C-130J Inventory Control Point Location Determination

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Abstract

Since the first C-130J delivery in 1999, Lockheed Martin has managed the USAF's C-130J "peculiar" parts inventory at Keesler AFB. Now with 193 aircraft assigned to 17 operating locations across the globe, effective supply chain management and recognized cost savings are essential components to mission success and fleet longevity. Previous research within the area of location analysis has shown that minimizing the average weighted distance of shipping products can assist in cost reduction efforts. Due to this, the goal of this study is to determine if alternative CONUS C-130J locations can be utilized as the Inventory Control Point to help reduce total transportation costs for the fleet's "peculiar" spares inventory. Using the 2017 FedEx Service Guide in conjunction with five years of historical shipping data, five alternative C-130J bases were evaluated in order to identify which of the locations could offer transportation cost savings. Additionally, inventory/personnel relocation and new infrastructure costs were collected to project pay-off periods for capital investment. Based on this analysis, Little Rock AFB is the only C-130J CONUS operating location which would reduce the total transportation costs. In conclusion, this research can drive cost effective warehousing prior to staging aircraft and establishing the full supply chain structure.

To my amazingly supportive and loving wife and puppies, my parents, and finally my Dodgeball/Basketball/Softball/Inspiration Coach, Lank the Tank.

Acknowledgments

I would like to give thanks to my advisor, William A. Cunningham, PhD, for the guidance and constant support he gave me as I worked my way through AFIT. I also want to thank the C-130J Logistics and Production Development Office for their support throughout this endeavor. Finally, to my classmates, I had so much fun and learned a lot from all of you. I hope to cross paths again someday as we make our Air Force even better.

Joshua P. Casey

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I. Introduction

Background

On 12 September 2016, the C-130J Product Support Business Case Analysis (PS BCA) was published with the purpose of outlining six alternatives for long-term sustainment strategy. The problem statement for the C-130J PS BCA is "The C-130J Product Support BCA will determine the best value alternative long-term sustainment strategy for the C-130J peculiar items consistent with Air Force objectives." The alternatives evaluated the best mix of Government and Contractor Logistics Support (CLS) in 4 categorical areas: Program Management/Product Support Integration, Sustaining Engineering, Supply Support, and Depot Maintenance. The BCA concluded that the United States Air Force (USAF) should continue to utilize CLS for its supply support function. The recommendation was based on the highest weighted score of the following scoring criteria: benefit score, cost, identified risks, and aircraft availability rates (*C-130J PS BCA Final Report V2*, 2016). The study did not consider alternative locations for the C-130J Inventory Control Point, but rather held that variable constant. The C-130J Logistics Development and Production office, located at Wright Patterson Air Force Base (WPAFB), Ohio explicitly listed this as an area of interest, which resulted in this study.

The Warehouse-Location problem has long been applied in operations and logistics research. The same principles that have been applied to civilian agencies and Fortune 500 companies can be applied to the U.S. military as a whole. Specific to USAF, logistics professionals rely on an efficient and expansive supply chain network to meet military commanders' needs during times of war, peace, disaster relief, and other essential missions. Cost effective and timely delivery of spare and repairable parts is what allows our Air Force to function effectively in today's operational environment. According to Lockheed Martin, more than 330 C-130Js are on order or have been delivered to 16 different countries, meaning the C-130J supply chain is an expansive network.

Currently, the USAF's C-130J fleet receives spare parts from several locations across the continental U.S., but parts classified as "C-130J peculiar" parts are located at Keesler AFB, Mississippi. Lockheed Martin currently stores and manages C-130J peculiar parts at the Keesler AFB Inventory Control Point This location was chosen for the aircraft in 1999 since it was the first base to field the aircraft, but there are now 193 aircraft assigned to 16 different USAF operational installations across the globe.

Problem Statement

Currently, the U.S. Air Force has a contract with Lockheed Martin to store and manage initial spares that are specific to the C-130J model at Keesler Air Force Base, Mississippi. Decision makers need to know if Keesler AFB is still the most cost-effective location for the C-130J Inventory Control Point (ICP) with respect to transportation expenses.

Research Question

In order to address the previously mentioned problem statement, the following question was formulated: With respect to C-130J "peculiar parts" transportation expenses, what other Continental United States (CONUS) C-130J operating locations can offer realized spare part transportation cost savings? The following questions will further enhance the researcher's findings:

IQ1: What are the associated costs to ship the parts unique to the C-130J?

IQ2: What are the costs to relocate inventory/personnel to the candidate sites and build new infrastructure to meet warehousing needs?

IQ3: What is the projected payoff period of the candidate sites which project cost savings?

Methodology

The methodology will be quantitative in nature and be comprised of four stages. First, five years of historical data will be collected for all C-130J peculiar parts that were shipped back to Keesler AFB by the respective C-130J locations. Next, associated mileage and FedEx rates will be used to develop cost estimations for all parts shipped from 5 alternative locations, using Keesler AFB as the baseline, to all CONUS C-130J bases. Additionally, existing infrastructure data will need to be collected in order to conduct a cost comparison across the alternative locations. If infrastructure to support the C-130J peculiar parts storage needs does not exist, cost estimates for new construction will be collected. In conjunctions with infrastructure estimates, one-time shipment calculations will need to be determined for the entirety of the warehouse stock at Keesler AFB in order to project the pay-off period of relocation efforts.

Data

The data required for analysis will be provided by the C-130J Logistics and Production Development Office at Wright-Patterson AFB, OH. Only Keesler AFB inbound data (unserviceable parts shipped from operational locations to the ICP) is available for analysis. Additionally, published FedEx rates will be used to set baseline costs for all items shipped (weight and mileage shipped being the inputs for varying shipping estimates).

Assumptions/Limitations

In order to formulate the model, a snapshot of data will be needed in order to develop an optimal solution. The projected solution will be a multi-year operation, meaning cost data and available resources are subject to change. The overarching assumption of this study is that cost data and available resources will remain relatively constant. Below is a more detailed listing of additional assumptions for this research.

- C-130J peculiar parts will be the only consideration points for this research
- Since only inbound data is available, it will be assumed that a one-for-one swap will occur between serviceable and unserviceable parts at Keesler AFB
- Lockheed Martin will be able to manage the ICP at the proposed C-130J candidate sites
- The USAF will continue to utilize General Services Administration (GSA) approved carriers to ship C-130J peculiar parts
    - FedEx Express and Freight rates will be used to baseline the cost estimation since roughly 60% of items were shipped via FedEx.
- Only the published FedEx 2017 Service Guide was available for shipping cost determination; therefore, no discounts/government rates were used.

Implications

Based on this study, leaders will able to determine the optimal minimum-cost location for the C-130J ICP. With the fleet of C-130Js still expected to grow until FY2020 (*C-130J PS BCA Final Report V2*, 2016), it is vitally important that costs are continuously reduced while the aircraft continue to move towards ideal operating efficiencies. Although the ICP may be transferred to organic government management, the location will still be optimal if the same shipment methods are utilized. Additionally, the C-130H has several modifications/upgrades scheduled according to the C-130J Logistics and Production Development Office. With that, the C-130J and C-130H may share similar parts that are currently labeled as “C-130J peculiar” and decision makers may be able to utilize warehouse space in the future for both variants of the C-130.

