played by each of these types of costs.

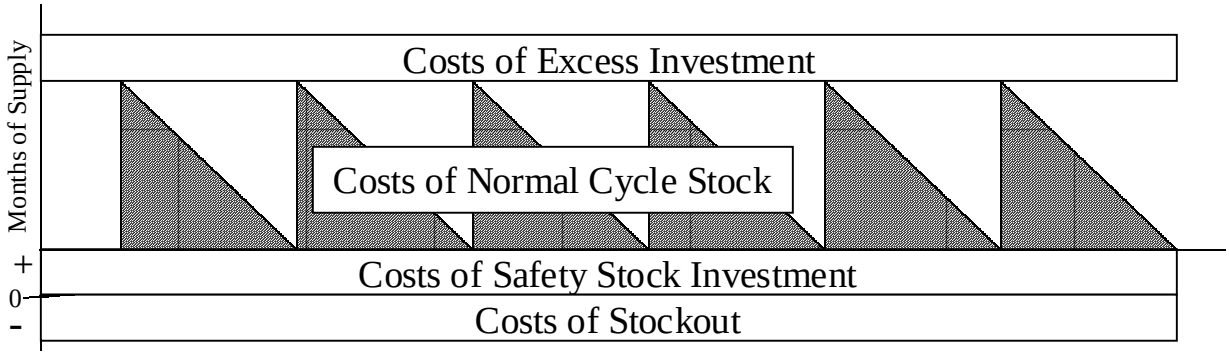


Figure 17: Inventory Investment

Risk is inherent with there is uncertainty in any of the timelines and "slopes" of these functions. For example, if the slope of the normal cycle stock were to increase do to unexpected demand, then safety stocks would be consumed leading to potential costs of stockouts. Similarly, an unanticipated change in the production lead time or an error the forecasts of any of these variables could lead to stockouts and economic losses.

To mitigate the impact of these various types of stockouts, inventory managers invest in inventory – essentially as an insurance premium in the face of uncertainty (risk). In broad terms, there are at least six elements of risk which are being managed by means of investments in inventory:

1. the risk of unforeseen changes in demand,
2. the order-frequency-driven risk of stock-outs,

3. the risk of unplanned changes remaining undetected,
4. the risk of an inability to respond to changes (length of lead-times),
5. the risk of unreliable replenishment, and
6. the performance risk attendant to high target service levels.

In the context of this case study, the risks from the first three elements above have been considered by assumption. That is, the variability in the baseline customer demand data is used as the variability in the new situation of reduced inventory investments. In essence, the customer demand patterns (with all of their variability) are assumed to be constant between the baseline and the alternative case with reduced inventories. This assumption was in fact critical to isolating the effects of changing inventory investments. If the variability of customer demand were not held constant[23], then the pure effect of reduced transit times would be clouded by other factors. Of course, there are several factors that influence demand dynamics such as competitor actives, new market entrants, customer volatility, seasonal and cyclical functions and macro economic events. The risk due to unplanned changes is assumed to decrease with a reduced pipeline to suppliers. As changes surface, they can be accommodated with less cost with a more responsive transportation service provider with a shorter transit cycle time.

Given the multiplicity of factors that could impact demand dynamics, however, the impacts of varying the customer demand rates is investigated through a Monte Carlo simulation. The system of equations (specified in Section II) are implemented in a collection of Excel spreadsheets (see Appendix E: Model Data) based on the specifics contained in Section II.B Parameter Values and Model Mechanics. The tool for conducting the Monte Carlo simulation on the model is @RISK by Palisade. The @RISK software integrates with the Excel model to provide a wide set of dynamic probability distribution functions. These dynamic functions are substituted for static

[23] Holding customer variability constant is not the same has setting it to zero. The variability in the actual demand data are preserved in the regime of reduced inventories. Holding demand variability constant, but not set to zero, allows for the effect of reduced inventories to be "drawn out" of the model.

input variables in the model. The dynamic functions generate random values for the model in accordance with the underlying distribution function selected by the user. For the case study, the most reasonable assumption for probability distribution functions was normal.

To examine the impact of risk, price was first considered a potential variable for the introduction of risk. The impact of risk can be felt by increasing the price of items in stockout situations when inventories were low. With lower inventories, demand pressure could increase price more so than if the inventory level were higher. The *differential* increase in price which could be attributed to reduced inventories (in the face of unexpected demand) is the object of the analysis. If the price were to go up (say due to a demand shock given the lower inventories), then there could be no *net* gain from substituting cheap transit for costly inventory[24].

When price variability is an input to the model via @RISK, negative net economic results as an output are indeed possible! Using price as a variable input, @RISK generated a range of prices sampled from a normal distribution with a variance equal to half the item price. The following figure shows the range of prices for the first inventory item in the sample.

[24] While increasing prices due to a demand shock is clearly possible, there are three practical restraints on price increases. First, any price increase would have to be associated with the *differential decrease* in inventory levels. For example, if a demand shock depleted *current* inventories, prices could increase by x. If that demand shock were to occur with *lower* inventories, the price increase would be y. The difference between y and x is the risk penalty from transportation and inventory substitution. Because the net difference in inventory levels is small (when counting all inventories of these items), changes in price are expected to be minimal. Second, there are substantial distributions of these high cost components in over 200 inventory storage locations. Each location has their own operating levels and safety levels in addition to national level stockpiles of these items. All of these inventories would have to be exhausted prior to startup of industrial production. This situation is imaginable only in case of extreme national emergency (i.e., full scale war). Thirdly, the sources of production for these costly components are typically DoD owned depot rebuild facilitates. The items in this study are not consumable items (i.e., green light bulbs). Rather, they are complex assemblies and components that are rebuilt many times during the lifetime of the weapon system which they support. Demand shocks could be absorbed by increasing depot rebuild programs. Due to overall reduction in military activity during the last 10 years, there is substantial excess capacity in DoD depot rebuild facilities. A substantial demand shock could increase prices on the factors of production at the depot, but the excess capacity mitigates this pressure.

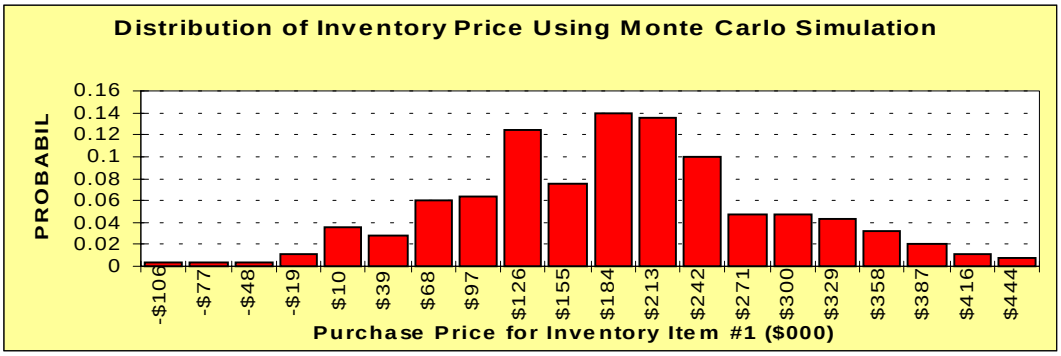


Figure 18: Input Distributions from Monte Carlo Simulation

The summary statistics for this inventory item are shown below.

Monte Carlo Statistics for Risk Analysis	Minimum	Mean	Maximum
Risk Driven Price for Inventory Item #1	-$211,447	$199,491	$471,677

The minimum price of –$221 is an artifact of the unbounded normal distribution function. In reality, there is no reason to suspect that the price would be negative. The mean price is the same price used in the baseline analysis and is based on a published catalogue of prices for these types of inventory items[25]. The maximum price is the upper value generated by @RISK. All of these values are the result of 250 iterations, if there had been more, then the overall shape of the distribution would have more closely approximated a typical bell curve.

Given a distribution of inputs to the model (i.e., price), the effected outputs are inventory savings via immediate reductions in investment requirements and longer term reductions in holding costs. If transportation substitution were a good idea, the investment change should be negative – which is a reduction in inventory investment. If price variability is considered, however, then there is a distinct possibility that the investment levels could actually increase. This case is clearly shown on the right hand side of the following figure.