Warehouse location determination is not a new methodology; however, the USAF sparingly applies the criterion that has been outlined in the respective literature. In 1999, the first C-130Js were produced and delivered to the USAF showing that aircraft production is a multi-year effort, often spanning several decades (*C-130J PS BCA Final Report V2*, 2016). This research effort seeks to fill the gap in how the USAF determines its ICP location for new aircraft acquisition, using the C-130J as a baseline study.

Preview

Chapter I provides the background and justification for this research topic. Location analysis is an important research area in the fields of operations research and industrial engineering. Like the private sector, the U.S. military needs to cut costs and improve efficiencies where able. Determining the optimal C-130J ICP can lead to drastic cost cuts, improved customer service, and more efficient supply chain flow. This research will provide decision maker’s with the ability to determine where the C-130 ICP should be located for future operations.

Chapter II presents the background of the C-130J supply chain management strategy in conjunction with the Lockheed-Martin management of the ICP. Additionally, the chapter will examine previous research in location analysis and transportations problems. Several techniques and lessons learned within the area of research will be presented.

Chapter III outlines the methodology for the research problem. It will frame the data collection process, data pre-processing, and model selection that best fits the problem at hand. Several alternative models will be used and compared for optimization.

Chapter IV will discuss the results of the alternative locations with transportation costs, infrastructure needs, and inventory relocation costs being the basis for comparison

Chapter V will provide conclusions, recommendations, and proposed areas of future research. Additionally, recommended model changes will be discuss to further enhance the model’s performance and accuracy.

II. Literature Review

This chapter provides an overview of the C-130J supply chain strategy determination and the history of the C-130J warehouse site selection criteria. Furthermore, research in the area of location analysis is reviewed in order to develop a methodology for the presented problem.

C-130J Business Case Analysis

The C-130J was first declared Initial Operating Capability (IOC) in October 2006, and then Full Operational Capability (FOC) was declared in August of 2013 when Dyess Air Force Base, Texas received its final aircraft delivery. To date, C-130Js are still being produced and scheduled for final delivery for the United States Air Force in FY2020. The Air Force currently has a Long-Term Sustainment contract with Lockheed Martin Aeronautics for all C-130J peculiar parts, which is the focus area of this study.

In September of 2016, the Military Deputy, Office of the Assistant Secretary of the Air Force for Acquisitions approved the C-130J Product Support Business Case Analysis. The intent of the BCA was to determine "the best value alternative long-term sustainment strategy for the C-130J peculiar items consistent with the Air Force objectives." At the time the case was published, the C-130J was positioned at 14 operating locations worldwide and was expected to increase to twenty locations by FY20. The evaluation focused on the four primary areas of product sustainment: Program Management/Product Support Integration (PM/PSI), Sustaining Engineering (SE), Supply Support (SS), and Depot Maintenance (DM). With these established focus areas, six alternatives were developed with full contractor managed support set as the baseline(*C-130J PS BCA Final Report V2*, 2016). Table 1 outlines the six alternatives with "Ktr" being defined as Contractor Logistics Support (CLS) and "Government" being defined as organic military management.

Table 1. Alternative Management Options (*C-130J PS BCA Final Report V2*, 2016)

Alternatives	Program Management / Product Support Integration (PM/PSI)	Sustaining Engineering	Supply Support	Depot Maintenance
1 (Baseline)	Ktr	Ktr	Ktr	Ktr
2	Government	Ktr	Ktr	Government
3	Government	Ktr	Government	Government
4	Government	Government	Ktr	Government
5	Government	Government	Government	Government
6	Government	Ktr	Ktr	Ktr
7	Government	Government	Government	Ktr

Although the baseline has PM/PSI listed as a CLS function, the ground rules established prior to the evaluation stated that function will strictly be a Government managed function.

The case identified several assumptions prior to conducting the evaluation; therefore, these same assumptions will be used for the analysis portion of this study. With the established assumptions, four areas were analyzed and applied to the four categories: cost, risk, Aircraft Availability, and performance metrics. The latest long term sustainment contract is a bridge contract signed in February of 2017. The contract contains four 1-year options and, if at any time, the Government wishes to manage the supply function organically, the Government can refrain from using Contractor Logistics Support.

In order to evaluate the benefits (performance) metrics, the PS BCA utilized Multi-Objective Decision Analysis (MODA). Subject matter experts (SME) assessed the subjective metrics and in turn, graded weights were used to formulate stakeholder assessments. The point scale is as follows: the stakeholders allocated 100 points among the 3 work streams (DM, SS, and SE) in order of importance. Thus, the work stream a stakeholder considered most important received the most points and the least important received the least points. This process was repeated for the metrics within each of the work streams; a total of 4 votes per Stakeholder. Finally, the votes were averaged to calculate the local weights, which was each metric's relative importance to the metrics within the same work stream.

Global weights were then applied to the three functions being analyzed: Depot Maintenance, Supply Support, and Sustaining Engineering. As stated before, the Program Management/Product Support Integration piece was only evaluated for the baseline alternative. Additionally, the scores were normalized so that the respective scores could be compared to contractor options. Next, total costs were calculated for each alternative. Table 2 shows the combined benefit scores, total cost, ID'd Risk, and aircraft availability change. Given the detailed analysis, it was determined that Alternative 4 was the best option currently for the USAF (*C-130J PS BCA Final Report V2*, 2016).

Table 2. Alternative Management Options (*C-130J PS BCA Final Report V2*, 2016)

Alternative	PM/PSI	Sustaining Engineering	Supply Support	Depot Maintenance	Benefit	Cost (PV $M)	ID'd Risk	Availability Change
1 (Baseline)	Ktr	Ktr	Ktr	Ktr	0.715	$4,740	N/A	0%
2	Government	Ktr	Ktr	Government	0.712	$3,180	N/A	0%
3	Government	Ktr	Government	Government	0.666	$3,093	Yes	-2.7%
4	Government	Government	Ktr	Government	0.702	$3,035	N/A	0%
5	Government	Government	Government	Government	0.656	$2,949	Yes	-2.7%
6	Government	Ktr	Ktr	Ktr	0.715	$4,174	N/A	0%
7	Government	Government	Government	Ktr	0.659	$4,313	Yes	-2.7%

History of Location Analysis

By no means is location analysis a new area of research. For centuries, military leaders and managers in retail have been concerned with where to place resources in order to meet demand, minimize response time, and save money. Retail giants want to meet all customer demands while minimizing cost which will often lead to profit maximization. Also, emergency and first responders need to ensure 100% coverage while also minimizing the total number of resource sites. Moreover, military leaders want to position warfighting assets that meet the defense needs of their country and other partner nations. With minimizing distance, minimizing response time, minimizing cost, maximizing profit, or maximizing customer service as decision factors, one can see how location analysis has its place in operations research and supply chain management.

With restricted government budgets, the USAF has to find areas in which cost reductions can be identified. With optimal location analysis, cost minimization is imperative while still meeting certain demand times and other constraints. This research seeks to use location analysis as the basis for the literature search and methodology development. Several approaches and applications of location analysis will be discussed to further enhance the research findings.

Early Location Modeling

Alfred Weber has been credited as one of the contributing authors/researchers in the field of location analysis. Frierdrich (1929) first published Weber's work, appropriately titled, "*Alfred Weber's Theory of Location Analysis*"; however, Weber formally began research in 1909 when he considered where to position a single warehouse (Owen & Daskin, 1998). Weber focused on minimization of total transportation costs across all supply and demand sites within a transportation network by positioning production centers or warehouses optimally. Several limitations exist within Weber's approach, but it still is used as a baseline by those conducting location analysis research. Weber used linear production as the basis for cost determination; therefore quantity discounts due to economies of scale were not applicable. Additionally, his research was scoped to single objective, single source, homogenous products across the transportation network (Tellier, 1972). With those assumptions, cost minimization leads to profit maximization for a firm. In theory, finding the minimum transportation costs was equivalent to finding equilibrium points of a system of forces within a two-dimensional space (Tellier, 1972). Although this will not work for many complex transportation networks operational today, it is applicable to this research topic.