[25] FED LOG: Federal Logistics Data on Compact Disc, Defense Logistics Services Center

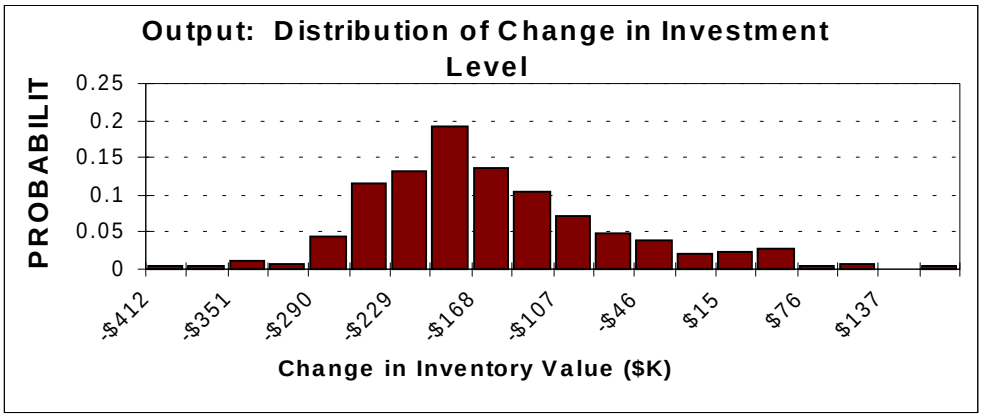


Figure 19: Output Distribution from Monte Carlo Simulation

As investment levels change, there is an associated change in holding costs. This cost is essentially a scalar of investment levels and the distribution of changes in holdings costs closely reflects the distribution of inventory changes.

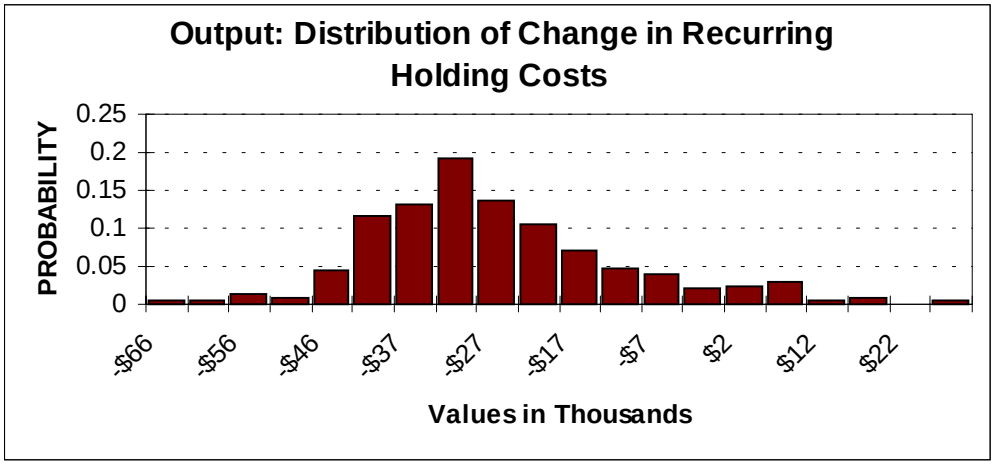


Figure 20: Output Distributions from Monte Carlo Simulation

As with the change in inventory values, an increase in holding costs suggests that there are conditions where substitution diseconomies exist. The complete outputs

of the Monte Carlo simulation are contained in Appendix F: Monte Carlo Simulation Output.

Risk Pooling

Risk pooling is an alternative technique that could be used with or independently of pipeline reduction to reduce inventory costs. While this analysis focused on the impacts of pipeline reduction, risk pooling is a legitimate approach to inventory reduction although the benefits are not quantified. Under the concept of risk pooling, consumers with independent demand patterns could agree to laterally redistribute inventory when one consumer experiences a demand shock which exceeded their inventory and safety levels. As a rule, warehouses in this study population exhibit independent demand patterns. Consequently, risk pooling is a clear possibility. Each consumer's training activity (which drives demand quantity) is typically independent of other consumers. An unexpected demand shock at one location will not typically effect the demand patterns at other locations due to the local nature of the demand shock.

Under this condition of independent demand patterns, pooling assets should allow the total asset investment to decrease with no immediately adverse impacts beyond increased transportation expenses. Pooling risk will allow customers to lower their own safety-level inventories as their stocks are joined into one virtual inventory for extraordinary demands. As customers lower their individual safety-level investments in response to increased stock availability, the total investment will decrease.

There are potential increasing costs do to risk pooling. The first cost is increased transportation costs. These costs have been estimated and documented in this study. The second cost may come from increased price pressure from large shocks that effect multiple sites and deplete the system's lower safety-stocks. Under this scenario, military customers follow a plan to use external stockpiles of contingency items. There are typically many sources of external contingency stocks. If a military consumer exhausted their own safety stocks they would then reach out to other inventory sites and "tap" their operating inventory. If the second site's operating inventory were depleted, the second site normally offers its own safety stock to the "out of stock"

consumer. This pattern could extend itself until all stocks are consumed. At that point, there are national-level inventories that are available to military consumers in the field when extraordinary situations arise. If national inventories are depleted, then industrial sources may be called into play. Under this condition, it is possible that a limited number of manufactures with near monopoly positions could extract price premiums from the consumers and push up prices. In this case, the benefit of reducing inventories would be reduced by any increase in price. If the price increase were sufficient, the net gain from substituting inventories with transportation could be negated. *In fact, under conditions of highly inelastic demand, potential price increases could more than offset any potential savings from inventory reduction.*

Inventory shifts from consumers to suppliers would have an effect of shifting the cost of inventory, but not reducing the total inventory costs. If inventory is shifted, it is likely that the costs will be passed back to the consumer in the form of higher prices as manufactures or intermediaries seek to recover increasing expenses. If the cost of holding inventory is higher at the manufacturer or intermediary than it is at the consumer level, then total costs would increase, offsetting any potential savings from consumer inventory reduction. *Under this condition of higher inventory holding costs, potential price increases due to inventory shifts could more than offset any potential savings.*

V. Analysis of Sensitivity

The results of the model are sensitive to changes in customer demand patterns, price changes, holding cost assumptions and transit times. A review of the demand data indicates that demand is very uniform over time. Army units follow regular sequential training cycles in the same environments during the same times. This standardized training helps to generate very stable demand patterns. Unit price data change only once a year and then usually only reflect changes in inflation. The transit times, however, for the base case are substantially variable. This existing variability has driven the current base case levels of safety stocks to require 5 days of additional stocks as "insurance" for unexpected changes in supply times. Arguably, the variability of FexEx is substantially lower than current carriers. The figure below shows the actual variability of supply times.

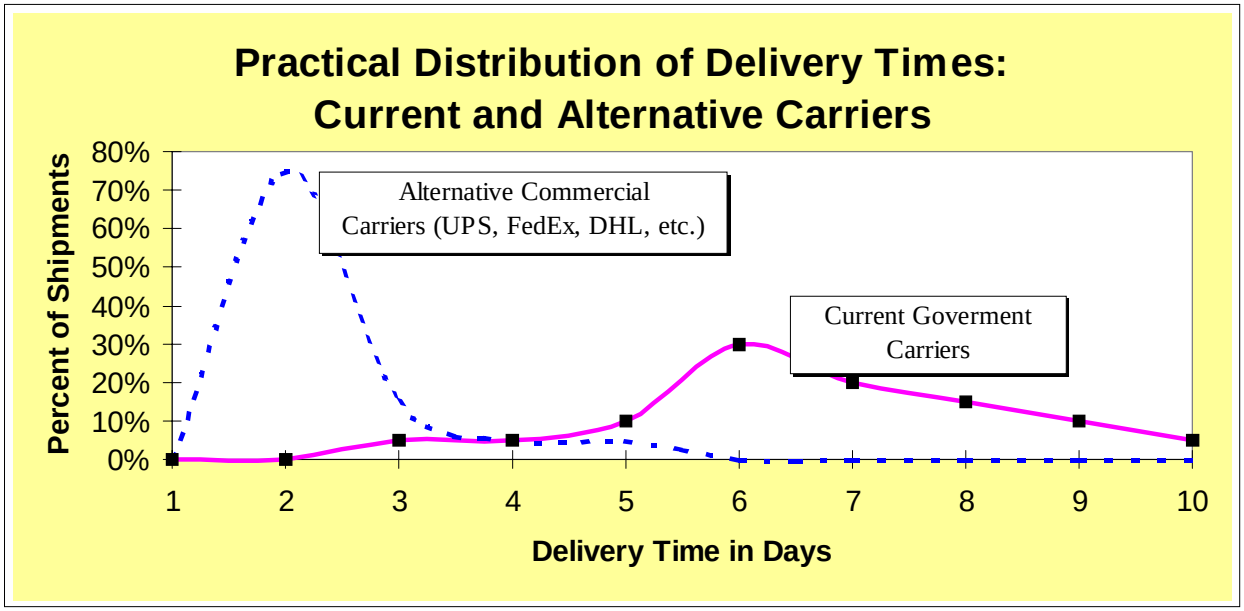


Figure 21: Practical Distribution of Delivery Times

Note that the mode value of the alternate carrier is 2 days. This study assumed a conservative 3 days (see Figure 1). The base case government carriers do not

guarantee delivery on a specific date, have no means to locate specific parts while en route, and have an anecdotal record which does not inspire confidence. Next-day commercial carriers, however, have built their entire business base addressing these limitations with clear success. Under a regime of commercial next-day carriers, the "risk premium" currently built into the system could be relaxed. This would further lower stocks and increase the return on investment, all other things being equal.

In any case, the risk of changing supply modes is mitigated by the type of items being demanded in the population. These items are required for routine, non-critical stockage replenishments. In no cases are these supplies directly related to readiness. These replacement supplies are ordered when stockage levels reach a predetermined ordering point. The actual consumer of the part is usually unaware of the replenishment supply action.

To derive a quantitative estimate of the impact of reducing the risk levels under the alternative case (2 days safety stock) from the base case (5 days safety stock), the model was re-run with the new safety stock levels. The results of this re-run were to increase the population group's benefit to cost flow ratio from 20 to 1 up toward 26 to 1. On a unitary basis, every one-day change in safety level stocks changes the cost to benefit ratios by 7 percent. The ratios increased a proportionate amount when the one-time inventory savings were excluded. Reducing the risk premium had the expected effect of further reducing stocks and the costs (i.e., investment, holding, transportation) associated with those stocks.

The last area of potential variability lies in the assumption of the holding cost factors. The source of these factors is documented in the methodology section and they are the factors currently proscribed for use in DoD inventory research. Nevertheless, it is useful to assess the degree to which the conclusions of this thesis are dependent upon the policy prescriptions.

To vary holding costs from their current 16% (policy level) requires a specific scenario of alternative assumptions. In the commercial retail sector, storage costs are

likely to be higher than the DoD level of 5% up to 25%-30% of inventory value[26]. Assuming the high-end value of 30%, and keeping the 10% cost of funds constant, an alternative total holding percent is 40%. Re-running the model with these higher holding costs increases the long-term benefits ratio to approximated 40 to 1. The net effect of using generally accepted commercial-based holding cost factors is to increase the apparent rate of return on utilization of next day carriers.

If a different federal funds rate were assumed from the 10% policy rate, a reasonable lower rate would be between 6% and 7% to reflect the current cost of federal borrowing. Using the commercial holding costs (30%) plus a lower borrowing cost, creates a new total holding cost of 37%. This rate is not materially different from the previous case (40%). The results are expected to be very similar.

An alternative excursion is to assess the impact of changes in next day carrier rates on the results of the analysis. If next day air rates increased due to (for example) an oil price shock which could lead to an increase in jet fuel (this was observed in the 1970's oil embargo), or consolidation of service providers moving towards monopoly pricing, the benefits would be reduced. As a quantitative measure, the model was re-run using double the expected next day air rates. As expected, the long term benefit ratio dropped from 11.6/1 down to 1/1. Even though the population total dropped to 1/1, there were still items with individual benefit ratios of over 10/1.

[26] Common Inventory Management Issues: Purchase and Storage of Commercially Available Parts and Equipment; http://www.tbs-sct.gc.ca:80/tb/materiel/invman/inmp07e.html.

When should airlines dispose of their aircraft spare parts inventories? by Thomas Donegan Executive Vice President Avatar Alliance; http://www.avatar1.com:80/sp_td01.htm

VI. Discussion

The benefit ratios presented in the previous section suggest that under certain conditions total costs can be lowered via the reduction of low priority requisition shipment times. There appears to be a favorable impact on risk due to reduced variability in shipment receipt times. These results do not appear to be substantially sensitive to reasonable changes in assumptions of factors or policy.

Interestingly, these gains will accrue if any segment of the low priority transit cycle time is reduced. If there were less costly ways to reduce the low priority shipment times, then the benefit ratios would actually be higher as the expenses are lowered. For example, a portion of the shipment time is due to installation and depot processing time. If this time segment were decreased at no material cost via change in policy or procedures, then benefits could accrue. For example, if orders for parts were received by suppliers within hours of being created by field units, and if the cost of electronic messaging were less than premium transportation, then the benefit ratios calculated in this study would be greater. Clearly, benefit ratios make a strong financial case for reducing inventory levels via increased transportation expenses.

There are caveats to these conclusions, however.

Automated inventory management systems adjust slowly to changes in ship time (OST).

In normal operations, these systems use an average OST based on the last 6 shipments. Consequently, inventory levels (RO_q) will not decrease over-night with the first shipment by commercial 2-day delivery service. The benefit ratios in this study assume immediate reduction of RO_q -- in fact, the RO_q will be reduced over time.

Human intervention can slow response to changes in transit time.

Some inventory managers may be hesitant to rely on the lower time level. Personnel in the field have ways to manually override inventory levels set by the

system. At some inventory sites, management personnel have set “minimums” or floor rates under which inventory levels may not be set, either by machine or man.

These practices all conspire to limit the immediate impact of reduced shipment time on inventories.

A related question is the applicability of commercial practices (use of next-day carriers) to a DoD environment. A RAND analysis offers the following insight:

“DoD distribution [personnel] believe industry approaches will not apply to DoD problems because industry faces very different problems and much lower volume. That lower volume, they argue, makes it easier to track items in the system. Industry does face different challenges, but in many ways its volume and problems compare with those of DoD. First, commercial enterprises are "at war" every day, albeit economic war. In an environment where attracting and retaining customers constitute victory, there are no respites. Second, individual companies process greater volume than the DoD does. During the height of the Persian Gulf War, DoD was processing 35,000 requisitions a day for the theater. The daily average for DoD in 1991 was 65,000. On an average day, United Parcel Service ships 11.5 million packages, and Federal Express moves 1.5 million. Of course, a single requisition could represent many packages, but in terms of tracking items in a system, the two are comparable.

Furthermore, many companies use a combination of their own system and commercial shipping companies to achieve highly responsive performance. They routinely guarantee overnight delivery in the United States. One large heavy-equipment manufacturer, for example, receives 78,000 parts requests a day, maintains a spare parts inventory of over 470,000 line items (some of which are identical to DoD parts) and guarantees 48-hour delivery in the United States or to an air or seaport, or the customer does not have to pay for the part. It meets the 48-hour standard 99.8 percent of the time.”[27]

This suggests that applications of commercial practices are appropriate to the movement of low priority non-mission critical inventory.

[27] Industry Distribution Practices, RAND Corp. John M. Halliday, Nancy Y. Moore

VII. Conclusions

The results of this analysis suggest that under normal circumstances, and given the test data, there appears to be the potential for reduction in total costs through transportation substitution. The insight here is that the inventory management systems look at time spent in shipment – the more time en route, the higher the associated inventory values – the lower time spend in route, the lower inventory levels. As long as the cost of transportation is low relative to the cost of inventory, large potential savings will exist. Focusing only on the parts identified in this analysis, substituting transportation for inventory could have positive economies.

Changes in assumptions did not appear to materially effect the outcome. This raises the confidence of the results. In fact, the basic results were based on the most conservative values for assumptions. The sensitivity analysis indicated that the 10 to 1 ratios of steady state benefits to costs are a minimum expected value.

Given the substantial improvement in reliability of ship times offered by next day air carriers, the risk is expected to decrease from its current level. Additionally, storage locations are able to laterally redistribute inventory in time of need. This further reduces risk. Lastly, risk is reduced by the nature of the items that would receive next day transit. This analysis excludes war reserve stocks, contingency stocks, and critical availability stocks.

At a minimum, the DoD should reduce shipment times via next day carriers and observe the effects on inventory and inventory holding costs on a test basis for high value parts identified in this analysis. Those effects could be observed through a limited test fielded to limited areas. Alternatively, a change in policy could be implemented to decrease shipment times for low priority inventory demands by increasing transportation expenditures for premium transportation. The results of this policy change should be easily measured in periodic inventory reports that contain data on inventory values and periodic transportation performance reports.

Appendix A. Data Sources

This section identifies the data sources used in this analysis.