Alfred Weber's geographical approach held for several decades until the emergence of computer software that could handle larger scale transportation problems. Boumal and Wolfe conducted one of the first studies for a large organization that rented public warehouse space to meet its storage needs, due in part to the software emergence. The study primarily focused on changing demand and supply nodes with growth of companies (Baumol & Wolfe, 1958). Given the U.S. Air Force is in the business of national defense, varying warehouse locations may not be an option for the service; however, the principles still apply. Given that, several of the assumptions the authors established apply to the given C-130J warehouse location problem, primarily the need for 100% of demand be met, and warehouse capacity constraints. With that, strategic facility location and location analysis have flourished in both the private and public sectors leading to a vast number of analytical techniques and heuristics (Owen & Daskin, 1998).

Current Location Analysis

Through the evolution of technology and processing capabilities, many more types of location models have been able to be solved. Ozsen, et al. (2008) outline four taxonomies within location modeling/analysis theory: analytical models, continuous models, network models, and discrete models. Analytical Models are the simplest form since they assume that demand is known and uniformly distributed. These assumptions often limit the usefulness of the model for decision making purposes. Next, continuous models model demand points at discrete points within a transportation network. This type of model is closely related to Weber's theory as previously discussed. The third taxonomy is network models. This modeling technique assumes demands will arise and facilities or production sites can be located anywhere on the link between the nodes (demand/source sites) and links (travel path). The warehouses can be located anywhere within the plane which is useful if warehouse location is fluid and/or rented. The last model outlined is the discrete modeling. Within this type, a distance metric is established with a finite set of candidate locations. Also known as a set-covering problem, it is often used when determining where to position emergency services/first responders (Ozsen et al., 2008).

Discrete Modeling is the most applicable to this research topic. The authors further further broke down discrete models into 3 sub-categories: Covering-based Models, Median-base Models, and "Other Models". Covering models can minimize total number of sites needed to cover all demands, maximize the number of covered demands with a set number of sites, and can also minimize the distance needed to cover all demand with a set number of sites. Median-base models can minimize the average distance between demands and the nearest set sites and can minimize fixed facility and transport costs. Within the "other" category, he covers the P-dispersion problem, which maximizes the minimum distance between a pair of facilities in order to prevent customers from having to choose between multiple source sites.

Capacitated v. Uncapacitated Warehouse

In order to meet demands across a transportation network, inventory has to be present at the production site or within the warehouse. Warehouse capacity is often a constraint within supply chains; however, it may not be viable or cost effective to build/acquire new warehouse space. Daskin first introduced the uncapacitated facility location/network design problem (UFLNDP) with the underlying assumption that it may be more cost effective to expand warehouse capacity versus finding additional warehouse space (Melkote & Daskin, 2001). Tradeoffs between building warehouses, expanding space, and transportation costs must be made in order to provide the optimal, cost effective warehouse site. Within the UFLNDP, it is assumed that the facilities will serve an infinite amount of demand; however, within the C-130J supply network, demand sites are held constant while the aircraft fleet size is projected to cease expansion in FY2020. The issue with UFLNDP is that most networks have existing constraints which will prevent infinite demand on a specific node.

Building onto the UFLNDP, Daskin introduced a variant called, the capacitated facility location problem (CFLP) in which the capacity is measured at a given warehouse and used as a constraint for the integer programming model. Four assumptions were established prior to model formulation: each node represents a demand point, facilities may only be located at given nodes, only one facility may be located at each node, and the network is a customer-to-server system in which the demands travel to the facilities. Several iterations of the CFLP model have been tested and developed with added constraints and additional variables. One example is the capacitated warehouse location model with risk pooling (CLMRP), which incorporates inventory policies associated with the CFLP. The overall objective of CLMRP is to minimize the fixed facilities sites while still minimizing inventory and carrying costs, making it a multi-objective integer program (Ozsen et al., 2008). For the purpose of this research, inventory polices will not be included, but it shows that several considerations factors can be present with warehouse location determination.

P-Median Problem

Hakimi (1964) first introduced the P-median problem when discussing the optimal location of switching centers among a transportation network which contain weighted demands. Certain weights are attached to the vertices and branches which results in the "geographic" optimal location for a switching center. As mentioned previously, several models exist under the discrete location models outlined by Daskin. Within the median-based models is the P-Median problem which seeks to minimize the average distance between the demand and set number of sites, P. In theory, the smaller the average distance, the more accessible the system is to the users (Church & ReVelle, 1976). Church and ReVelle go on to explain that the approach of minimizing the average total distance is equivalent to an objective of minimizing total weighted travel distance. Within the C-130J supply chain, the number of aircraft varies by base; therefore leading to the applicability of total weighted travel distance. It is assumed that varying number of aircraft will lead to varying numbers of part demand data (more aircraft = higher demand).

Warehouse Location Determination

Redesigning a warehouse or transportation network can take serious capital investment and thoughtful thinking among subject matter experts and decision makers. Warehouses will serve a number of objectives to include: reduction of transportation costs through quantity discounts, reduction of delivery costs by combining commodities, and improving customer satisfaction through delivery time reduction (Kuehn & Hamburger, 1963). The goal of most re-warehousing and modernization ventures is to phase out underutilized or redundant warehouses within a given supply chain (Melachrinoudis & Min, 2007). Changing a warehouse network can offer potential cost savings for an organization, but delays and/or decline in lead times/service rates may occur. Additionally, learning curve delays must be accounted for when a supply network significantly changes. Furthermore, if investments are made, it must be used for an extended period of time to offer a payback period. Procurement and development of new facilities is often cost and time-sensitive; therefore, facility capacities must be determined for current and future operations (Owen & Daskin, 1998).

Inventory management and placement is key to any large corporation's success within a competitive market and the USAF is no different. Although the goal may not be to maximize profits, or minimize costs, the USAF still wants to be the world's premier Air Force. When designing its supply chain, the USAF is most concerned with defending the nation through agile combat support; however, minimizing costs while doing so should be a major consideration factor since the budget comes from American taxpayers. Model accuracy and data reliability tend to be an area of concern when you have a dynamically changing environment (Tsao & Lu, 2012). Due to this, Tsao and Lu outlined a two phased approach to transportation discounts: quantity discounts and distance discounts. Applicable to this problem are the distance discounts which could be recognized through warehouse relocation.

As mentioned in Chapter 1, Keesler AFB was chosen as the ICP location since it was the first operating location for the C-130J, but with the demand sites changing, the issue needs to be addressed. Transportation costs will vary with distance, given fuel and labor are major functions of distance. Additionally, there will be some fixed and variable cost within transportation cost estimation (Tsao & Lu, 2012); therefore, the goal should be to minimize or even eliminate those variable costs associated with distance.

Warehouse Relocation

The concept of warehouse location determination and warehouse relocation is not central to a specific industry sector. Although most research has been conducted within the commercial sector, the military can recognize significant cost savings/avoidance by applying those techniques that Fortune 500 companies have proven to be useful.