1. Inventory Data

Data on inventory items used in this analysis were extracted from the Logistic Intelligence File (LIF). This database contains records of all world wide inventory requests from hundreds of inventory storage locations. For this file, initially, all low priority records from the continental United States, Europe and Korea were extracted from the database from October 93 to May 94. This data set was further analyzed to find the parts that represented the largest costs of all inventory items. From this analysis, the top 100 cost driving inventory parts were identified and extracted for used in this analysis. The benefit of using only the most expensive inventory items in this analysis were that the number of records were reduced substantially while preserving the high degree of cost coverage. Nine of the 100 cost driving parts were subsequently excluded due to data problems.

2. Price Data

Price information for each inventory item was extracted from the Army's price catalog called the Army Master Data File (AMDF). This database (available on CD-ROM) contains attribute data on each item in the study. Critical attribute data include price, description, source of supply, and weight. Price data for transportation came from published rate tables and telephone interviews.

3. Location Data

Location data for each field organization was extracted from the Depart of Defense Active Address File (DoDAAF). This database contains location and organizational hierarchy attributes. Critical attribute data include location and higher headquarters.

4. Credit Data

The value of credit was based on published credit rates created by the manager of secondary items for the Army in the Pentagon. These credit rates are expressed as percents of new price by type of commodity.

5. Baseline Transportation Data

Baseline transportation times were extracted from a database of average transportation times for low priority shipment of parts to various locations over time. This source is the Direct Support System Performance Evaluation Report. Critical attributes from this file were geographic location, priority and transportation time.

Appendix B. Critical Terms and Definitions

This section identifies the major terms and their definitions used in this analysis.

1. Transportation priority. This is a designation specifying the allowable elapsed time of transportation. Higher priority transportation reduces time in transit and costs relatively more than its lower priority counter part.

2. Requisition priority. This is a designation of the criticality of the item with respect to keeping the weapon system in an operational status. Requisitions with high priority have an immediate impact on readiness. Requisitions with low priority High requirement for additional inventory, with higher requirement priority having greater impact on readiness than its lower priority counter part. In this analysis, the focus is exclusively on low "priority" requirements.

3. Requirements Objective (RO). This is calculated in the legacy software by taking a simple average of the shipment time of the last six shipments and the average quantity demanded on each of the shipments.

4. Oh hand (OH). This value is calculated in the legacy software by summing the physical inventory plus the amount due in minus the quantity due out.

5. Excess Quantity. This quantity is calculated in the legacy software by taking the difference between On hand and Requirements Objective when the difference is positive (OH>RO)

6. Credit Rate. Credit is the value of funds received by a field unit from a parts supplier upon receipt of a retrograded part. For example, if the credit rate is 40% for aircraft components, then a field unit would receive $40 upon turnin of a $100 aircraft part.

7. Credit Adjusted Value. In general, all requisitions for low priority items are accompanied by a turnin of a "core" of the same type item. After receipt of credit, the effective cost of a $100 item is $60 ($100-$40=$60), assuming a %40 percent credit rate.

Appendix C. Adjusting Prices for Refunds

There are in practice two prices for parts inventory. The first price is the normal catalog price or list price. The second price is a price **net of refunds or credits**. Under certain conditions, DoD has a policy of issuing refunds to organizations that turn in excess parts inventories. This policy is designed to reduce the occurrence of one group "dumping" an item while another group is procuring the same item. The key to this policy is the granting of refunds or credits when excess inventory is returned to the central inventory manager. For example, if the desired level of inventory is reduced for any reason, then the inventory may have excess inventory. To encourage personnel to return excess inventory, a refund is offered for turn in. This management practice helps discourage the dumping of excess parts that are still in need elsewhere.

For example, an car battery has a list price. There is another effective price, however, if the purchaser has an old battery to turn in. The credit from the old battery is normally applied against the price of the new battery to create a new effective *lower* price. For the inventory items in this study, however, the excess items are like new and receive substantial credit value, approximately equal to half the original purchase price.

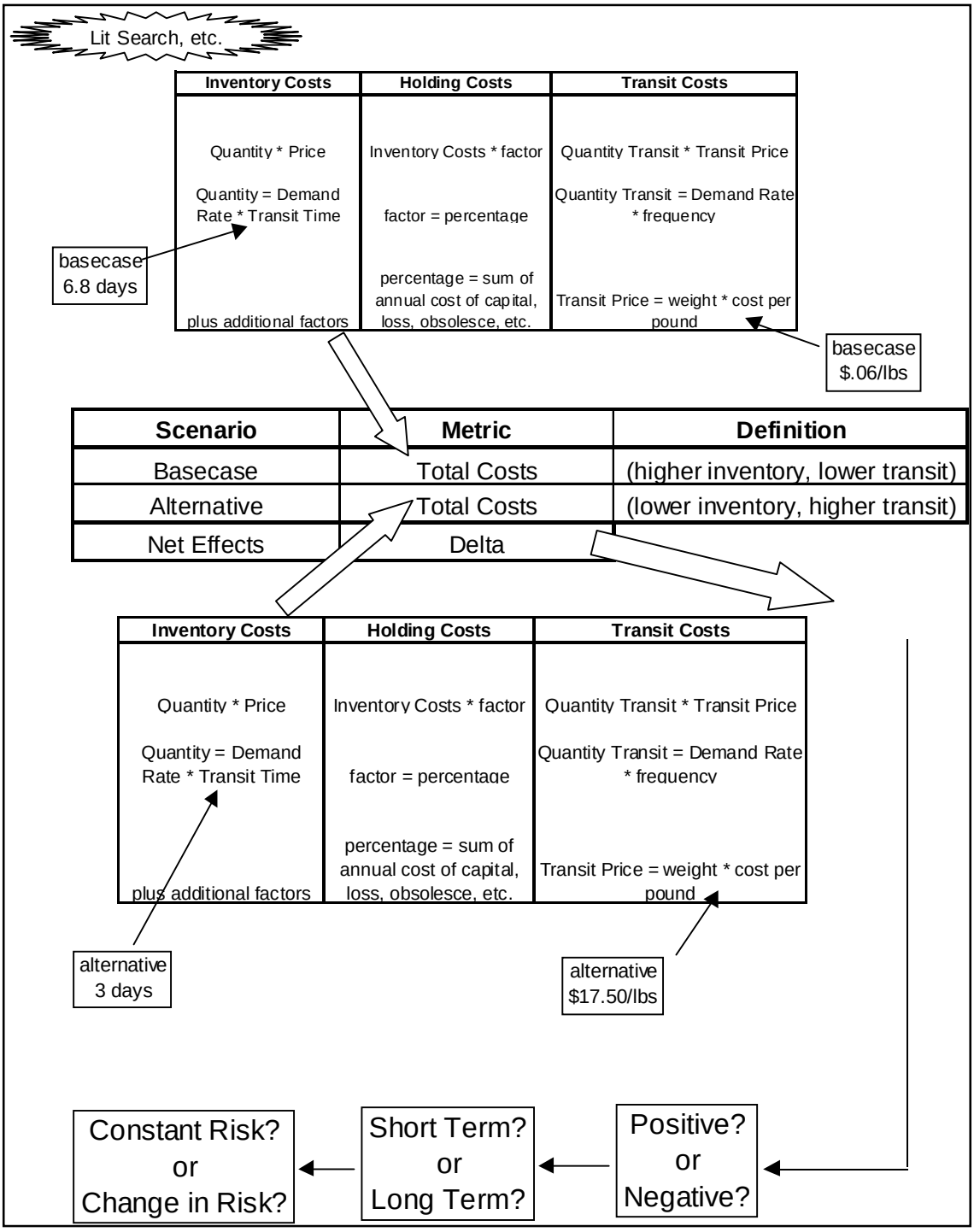
To figure the price net of turn-in credit, an average credit rate of 56 percent was assumed resulting in savings of 44 percent of the item's list price. Credit rates were determined in a recent study of actual credit rates as shown in the table below. Credit rates are based on six general types or categories of items. To calculate the average credit rate used in this analysis, the six values individual credit values were summed and then divided by 6.

Table 6 Credit Rates Used to Adjust Item Prices

Type of Part	*CREDIT RATE*
Ground Support Parts	0.578
Electronic Parts	0.477
Aviation Parts	0.588
Other Ground Support	NA
Tank/Automotive Parts	0.565
Missile Parts	0.607
Weapons Parts	0.55
Average:	0.5608

For this analysis, the value of the reduction in inventory is computed two ways: straight catalog price and the price net of refund. The effect of using credit-adjusted prices is to reduce the value of apparent savings for items with the lowest benefit ratios.

Appendix D. Methodology Overview



Appendix E: Model Data

A. Base Case Investments and Recurring Costs for all Domestic Inventory Sites

Item Part Number	Item Name	MRC92	Total Quantity Demanded During Sample Period	Average Shipment Days Intransit	Actual Average Daily Demand (ADD)	Safety Level Days	Safey Level Factor for Variability in Supply and Demand	Acquisition Price	ROq Total Inventory Level (OSTq + SLq)	Inventory Investment
1270013083019	TURRET,SENSOR-SIGHT	D	32	6.8	0.1	5	11%	$200,160	1.4	$277,590
1270011775497	TRANSCEIVER,UNIT	D	63	6.8	0.3	5	11%	$72,948	2.7	$199,173
1055012404957	STABL REF PKG SRP	D	47	6.8	0.2	5	11%	$153,607	2.0	$312,886
1260012936337	THERMAL IMAGING SEN	D	11	6.8	0.0452	5	11%	$287,676	0.5	$137,143
1240012939706	THERMAL RECEIVER WI	D	78	6.8	0.3	5	11%	$87,191	3.4	$294,743
6675011828813	INERTIAL MEASUREMEN	D	16	6.8	0.1	5	11%	$159,460	0.7	$110,573
5855013283540	IMAGE INTENSIFIER,N	D	862	6.8	3.5	5	11%	$2,666	37.4	$99,597
5855011514191	IMAGE INTENSIFIER,N	D	760	6.8	3.1	5	11%	$3,013	32.9	$99,241
5855012329440	NIGHT SENSOR ASSEMB	D	11	6.8	0.0	5	11%	$184,046	0.5	$87,740
1270011873439	OPTICAL RELAY COLUM	D	25	6.8	0.1	5	11%	$80,333	1.1	$87,038
6605011613919	ATTITUDE HEADING	D	25	6.8	0.1	5	11%	$73,582	1.1	$79,724
1650011431226	SERVO ASSY,PRIMARY	D	59	6.8	0.2	5	11%	$31,830	2.6	$81,389
5999012326667	ELECTRONIC COMPONEN	D	60	6.8	0.2	5	11%	$26,771	2.6	$69,613
2840010304890	ENGINE,AIRCRAFT,TUR	D	8	6.8	0.0	5	11%	$610,167	0.3	$211,551
1430011349344	NORTH SEEKING GYRO	D	16	6.8	0.1	5	11%	$99,491	0.7	$68,989
1240012326568	DAY SENSOR SUBASSEM	D	11	6.8	0.0	5	11%	$139,917	0.5	$66,702
5865011218982	RECEIVER-TRANSMITTE	D	9	6.8	0.0	5	11%	$174,336	0.4	$68,000
1270012656947	COMPUTER UNIT,FIRE	D	14	6.8	0.1	5	11%	$107,202	0.6	$65,044
6625011637135	INDICATOR,DIGITAL D	D	45	6.8	0.2	5	11%	$33,202	2.0	$64,752
7021011197180	COMPUTER,DIGITAL	D	39	6.8	0.2	5	11%	$36,289	1.7	$61,336
1270011992049	TELEVISION SENSOR A	D	33	6.8	0.1	5	11%	$41,441	1.4	$59,268
1440006253702	AMPLIFIER,STABILIZE	D	37	6.8	0.2	5	11%	$35,431	1.6	$56,815
1440012717428	SIGHT,OPTICAL,GUIDE	D	42	6.8	0.2	5	11%	$31,145	1.8	$56,691
5855012590151	RECEIVER,INFRARED	D	7	6.8	0.0	5	11%	$184,046	0.3	$55,834
1240012736038	DETECTOR COOLER ASS	D	68	6.8	0.3	5	11%	$17,716	2.9	$52,210
1430012914763	THERMAL IMAGING SYS	D	11	6.8	0.0	5	11%	$105,194	0.5	$50,149
5841012459091	RECEIVER-TRANSMITTE	D	104	6.8	0.4	5	11%	$10,788	4.5	$48,624
5855012280942	IMAGE INTENSIFIER,N	D	402	6.8	1.7	5	11%	$2,776	17.4	$48,364
1240010965151	INTEGRATED SIGHT AS	D	28	6.8	0.1	5	11%	$199,776	1.2	$242,426
1055012701360	HOIST ASSEMBLY	D	67	6.8	0.3	5	11%	$18,510	2.9	$53,747
1270012269932	SIGHT,HEADS-UP	D	18	6.8	0.1	5	11%	$58,824	0.8	$45,889
5811011875789	MULTIPLEXER-POWER S	D	22	6.8	0.1	5	11%	$46,897	1.0	$44,714
1270013079447	TURRET,SENSOR-SIGHT	D	50	6.8	0.2	5	11%	$186,096	2.2	$403,259
1270013310006	TURRET,SENSOR-SIGHT	D	5	6.8	0.0	5	11%	$186,096	0.2	$40,326
5865013234999	TRANSMITTER,COUNTER	D	34	6.8	0.1	5	11%	$27,330	1.5	$40,271
5998013069002	ELECTRONIC COMPONEN	D	8	6.8	0.0	5	11%	$115,031	0.3	$39,882
5998013342630	ELECTRONIC COMPONEN	D	9	6.8	0.0	5	11%	$100,903	0.4	$39,357
5855011127725	BASIC SIGHT ASSY	D	16	6.8	0.1	5	11%	$55,050	0.7	$38,173
6130012326666	POWER SUPPLY SUBASS	D	38	6.8	0.2	5	11%	$21,862	1.6	$36,004
1240012461872	IMAGE CONTROL UNIT	F	44	6.8	0.2	5	11%	$17,954	1.9	$34,237
4931013013226	ELECTRONIC UNIT,LAS	D	17	6.8	0.1	5	11%	$48,533	0.7	$35,757
1055013008212	ELECTRONICS UNIT	D	7	6.8	0.0	5	11%	$117,264	0.3	$35,575
1430012604963	EXCITER GROUP	D	4	6.8	0.0	5	11%	$208,110	0.2	$36,077
1270011429546	RANGE FINDER-TARGET	D	19	6.8	0.1	5	11%	$41,725	0.8	$34,358
1270011716187	RECEIVER UNIT	D	25	6.8	0.1	5	11%	$32,263	1.1	$34,956
2840010131339	ENGINE,AIRCRAFT,TUR	D	11	6.8	0.0	5	11%	$134,087	0.5	$63,923
6130006253744	POWER SUPPLY	D	8	6.8	0.0	5	11%	$99,036	0.3	$34,337
3010013724157	DRIVE UNIT,ANGLE	D	20	6.8	0.1	5	11%	$37,709	0.9	$32,685
7025012631815	MULTIPLEXER,DIGITAL	D	28	6.8	0.1	5	11%	$28,348	1.2	$34,400
1615013159365	TRANSMISSION,MECHAN	D	4	6.8	0.0	5	11%	$202,655	0.2	$35,131
5855010343845	IMAGE INTENSIFIER,N	D	601	6.8	2.5	5	11%	$1,274	26.0	$33,183
1615010146006	TRANSMISSION	D	7	6.8	0.0	5	11%	$140,419	0.3	$42,599
5826012123265	VISUAL RELAY MULTIP	D	24	6.8	0.1	5	11%	$30,229	1.0	$31,442
1260011205364	TRANSCEIVER ASSEMBL	D	11	6.8	0.0	5	11%	$65,199	0.5	$31,082
1240012166331	INTEGRATED SIGHT AS	D	42	6.8	0.2	5	11%	$132,891	1.8	$241,892
1650012166000	SERVOCYLINDER	D	84	6.8	0.3	5	11%	$8,639	3.6	$31,450
1430010855520	VISUAL MODULE ASSEM	D	23	6.8	0.1	5	11%	$29,684	1.0	$29,589
5995011868601	WIRING HARNESS,BRAN	D	102	6.8	0.4	5	11%	$6,846	4.4	$30,263
1240013396326	VISUAL MODULE ASSEM	D	32	6.8	0.1	5	11%	$21,999	1.4	$30,509
2910012937131	FUEL CONTROL,MAIN,T	D	121	6.8	0.5	5	11%	$12,247	5.2	$64,223
4730013261804	MANIFOLD,HYDRAULIC	D	15	6.8	0.1	5	11%	$44,290	0.7	$28,792