In the early 1980's, Lockheed Martin faced a managerial dilemma when trying to determine whether it would relocate or modernize one of its office supply and stationary goods warehouses. Goods from this warehouse were used by more than 24,000 of its employees on a daily basis. The company compared four alternatives: status quo; same location, but modernized warehouse; relocated warehouse, but using same operating procedure; relocated and modernizing. Site surveys, observation, measurement of facilities, and pricing on new MMHE equipment and/or required upgrade equipment were used to evaluate the alternatives. Specific to costs, the company applied mixed integer programming to compare facility and utility costs, operating costs, transportation costs. This same method can be applied to any military relocation effort considerations (Economides & Fok, 1984). Air Freight Forwarders at the Hong Kong International Airport faced a similar situation in the mid-1990s due to increased air cargo throughput. In order to alleviate some of the air traffic, a new airport was built further outside the city. The air freight forwarders analyzed the advantages and disadvantages of warehouse relocation and focused primarily on response time, customer service levels, and transportation expenses. Quantitative measures of rental cost, parking facilities, accessibility, time spent by customers, cost spent by customers, time from warehouse to operating location, cost from location to warehouse, customer preference were all used to help the managers make a cost effective, yet customer focused decision (Wan, Cheung, Liu, & Tong, 1998).

Cargo Movement Directives/Information

USTRANSCOM/USAF Regulations

The Defense Transportation Regulation, Part II (Cargo Movement), published by USTRANSCOM, and the USAF's Air Force Instruction (AFI) 24-203, Transportation Preparation and Movement of Air Force Cargo, are the guiding documents for all shipments managed by the USAF. When planning for shipment, it requires the transportation authority to select a shipping mode/method (motor, rail, small package carrier, etc.) and carrier (FedEx, UPS, USPS, Military Airlift, etc.). When selecting the method of transportation, transportation authorities must do so based on delivery requirements/physical characteristics of the cargo, and comply with all Transportation Protective Services and current Force Protection requirements. When selecting a package carrier, the best value for the respective delivery date, weight, size, and distance item has to travel must be considered. The user has the ability to challenge any excessively high rates using the Global Freight Management Rate Quotation application. Additionally, it is important to note that the transportation authority uses pre-approved carriers for his/her location. Carriers other than the U.S. Postal Service, must have an approved General Services Administration (GSA) contract on file (U.S. Air Force, 2017).

Mission Capable (MICAP) Parts

Previous research has shown that the Air Force has spent considerable dollar amounts on shipping mission-capable (MICAP) items to nearly all military installations worldwide (Masciulli & Cunningham, 2001). It was found that the Air Force is operating at a less than optimal level with its transportation and method decisions. For the purpose of this research, a total percentage of parts shipped MICAP will be provided in order to determine a weighted cost due to difference in FedEx service required to ship MICAP v. standard shipping.

FedEx Services Offered

Under the Federal Express 2017 Service Guide, several shipping services are offered for expedited shipping. The service categories used in this analysis are the FedEx U.S. Express Package Rates and the FedEx Freight Rates. Within the U.S. Express Package Rates, there are 5 separate delivery timeframes to choose from: Next Day by 8 or 8:30 a.m., Next Day by 10:30 a.m., Next Day by 3 p.m., 2nd Day by 10:30 a.m., and 3rd Day by 4:30 p.m. Within the FedEx Freight rates, 4 separate delivery times exist: FedEx First Overnight Freight, FedEx 1Day Freight, FedEx 2Day Freight, and FedEx 3Day Freight. FedEx also provide rates for shipments to/from Hawaii and Alaska as well as international rates for all weight and distance categories (Federal Express, 2017). These rates were not used for the purpose of this research since the focus area included the continental United States.

Summary

This chapter identified the history of the C-130J supply chain strategy and the reasoning behind Contractor Support Logistics for the supply function while also showing the shortfall of warehouse relocation. Additionally, the history of location analysis along with several modeling taxonomies were presented for the purposes of methodology development. Warehouse site selection is a primary focus and area of interest for potential cost savings and/or profit maximization across organizations. In the next chapter, the models will be applied to the given research question proposed in Chapter 1.

III. Methodology

Introduction

This chapter outlines the context for the analysis methods used to solve the C-130J warehouse location problem. The chosen model technique that best answers the research question is presented for final analysis across the 5 alternative locations and Keesler AFB within the contiguous United States. Additionally, infrastructure needs and cost calculations are presented in order to compare warehouse relocation costs with projected payoff periods against the Keesler AFB ICP baseline model. The final model results will be discussed in Chapter IV.

Data

Data was provided by the C-130J Logistics and Production Development Office, Air Force Life Cycle Management Center (AFLCMC) at Wright-Patterson Air Force Base (WPAFB), OH using the military's Cargo Movement Operations System (CMOS). The data detailed the shipping origin and destination, item weight, item nomenclature/description, Standard Carrier Alpha Code (SCAC), and shipping mode (truck, air, etc.) for 12,363 items over a 5-year period (October 2012-September 2017). The C-130J Program Office handles all supply chain strategy for the C-130 fleet, with supply strategy being a primary focus. Although warehouse location determination is not strictly limited to transportation cost, for the purpose of the methodology formulation, only transportation costs to/from the respective C-130J bases were used as consideration factors. Though cost minimization is the goal, future growth projection could lead to other optimal solutions.

Model Parameters

Model parameters were set in order to select certain techniques and heuristics that are applicable to the presented problem. These parameters include: candidate sites, transportation cost data, and infrastructure needs/costs. Candidate sites for all single source models were provided by the C-130J Logistics and Production office.

Base Location

The selected bases are Keesler AFB (current location), Little Rock AFB, Dyess AFB, Cannon AFB, Hurlburt Field, and Robins AFB. All bases, but Robins AFB are operating locations for the C-130J. Robins AFB is the site for the C-130J depot maintenance and overhaul; therefore, it was deemed a viable alternative for consideration. Figure 1 shows the relative location of each base within the United States. As mentioned previously, only stateside bases were used in this analysis since international rates are standard, no matter the shipping origin in the contiguous United States. Additionally, it is assumed that all bases can support the warehouse footprint through current infrastructure or new construction. Next, it is assumed that the base has ample access to approved GSA carriers for the purpose of peculiar parts transportation. Finally, it is assumed that no local, state, or federal restrictions exist for warehouse relocation or the presence of contractor managed supply points.