B. Estimated Inventory Values Using Rapid Transportation

Assumed Transportion Days with Fed Ex/Emory Air	Actual Average Daily Demand (ADD)	Safety Level Days	Safey Level Factor for Variability in Supply and Demand	ROq Total Inventory Level (OSTq + SLq)	Inventory Values with Risk Driven Prices w/@RISK	Investment Level same price	Annual Recurring Holding Cost Factor	Recurring Annual Holding Costs	Holding Costs with Risk Driven Prices w/@RISK
3	0.1	5	11%	0.6	$122,466	$122,466	16%	$19,594.61	$19,594.61
3	0.3	5	11%	1.2	$87,871	$87,871	16%	$14,059.29	$14,059.29
3	0.2	5	11%	0.9	$138,038	$138,038	16%	$22,086.06	$22,086.06
3	0.0	5	11%	0.2	$60,504	$60,504	16%	$9,680.68	$9,680.68
3	0.3	5	11%	1.5	$130,034	$130,034	16%	$20,805.38	$20,805.38
3	0.1	5	11%	0.3	$48,782	$48,782	16%	$7,805.15	$7,805.15
3	3.5	5	11%	16.5	$43,940	$43,940	16%	$7,030.35	$7,030.35
3	3.1	5	11%	14.5	$43,783	$43,783	16%	$7,005.23	$7,005.23
3	0.0	5	11%	0.2	$38,709	$38,709	16%	$6,193.39	$6,193.39
3	0.1	5	11%	0.5	$38,399	$38,399	16%	$6,143.89	$6,143.89
3	0.1	5	11%	0.5	$35,172	$35,172	16%	$5,627.57	$5,627.57
3	0.2	5	11%	1.1	$35,907	$35,907	16%	$5,745.11	$5,745.11
3	0.2	5	11%	1.1	$30,712	$30,712	16%	$4,913.89	$4,913.89
3	0.0	5	11%	0.2	$93,331	$93,331	16%	$14,933.03	$14,933.03
3	0.1	5	11%	0.3	$30,436	$30,436	16%	$4,869.82	$4,869.82
3	0.0	5	11%	0.2	$29,427	$29,427	16%	$4,708.39	$4,708.39
3	0.0	5	11%	0.2	$30,000	$30,000	16%	$4,799.97	$4,799.97
3	0.1	5	11%	0.3	$28,696	$28,696	16%	$4,591.35	$4,591.35
3	0.2	5	11%	0.9	$28,567	$28,567	16%	$4,570.74	$4,570.74
3	0.2	5	11%	0.7	$27,060	$27,060	16%	$4,329.61	$4,329.61
3	0.1	5	11%	0.6	$26,148	$26,148	16%	$4,183.63	$4,183.63
3	0.2	5	11%	0.7	$25,065	$25,065	16%	$4,010.46	$4,010.46
3	0.2	5	11%	0.8	$25,011	$25,011	16%	$4,001.72	$4,001.72
3	0.0	5	11%	0.1	$24,633	$24,633	16%	$3,941.25	$3,941.25
3	0.3	5	11%	1.3	$23,034	$23,034	16%	$3,685.39	$3,685.39
3	0.0	5	11%	0.2	$22,124	$22,124	16%	$3,539.92	$3,539.92
3	0.4	5	11%	2.0	$21,452	$21,452	16%	$3,432.29	$3,432.29
3	1.7	5	11%	7.7	$21,337	$21,337	16%	$3,413.93	$3,413.93
3	0.1	5	11%	0.5	$106,952	$106,952	16%	$17,112.39	$17,112.39
3	0.3	5	11%	1.3	$23,712	$23,712	16%	$3,793.94	$3,793.94
3	0.1	5	11%	0.3	$20,245	$20,245	16%	$3,239.19	$3,239.19
3	0.1	5	11%	0.4	$19,727	$19,727	16%	$3,156.29	$3,156.29
3	0.2	5	11%	1.0	$177,908	$177,908	16%	$28,465.34	$28,465.34
3	0.0	5	11%	0.1	$17,791	$17,791	16%	$2,846.53	$2,846.53
3	0.1	5	11%	0.7	$17,767	$17,767	16%	$2,842.68	$2,842.68
3	0.0	5	11%	0.2	$17,595	$17,595	16%	$2,815.23	$2,815.23
3	0.0	5	11%	0.2	$17,363	$17,363	16%	$2,778.15	$2,778.15
3	0.1	5	11%	0.3	$16,841	$16,841	16%	$2,694.55	$2,694.55
3	0.2	5	11%	0.7	$15,884	$15,884	16%	$2,541.46	$2,541.46
3	0.2	5	11%	0.8	$15,104	$15,104	16%	$2,416.70	$2,416.70
3	0.1	5	11%	0.3	$15,775	$15,775	16%	$2,524.04	$2,524.04
3	0.0	5	11%	0.1	$15,695	$15,695	16%	$2,511.15	$2,511.15
3	0.0	5	11%	0.1	$15,916	$15,916	16%	$2,546.61	$2,546.61
3	0.1	5	11%	0.4	$15,158	$15,158	16%	$2,425.27	$2,425.27
3	0.1	5	11%	0.5	$15,422	$15,422	16%	$2,467.48	$2,467.48
3	0.0	5	11%	0.2	$28,201	$28,201	16%	$4,512.20	$4,512.20
3	0.0	5	11%	0.2	$15,149	$15,149	16%	$2,423.78	$2,423.78
3	0.1	5	11%	0.4	$14,420	$14,420	16%	$2,307.20	$2,307.20
3	0.1	5	11%	0.5	$15,176	$15,176	16%	$2,428.23	$2,428.23
3	0.0	5	11%	0.1	$15,499	$15,499	16%	$2,479.86	$2,479.86
3	2.5	5	11%	11.5	$14,640	$14,640	16%	$2,342.36	$2,342.36
3	0.0	5	11%	0.1	$18,794	$18,794	16%	$3,007.00	$3,007.00
3	0.1	5	11%	0.5	$13,872	$13,872	16%	$2,219.45	$2,219.45
3	0.0	5	11%	0.2	$13,713	$13,713	16%	$2,194.03	$2,194.03
3	0.2	5	11%	0.8	$106,717	$106,717	16%	$17,074.74	$17,074.74
3	0.3	5	11%	1.6	$13,875	$13,875	16%	$2,220.00	$2,220.00
3	0.1	5	11%	0.4	$13,054	$13,054	16%	$2,088.62	$2,088.62
3	0.4	5	11%	2.0	$13,351	$13,351	16%	$2,136.22	$2,136.22
3	0.1	5	11%	0.6	$13,460	$13,460	16%	$2,153.59	$2,153.59
3	0.5	5	11%	2.3	$28,334	$28,334	16%	$4,533.40	$4,533.40
3	0.1	5	11%	0.3	$12,702	$12,702	16%	$2,032.39	$2,032.39