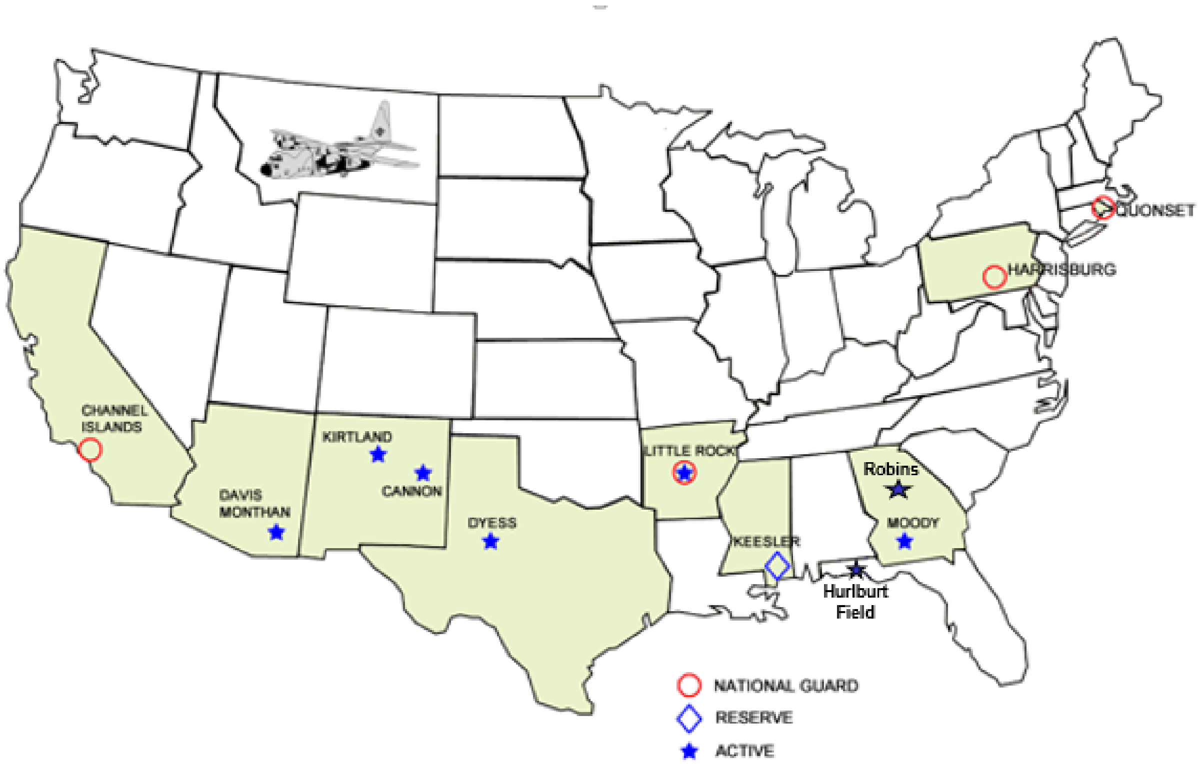


Figure 1. C-130J Locations (*C-130J PS BCA Final Report V2*, 2016)

Transportation Cost Data

The USAF used several shipping methods and carriers to ship 12,000+ items to Keesler AFB over a 5 year time period. Nine different modes of transportation amongst eleven shipping companies were used to transport the parts. As mentioned in Chapter 1, Federal Express was the primary GSA approved provider used to ship the peculiar parts; therefore, FedEx Freight and FedEx Priority rates were used to formulate the cost data for comparison purposes. Additionally, special handling fees and other surcharges were not included in this analysis since special handling requirements were not provided in the data set. FedEx uses weight, zone categories (mileage), and service type to determine shipping costs. Figure 2 gives an example of the FedEx, Zone 2 U.S. Express Delivery rate chart. Each row represents a weight, ranging from 1-49 lbs., while each column represents differing services offered by FedEx.

Delivery Commitment[2]	Next day by 8 or 8:30 a.m.	Next day by 10:30 a.m.	Next day by 3 p.m.[3]	2nd day by 10:30 a.m.	2nd day by 4:30 p.m.[3]	3rd day by 4:30 p.m.[3]
	FedEx First Overnight®	FedEx Priority Overnight®	FedEx Standard Overnight®	FedEx 2Day® A.M.	FedEx 2Day®	FedEx Express Saver®
FedEx® Envelope up to 8 oz.	$ 51.28	$ 22.28	$ 21.95	$ 17.61	**	**
FedEx® Pak	*	*	*	*	*	*
Shipments in All Other Packaging / Maximum Weight in Lbs.						
1 lb.	$ 55.59	$ 26.59	$ 24.59	$ 18.41	$ 16.50	$ 14.83
2 lbs.	55.94	26.94	25.97	18.72	16.78	15.10
3	59.16	30.16	28.23	19.04	17.07	15.53
4	61.51	32.51	30.44	19.62	17.58	15.80
5	62.22	33.22	30.99	20.19	18.10	16.07
6	66.63	37.63	32.70	21.07	18.89	17.37
7	67.08	38.08	33.75	21.97	19.69	17.64
8	67.42	38.42	35.52	22.84	20.48	18.34
9	67.91	38.91	36.78	24.06	21.56	18.60
10	68.26	39.26	37.12	25.19	22.58	18.87
11	73.88	44.88	39.59	26.33	23.60	22.17
12	75.73	46.73	40.91	28.58	24.85	22.65
13	76.37	47.37	41.36	29.69	26.61	24.70
14	77.17	48.17	42.96	31.14	27.92	24.97
15	77.52	48.52	44.62	33.33	28.99	25.24
16	79.29	50.29	45.55	34.12	29.67	26.65
17	83.63	54.63	47.87	35.16	30.58	27.51
18	84.07	55.07	49.30	36.35	31.61	29.24
19	84.42	55.42	50.62	37.76	32.85	29.99
20	84.71	55.71	51.56	37.91	33.99	30.26
21	87.15	58.15	52.95	40.91	35.57	32.31
22	89.81	60.81	54.81	42.16	36.66	33.24
23	90.15	61.15	55.75	43.20	37.56	34.68
24	91.77	62.77	57.14	44.09	38.41	35.56
25	92.10	63.10	58.46	44.24	39.67	35.82
26	95.96	66.96	59.73	45.57	40.85	38.09
27	96.35	67.35	60.72	48.27	42.16	39.32
28	97.77	68.77	62.60	48.54	43.52	40.52
29	98.11	69.11	63.92	49.87	44.72	41.70
30	98.42	69.42	64.97	52.33	45.50	41.97
31	101.06	72.06	66.19	53.90	46.87	42.67
32	103.13	74.13	67.56	54.06	47.56	44.72
33	104.89	75.89	69.05	56.26	48.91	45.96
34	106.53	77.53	70.26	58.01	50.45	46.88
35	108.18	79.18	72.25	59.19	51.47	47.79
36	111.47	82.47	73.58	60.10	52.26	49.14
37	112.05	83.05	74.95	60.25	53.23	49.41
38	112.38	83.38	76.28	62.25	54.13	49.68
39	114.97	85.97	78.21	64.21	55.84	49.95
40	115.30	86.30	79.48	64.41	57.26	50.22
41	119.12	90.12	80.85	67.53	58.73	54.54
42	120.44	91.44	82.35	68.65	59.70	55.51
43	122.89	93.89	83.72	70.09	60.95	56.59
44	125.01	96.01	85.16	71.27	61.97	57.51
45	126.33	97.33	86.54	71.42	62.25	57.78
46	129.00	100.00	87.86	71.57	64.18	58.92
47	130.21	101.21	89.74	73.10	65.55	59.18
48	130.54	101.54	91.06	74.55	66.85	59.45
49	130.87	101.87	92.44	76.90	68.21	59.72

Figure 2. FedEx Zone 2 Rates (Federal Express, 2017)

It is assumed that no delays due to natural disasters, holidays, or other factors will affect the delivery times projected by FedEx. Lastly, it is assumed that FedEx can handle all C-130J peculiar items no matter the weight, distance, or item hazard classification.

Mileage Estimation

Google Maps was used to calculate the mileage from the alternative candidate sites to the C-130J operating Location. The shortest mileage provided by Google Maps was used for each mileage estimation. Table 3 shows mileage from Keesler AFB to the other operation location. FedEx categorizes certain mileage distances into “Zone” Categories, which are located in Table 4. Within the FedEx Service Guide, a charge still exists for those items shipped to locations “zero” miles away from its destination; however, it is assumed that the shipping responsibility will be handled organically by the USAF for those items for which the base and the ICP are collocated. This is evident in FedEx’s Zone 2 rates for all service types. The service guide does not indicate how the mileage estimations are determined (straight line v. road mileage), but these zone categories were verified via the FedEx rate website. Though FedEx sets the rates via zones, mileage estimations were needed for analysis purposes in Chapter 4. Lastly, it is also assumed that these mileages will not change over the life of the ICP operation.