C. Net Changes in Inventory Investment and Holding Costs Due to Changes in Ship Times

Change inTransportion Days with Fed Ex/Emory Air	Change in Average Daily Demand (ADD)	Change in Safety Level Days	Change in Safey Level Factor for Variability in Supply and Demand	Change in Inventory Quantity Due to Change in Transit Time	Change in Investment Level	Change in Recurring Holding Costs
-3.8	0	0	0	-0.8	($155,124)	($24,820)
-3.8	0	0	0	-1.5	($111,303)	($17,808)
-3.8	0	0	0	-1.1	($174,848)	($27,976)
-3.8	0	0	0	-0.3	($76,639)	($12,262)
-3.8	0	0	0	-1.9	($164,709)	($26,353)
-3.8	0	0	0	-0.4	($61,791)	($9,887)
-3.8	0	0	0	-20.9	($55,657)	($8,905)
-3.8	0	0	0	-18.4	($55,458)	($8,873)
-3.8	0	0	0	-0.3	($49,031)	($7,845)
-3.8	0	0	0	-0.6	($48,639)	($7,782)
-3.8	0	0	0	-0.6	($44,552)	($7,128)
-3.8	0	0	0	-1.4	($45,482)	($7,277)
-3.8	0	0	0	-1.5	($38,902)	($6,224)
-3.8	0	0	0	-0.2	($118,220)	($18,915)
-3.8	0	0	0	-0.4	($38,553)	($6,168)
-3.8	0	0	0	-0.3	($37,275)	($5,964)
-3.8	0	0	0	-0.2	($38,000)	($6,080)
-3.8	0	0	0	-0.3	($36,348)	($5,816)
-3.8	0	0	0	-1.1	($36,185)	($5,790)
-3.8	0	0	0	-0.9	($34,276)	($5,484)
-3.8	0	0	0	-0.8	($33,120)	($5,299)
-3.8	0	0	0	-0.9	($31,749)	($5,080)
-3.8	0	0	0	-1.0	($31,680)	($5,069)
-3.8	0	0	0	-0.2	($31,202)	($4,992)
-3.8	0	0	0	-1.6	($29,176)	($4,668)
-3.8	0	0	0	-0.3	($28,024)	($4,484)
-3.8	0	0	0	-2.5	($27,172)	($4,348)
-3.8	0	0	0	-9.7	($27,027)	($4,324)
-3.8	0	0	0	-0.7	($135,473)	($21,676)
-3.8	0	0	0	-1.6	($30,035)	($4,806)
-3.8	0	0	0	-0.4	($25,644)	($4,103)
-3.8	0	0	0	-0.5	($24,987)	($3,998)
-3.8	0	0	0	-1.2	($225,351)	($36,056)
-3.8	0	0	0	-0.1	($22,535)	($3,606)
-3.8	0	0	0	-0.8	($22,505)	($3,601)
-3.8	0	0	0	-0.2	($22,287)	($3,566)
-3.8	0	0	0	-0.2	($21,994)	($3,519)
-3.8	0	0	0	-0.4	($21,332)	($3,413)
-3.8	0	0	0	-0.9	($20,120)	($3,219)
-3.8	0	0	0	-1.1	($19,132)	($3,061)
-3.8	0	0	0	-0.4	($19,982)	($3,197)
-3.8	0	0	0	-0.2	($19,880)	($3,181)
-3.8	0	0	0	-0.1	($20,161)	($3,226)
-3.8	0	0	0	-0.5	($19,200)	($3,072)
-3.8	0	0	0	-0.6	($19,534)	($3,125)
-3.8	0	0	0	-0.3	($35,722)	($5,715)
-3.8	0	0	0	-0.2	($19,188)	($3,070)
-3.8	0	0	0	-0.5	($18,265)	($2,922)
-3.8	0	0	0	-0.7	($19,223)	($3,076)
-3.8	0	0	0	-0.1	($19,632)	($3,141)
-3.8	0	0	0	-14.6	($18,544)	($2,967)
-3.8	0	0	0	-0.2	($23,805)	($3,809)
-3.8	0	0	0	-0.6	($17,571)	($2,811)
-3.8	0	0	0	-0.3	($17,369)	($2,779)
-3.8	0	0	0	-1.0	($135,175)	($21,628)
-3.8	0	0	0	-2.0	($17,575)	($2,812)
-3.8	0	0	0	-0.6	($16,535)	($2,646)
-3.8	0	0	0	-2.5	($16,912)	($2,706)
-3.8	0	0	0	-0.8	($17,049)	($2,728)
-3.8	0	0	0	-2.9	($35,889)	($5,742)
-3.8	0	0	0	-0.4	($16,090)	($2,574)

D. Net Change in Transportation Costs Between Current and Fed Ex/Emory Air

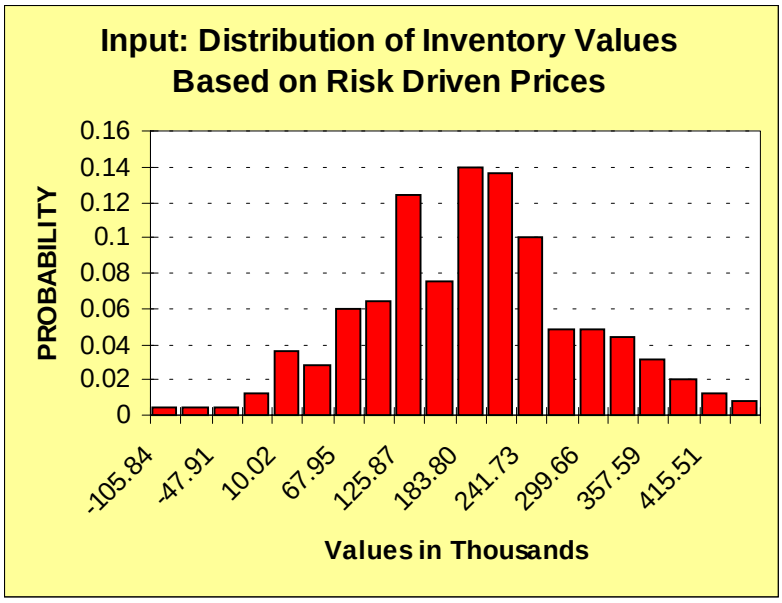
		New Transit Data			Current Transit Costs	
UNIT WEIGHTS (LBS.)	Total Weight for Transit per Transit Day	New Cost per Lbs Based on Carrier's Rate Tables	Minimum or ActualTotal Transit Costs for New Carriers Per Day	New Transit Total Costs for All Transit Days	Current Cost per Lbs for Existing Transit Carriers per Day	Current Total Transit Costs Per Day
127.10	16.72	$1.32	$22.08	$66.23	$0.06	$1.00
57.00	14.77	$1.32	$19.49	$58.47	$0.06	$0.89
137.90	26.65	$1.32	$35.18	$105.53	$0.06	$1.60
1.00	0.05	$1.32	$17.50	$52.50	$0.06	$0.00
115.50	37.04	$1.32	$48.90	$146.69	$0.06	$2.22
105.00	6.91	$1.32	$17.50	$52.50	$0.06	$0.41
1.00	3.54	$1.32	$17.50	$52.50	$0.06	$0.21
1.00	3.13	$1.32	$17.50	$52.50	$0.06	$0.19
154.30	6.98	$1.32	$17.50	$52.50	$0.06	$0.42
143.00	14.70	$1.32	$19.40	$58.21	$0.06	$0.88
32.30	3.32	$1.32	$17.50	$52.50	$0.06	$0.20
61.30	14.87	$1.32	$19.63	$58.89	$0.06	$0.89
50.50	12.46	$1.32	$17.50	$52.50	$0.06	$0.75
1,280.00	42.11	$1.32	$55.58	$166.74	$0.06	$2.53
65.00	4.28	$1.32	$17.50	$52.50	$0.06	$0.26
139.80	6.32	$1.32	$17.50	$52.50	$0.06	$0.38
48.00	1.78	$1.32	$17.50	$52.50	$0.06	$0.11
43.00	2.48	$1.32	$17.50	$52.50	$0.06	$0.15
1.00	0.19	$1.32	$17.50	$52.50	$0.06	$0.01
22.00	3.53	$1.32	$17.50	$52.50	$0.06	$0.21
47.50	6.45	$1.32	$17.50	$52.50	$0.06	$0.39
57.50	8.75	$1.32	$17.50	$52.50	$0.06	$0.52
80.00	13.82	$1.32	$18.24	$54.71	$0.06	$0.83
23.40	0.67	$1.32	$17.50	$52.50	$0.06	$0.04
8.40	2.35	$1.32	$17.50	$52.50	$0.06	$0.14
98.00	4.43	$1.32	$17.50	$52.50	$0.06	$0.27
9.50	4.06	$1.32	$17.50	$52.50	$0.06	$0.24
1.00	1.65	$1.32	$17.50	$52.50	$0.06	$0.10
647.00	74.49	$1.32	$98.33	$294.98	$0.06	$4.47
60.00	16.53	$1.32	$21.82	$65.46	$0.06	$0.99
22.50	1.67	$1.32	$17.50	$52.50	$0.06	$0.10
28.00	2.53	$1.32	$17.50	$52.50	$0.06	$0.15
645.00	132.61	$1.32	$175.04	$525.12	$0.06	$7.96
645.00	13.26	$1.32	$17.50	$52.51	$0.06	$0.80
31.50	4.40	$1.32	$17.50	$52.50	$0.06	$0.26
62.00	2.04	$1.32	$17.50	$52.50	$0.06	$0.12
62.00	2.29	$1.32	$17.50	$52.50	$0.06	$0.14
65.00	4.28	$1.32	$17.50	$52.50	$0.06	$0.26
56.40	8.81	$1.32	$17.50	$52.50	$0.06	$0.53
54.00	9.77	$1.32	$17.50	$52.50	$0.06	$0.59
62.30	4.35	$1.32	$17.50	$52.50	$0.06	$0.26
163.60	4.71	$1.32	$17.50	$52.50	$0.06	$0.28
118.70	1.95	$1.32	$17.50	$52.50	$0.06	$0.12
100.20	7.83	$1.32	$17.50	$52.50	$0.06	$0.47
49.50	5.09	$1.32	$17.50	$52.50	$0.06	$0.31
600.00	27.14	$1.32	$35.82	$107.47	$0.06	$1.63
48.50	1.60	$1.32	$17.50	$52.50	$0.06	$0.10
90.10	7.41	$1.32	$17.50	$52.50	$0.06	$0.44
1.00	0.12	$1.32	$17.50	$52.50	$0.06	$0.01
925.00	15.21	$1.32	$20.08	$60.25	$0.06	$0.91
1.00	2.47	$1.32	$17.50	$52.50	$0.06	$0.15
650.00	18.71	$1.32	$24.70	$74.09	$0.06	$1.12
39.00	3.85	$1.32	$17.50	$52.50	$0.06	$0.23
82.70	3.74	$1.32	$17.50	$52.50	$0.06	$0.22
647.00	111.74	$1.32	$147.49	$442.47	$0.06	$6.70
4.40	1.52	$1.32	$17.50	$52.50	$0.06	$0.09
71.00	6.71	$1.32	$17.50	$52.50	$0.06	$0.40
5.00	2.10	$1.32	$17.50	$52.50	$0.06	$0.13
1.00	0.13	$1.32	$17.50	$52.50	$0.06	$0.01
63.00	31.34	$1.32	$41.37	$124.12	$0.06	$1.88
83.00	5.12	$1.32	$17.50	$52.50	$0.06	$0.31

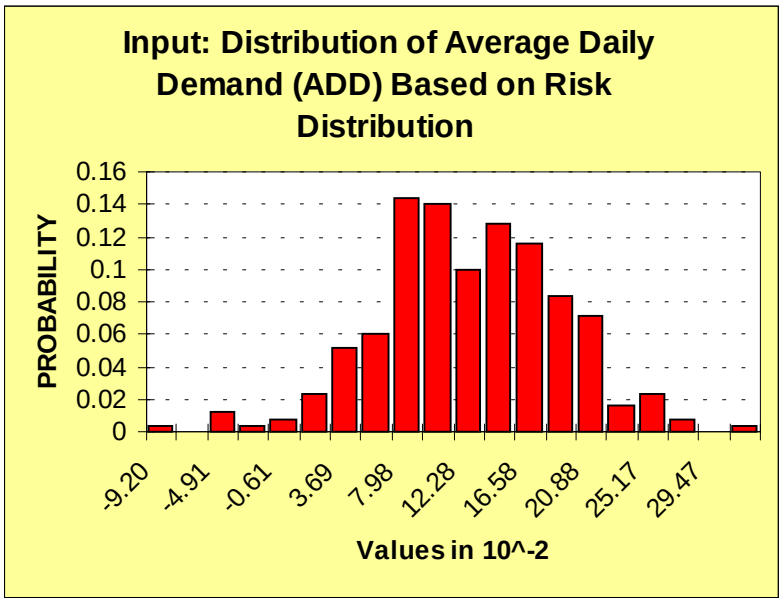
E. Analysis of Return on Investment

One Time Change in Investment Value	Annual Change in Transit Costs	Annual Change in Recurring Holding Costs	Present Value of Change in Transit Costs @ 10%/10 Years	Present Value of Change in Recurring Holding Costs @ 10%/10 Years	Total Costs Ratio (Inventory Windfall+(PV)Holding Costs) over (PV)Transit Cost
($155,124)	$59.4	($24,819.8)	$365.0	($152,507.2)	843
($111,303)	$52.4	($17,808.4)	$322.3	($109,425.1)	685
($174,848)	$94.7	($27,975.7)	$581.7	($171,898.4)	596
($76,639)	$52.5	($12,262.2)	$322.5	($75,345.8)	471
($164,709)	$131.6	($26,353.5)	$808.5	($161,930.7)	404
($61,791)	$49.7	($9,886.5)	$305.3	($60,748.4)	401
($55,657)	$51.1	($8,905.1)	$313.7	($54,718.0)	352
($55,458)	$51.2	($8,873.3)	$314.8	($54,522.5)	349
($49,031)	$49.7	($7,845.0)	$305.1	($48,203.9)	319
($48,639)	$52.2	($7,782.3)	$320.8	($47,818.6)	301
($44,552)	$51.1	($7,128.3)	$314.3	($43,800.0)	281
($45,482)	$52.8	($7,277.1)	$324.6	($44,714.8)	278
($38,902)	$47.4	($6,224.3)	$291.4	($38,245.4)	265
($118,220)	$149.6	($18,915.2)	$919.0	($116,225.6)	255
($38,553)	$50.8	($6,168.4)	$311.9	($37,902.4)	245
($37,275)	$49.9	($5,964.0)	$306.7	($36,646.0)	241
($38,000)	$51.8	($6,080.0)	$318.1	($37,358.8)	237
($36,348)	$51.5	($5,815.7)	$316.4	($35,735.0)	228
($36,185)	$52.4	($5,789.6)	$322.1	($35,574.6)	223
($34,276)	$51.1	($5,484.2)	$313.7	($33,697.9)	217
($33,120)	$49.9	($5,299.3)	$306.4	($32,561.7)	214
($31,749)	$48.9	($5,079.9)	$300.7	($31,213.9)	209
($31,680)	$49.1	($5,068.8)	$301.5	($31,145.9)	208
($31,202)	$52.2	($4,992.2)	$320.9	($30,675.2)	193
($29,176)	$51.5	($4,668.2)	$316.7	($28,683.9)	183
($28,024)	$50.7	($4,483.9)	$311.5	($27,551.6)	178
($27,172)	$50.8	($4,347.6)	$312.4	($26,713.9)	172
($27,027)	$51.8	($4,324.3)	$318.4	($26,571.0)	168
($135,473)	$264.6	($21,675.7)	$1,625.8	($133,187.8)	165
($30,035)	$58.7	($4,805.7)	$360.8	($29,528.7)	165
($25,644)	$51.8	($4,103.0)	$318.4	($25,211.0)	160
($24,987)	$51.5	($3,998.0)	$316.2	($24,565.8)	157
($225,351)	$471.0	($36,056.1)	$2,894.2	($221,549.1)	154
($22,535)	$47.1	($3,605.6)	$289.4	($22,154.9)	154
($22,505)	$50.7	($3,600.7)	$311.5	($22,124.9)	143
($22,287)	$51.7	($3,566.0)	$317.5	($21,911.3)	139
($21,994)	$51.6	($3,519.0)	$316.8	($21,622.7)	138
($21,332)	$50.8	($3,413.1)	$311.9	($20,972.0)	136
($20,120)	$48.9	($3,219.2)	$300.5	($19,780.5)	133
($19,132)	$48.5	($3,061.2)	$298.1	($18,809.5)	127
($19,982)	$50.7	($3,197.1)	$311.7	($19,644.9)	127
($19,880)	$50.6	($3,180.8)	$310.8	($19,544.6)	127
($20,161)	$51.7	($3,225.7)	$317.7	($19,820.6)	126
($19,200)	$49.3	($3,072.0)	$303.0	($18,876.1)	126
($19,534)	$50.4	($3,125.5)	$309.8	($19,204.7)	125
($35,722)	$96.4	($5,715.5)	$592.3	($35,119.0)	120
($19,188)	$51.8	($3,070.1)	$318.6	($18,864.5)	119
($18,265)	$49.5	($2,922.4)	$304.0	($17,957.2)	119
($19,223)	$52.5	($3,075.8)	$322.3	($18,899.2)	118
($19,632)	$54.0	($3,141.2)	$332.0	($19,301.0)	117
($18,544)	$51.5	($2,967.0)	$316.4	($18,230.8)	116
($23,805)	$66.5	($3,808.9)	$408.3	($23,403.8)	116
($17,571)	$50.9	($2,811.3)	$312.9	($17,274.2)	111
($17,369)	$51.0	($2,779.1)	$313.2	($17,076.4)	110
($135,175)	$396.9	($21,628.0)	$2,438.7	($132,894.8)	110
($17,575)	$51.9	($2,812.0)	$318.8	($17,278.5)	109
($16,535)	$49.8	($2,645.6)	$305.8	($16,256.0)	107
($16,912)	$51.6	($2,705.9)	$317.3	($16,626.5)	106
($17,049)	$52.4	($2,727.9)	$322.3	($16,761.6)	105
($35,889)	$111.3	($5,742.3)	$684.1	($35,284.0)	104
($16,090)	$50.4	($2,574.4)	$309.8	($15,818.3)	103

Appendix F: Monte Carlo Simulation Output

Input Simulations





Output Simulations