Table 3. Keesler AFB Mileage Distances

Base	Google Maps Mileage from Keesler AFB
Dyess	760
Kirtland	1,216
Little Rock	439
Moody	402
Channel Islands	2,018
Harrisburg	1,121
Keesler	0
Cannon	1,024
Davis Monthan	1,470
Quonset Point	1,439
Hurlburt	161
Gabreski	1,333
Patrick	625
Moffet	2,306

Table 4. Zone Mileage Categories

FedEx Zone Category	Inclusive Mileage
Zone 2	0-150
Zone 3	151-300
Zone 4	301-600
Zone 5	601-1,000
Zone 6	1,001-1,400
Zone 7	1,401-1,800
Zone 8	1,801+

Infrastructure Cost Estimation

The Air Force Civil Engineering Center and respective base-level Civil Engineering Squadrons will have the most accurate cost estimates and can use previous projects as a baseline for the construction cost determination. In addition to availability, infrastructure conversion costs and/or new construction costs will be estimated and provided by the Civil Engineering organization. It is also assumed that the base can support a warehouse of at least 30,000 square feet (current size of the ICP at Keesler AFB).

Data Pre-Processing/Spreadsheet Construction

Given that only Keesler inbound data was provided, and most parts were unserviceable parts being shipped back to the Keesler ICP, it is assumed a one-for-one swap for a serviceable part is occurring at the warehouse. Due to this assumption, we now have inbound and outbound demand data at each node. Six separate spreadsheets are created for the alternative locations (Keesler, Dyess, Cannon, Little Rock, Hurlburt Field, Robins). Within the spreadsheet, applicable weights (provided by CMOS) and mileage calculations (Google Maps) are then used to associate a shipping cost provided the FedEx Service Guide. The sum of costs from each FedEx service type (10 in total + 1 minimum cost function) over the 5 years will be used for comparison purposes. Due to the large size and structure of the spreadsheet, screenshots/pictures of the data set are not presented; however, the Microsoft Excel spreadsheet is available upon request. Contact Joshua Casey at joshua.casey.8@us.af.mil.

Analysis

In addition to the summation and comparison of transportation costs across all six candidate sites, several other exploratory data analysis will be presented in order further understand the data set and overarching problem. First, average shipping cost per item will be presented in order to show the relative cost to the Air Force each time an item is shipped. Next, that same average cost per item will be applied to those transportation costs; however, organic shipments ($0 cost to the Air Force) will be excluded in order to determine the average of all items physically shipped from the candidate site to other C-130J locations. Furthermore, the results will show how the average weight per item shipped by each base varied significantly. Due to this, reversion to the mean theory is applied to the weights of the items (53 lb. average weight). As mentioned earlier in this chapter, FedEx's rates vary by weight; mean reversion theory will account for the variability and give a projected cost for a data set containing a longer time period. Continuing the previous trend, the organic shipments are then excluded to find the average of items physically shipped, using mean reversion theory, via FedEx to other locations. Lastly, the total projected savings per year will be run against a cost curve for new construction and personnel/inventory relocation in order to determine a payoff period.

Summary

This chapter summarized the methodological approach to solving the research topic. First, data selection was introduced with respect to the model parameters needed to perform a proper analysis. Solution techniques and justification were outlined for the purpose of model comparison conducted in Chapter 4, Results and Analysis.

IV. Results and Analysis

Introduction

The chapter summarizes the results of the model outlined in Chapter 3. Each candidate site cost estimation was determined using the 2017 FedEx Service Guide. The model results lead to 11 total cost estimations for comparison purposes across the candidate sites (10 FedEx Service Category rates and 1 minimum cost function). The cost estimation rates are reflective of weight, mileage traveled, and service type selected for shipment. All weights were provided by CMOS while the mileage calculations were determined using Google Maps. These mileages were then sorted into "Zone" categories to determine the final cost of each service type from the respective candidate sites. Prior to presenting the model sets for each service type at the C-130J candidate sites, additional data set visualization and comparison will be presented since the methodology for establishing FedEx rates was not able to be obtained. This visualization will help paint the picture as to why the cost estimation results produced the given outputs.

Preliminary Data Analysis/Visualization

Over the timeframe of the data provided (Oct 2012-Sep 2017), 12,363 items were shipped from the C-130J bases in the continental U.S. to the Keesler AFB ICP. Though of crucial importance, it is necessary to note that total costs are not exclusively reliant on number of parts shipped. 12,000+ parts were moved over the 5-year time period, and not all bases moved an equal amount of parts. The 5 alternative candidate sites and Keesler AFB accounted for 78% of the part demand over the 5-year period. Although Robins AFB is a candidate site, it did not have any demand for the peculiar parts given it's the depot location; therefore, 4 of the 5 alternative sites accounted for the 78% demand. The bar chart depicted in Figure 5 shows the percentage of parts demanded by the C-130J candidate sites. Little Rock AFB, Keesler AFB, and Dyess AFB were the top 3 respectively ordered, and accounted for 69% of all candidate site demand. This is due in part to the number of aircraft located at those bases; therefore concluding that the number of aircraft at a given base plays a significant role in part demand levels.

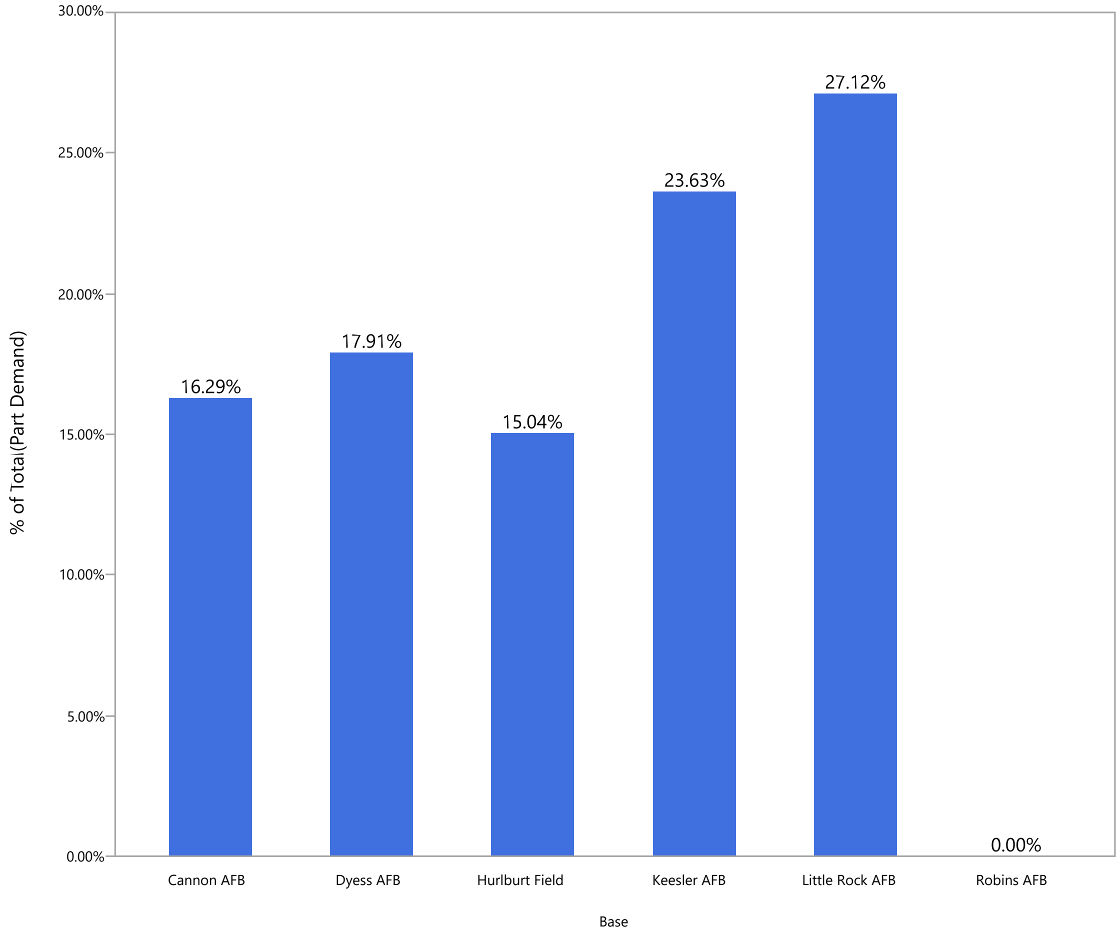
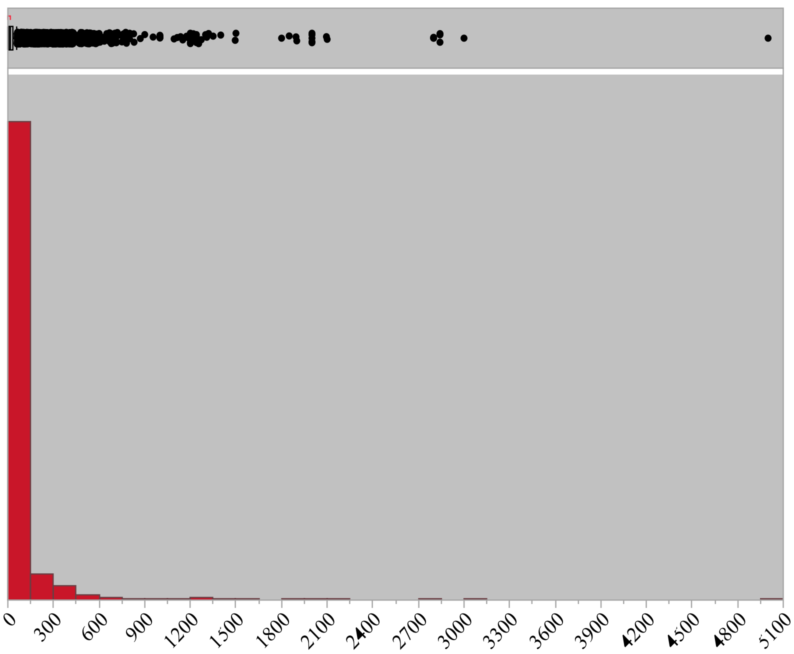


Figure 3. Percentage of Parts Demanded by Candidate Sites (One-way)

Aircraft are complex systems which require a number of parts varying in both size and weight. With 12,000+ parts in the data set, it can be assumed that the part weights will vary, which will have a direct impact on the shipping costs when shipping via FedEx. Figure 6 displays the distribution of the part weights.



100.00%	maximum	5000
99.50%		827.54
97.50%		370
90.00%		115
75.00%	quartile	30
50.00%	median	17
25.00%	quartile	10
10.00%		5
2.50%		2
0.50%		1
0.00%	minimum	1

Figure 4. Distribution of Part Weights w/ Summary Statistics

Within the data set, parts ranged from 1-5,000 lbs.; however, 75% of items were under the 30 lb. threshold with an overall mean of 52.79 lbs. (std. dev = 150.36). Most of the heavier objects were aircraft surfaces (i.e.- rudder, flap, etc.) and would usually be shipped via a Less-Than-Truckload (LTL) or Truckload carrier, but for consistency purposes, FedEx rates were applied.

As mentioned previously, Little Rock AFB, Keesler AFB, and Dyess AFB accounted for more than half of the total number of parts shipped over the entireity of the data set. Along with that, Little Rock AFB and Dyess AFB shipped the highest average weight/item (Ref Table 5).

Table 5. Average Weight Shipped by Candidate Sites

Base	Average Weight per Item Shipped (lbs.)
Cannon	33.24
Channel Islands	41.87
Davis-Monthan AFB	35.71
Dyess AFB	70.23
Harrisburg	51.34
Hurlburt Field	67.49
Keesler AFB	37.59
Kirtland AFB	33.36
Little Rock AFB	78.47
Moody AFB	36.18
Quonset Point	45.50

Both Little Rock AFB and Dyess AFB eclipsed the 70-lb. average weight threshold with Little Rock AFB accounting for 12 of the 20 heaviest items shipped over the time period (all over 2000 lbs.), while Dyess AFB accounted for 2 of the heaviest 20 items. Colocation of the ICP at the bases with the highest average weight could offer potential cost savings given those heavier items would not be shipped via FedEx, but rather organically.

In addition to weight, total distance between the shipping and receiving location greatly impacts total cost variation across the candidate sites. Longer distances require more fuel consumption and time allocated to getting the package to its final destination. Table 6 and Table 7 show the current sum and future sum of mileage respectively to the other C-130J bases within the Continental U.S. The Base location acts as the hub of the Inventory Control Point while the remaining operating locations act as the receiving location.

Table 6. Current Sum of Mileage from Candidate Site to Other C-130J Bases

Base Location	Current Sum of Mileage to ALL C-130J Locations
Keesler AFB	10,050
Little Rock AFB	9,346
Dyess AFB	9,569
Cannon AFB	10,010
Robins AFB	11,322
Hurlburt Field	10,588

Table 7. Future Sum of Mileage from Candidate Site to Other C-130J Bases

Base Location	Future Sum of Mileage to ALL C-130J Locations
Keesler AFB	14,314
Little Rock AFB	13,609
Dyess AFB	14,272
Cannon AFB	14,806
Robins AFB	15,283
Hurlburt Field	14,804

The sums of mileage differ because three additional bases (Patrick AFB, FL; Francis S. Gabreski Air National Guard Base, NY; Moffett Federal Airfield, CA) are projected to receive C-130Js within the next three years. These distances, however, are not weighted for total number of aircraft and simply reflect which candidate site is closest (in total) to all other C-130J bases in the continental United States. It was determined that Little Rock AFB, Dyess AFB, and Cannon AFB are the three closest for current C-130J basing, while Little Rock AFB, Dyess AFB, and Keesler are the closest for future C-130J basing respectively. Table 8 displays the total distance traveled by all parts received at the respective candidate sites ICP were collocated with the base, as well as the average distance traveled per item.

Table 8. Total Mileage of Items Shipped by Candidate Site

Base	Total Miles	"As Is Avg." $\left(\frac{Total\ Miles}{12,363}\right)$	Items Shipped via FedEx (Excluding Organic)	Excluding Organic Avg. Distance $\left(\frac{Total\ Miles}{Exluding\ Organic}\right)$
Keesler AFB	9,866,421	798	10,080	979
Little Rock AFB	8,565,632	693	9,743	879
Dyess AFB	9,433,767	763	10,633	887
Cannon AFB	10,522,345	851	10,789	975
Robins AFB	12,116,794	980	12,363	980
Hurlburt Field	11,006,865	890	10,910	1009

It has been shown how weight and mileage traveled can affect the total transportation costs of the data set presented, but the type of service provided (Next Day v. 3-Day) can have a considerable impact on total transportation costs. Conventional knowledge will tell you that a faster shipping time will be more costly, given a higher level of service would be required. FedEx's service rates are reflective of shipping time and type of service which is received. Figure 9 illustrates this point directly by comparing service type over the weight spectrum of the data set. Shown are the relative service types (ranging from Next Day Air by 8 or 8:30 a.m. to FedEx 3rd Day Freight) overlaid with weight and the respective costs associated with an increasing weight for the Zone 2 shipping category. The same pattern is present for all FedEx zone categories.

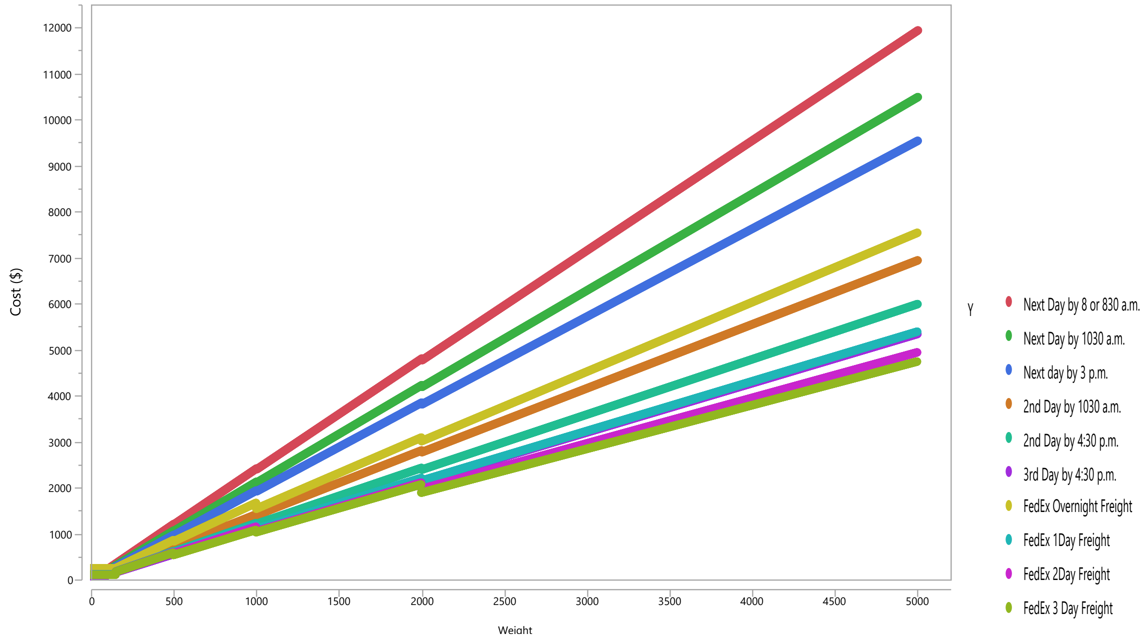


Figure 5. Overlay of Service Categories by Weight

3rd Day by 4:30 p.m. service is the most cost effective shipping method for a large majority of items within the data set since 90% of items are less than 115 lbs. One can see how the difference in cost increases as the weight of an item increases, showing that weight is a major consideration factor for items eclipsing the 150 lb. threshold. For all items less than or equal to 150 lbs., FedEx Priority services have established rates; however, Table 9 shows the multiplied constant for all item >100 lbs. in the Zone 2 category. For this analysis, only items >150 lbs. (not 100-150 lbs.) used the constant outlined in the FedEx Service Guide since rates were elsewhere in the Service Guide for parts ranging in weight from 1-150 lbs.

Table 9. Zone 2 High Weight Item Calculation (Federal Express, 2017)

Zone 2

Multiply by total shipment weight.

Weight	FedEx First Overnight®	FedEx Priority Overnight®	FedEx Standard Overnight®	FedEx 2Day® A.M.	FedEx 2Day®	FedEx Express Saver®
100–499 lbs.	$ 2.45	$ 2.16	$ 1.97	$ 1.45	$ 1.26	$ 1.13
500–999 lbs.	2.43	2.14	1.95	1.43	1.24	1.11
1,000–1,999 lbs.	2.41	2.12	1.93	1.41	1.22	1.09
2,000+ lbs.	2.39	2.10	1.91	1.39	1.20	1.07

Furthermore, Table 10 outlines the FedEx First Overnight Freight rates for all applicable zones. A minimum charge exists for all items <150 lbs. To put it into perspective, to ship a 150 lb. item via FedEx First Overnight (Next Day by 8 or 8:30 a.m.), it costs $367.50 in Zone 2, while the FedEx First Overnight Freight rate is $257.

Table 10. FedEx First Overnight Freight Rate Calculations (Federal Express, 2017)

FedEx First Overnight® Freight

Per-pound rates (multiply by total shipment weight).

Weight	ZONES									
	2	3	4	5	6	7	8	9–10	11	13–16
	0–150 miles	151–300 miles	301–600 miles	601–1,000 miles	1,001–1,400 miles	1,401–1,800 miles	1,801-plus miles	To AK/HI[1] metro	To AK rural	From AK/HI[1]
151–499 lbs.	$ 1.74	$ 2.94	$ 5.12	$ 7.35	$ 7.70	$ 9.25	$ 10.22	$ 11.44	$ 12.01	$ 7.43
500–999 lbs.	1.68	2.80	4.61	7.18	7.67	9.23	9.97	11.07	11.62	7.41
1,000–1,999 lbs.	1.55	2.74	4.58	6.90	7.53	9.16	9.72	10.63	11.52	7.22
2,000+ lbs.	1.51	2.72	4.24	6.19	7.43	9.10	9.59	10.51	11.28	7.18
Minimum Charge	257.00	438.00	762.00	1,095.00	1,143.00	1,364.00	1,520.00	1,703.00	1,786.00	1,099.00

In all, it is better to ship heavier items via 2-day and 3-day freight given FedEx Freight specializes in these types of shipments. Shipping parts by minimum cost only will produce a data set with varying service types selected to ship all 12,000+ items. This will be further outlined in the Results section of this chapter.

Results

All cost data within the Results section are displayed as one-way shipping costs. The one-for-one part swap assumption will be used to calculate the final costs for those candidate sites which offer recognized cost savings.

Next Day by 8 or 8:30 a.m.

For the Next Day 8 or 8:30 a.m. service, Little Rock AFB is the cheapest option by $592K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 11. Next Day by 8 or 8:30 a.m.

Base	Next Day by 8 or 8:30 a.m.
Keesler AFB	$ 3,994,464.07
Little Rock AFB	**$ 3,401,980.81**
Dyess AFB	$ 4,295,825.00
Cannon AFB	$ 4,301,578.73
Robins AFB	$ 4,873,101.42
Hurlburt Field	$ 4,353,394.80

Next Day by 10:30 a.m.

For the Next Day 10:30 a.m. service, Little Rock AFB is the cheapest option by $558K. Keesler AFB and Cannon AFB are 2nd and 3rd respectively. This service type is the only category which includes Cannon AFB as a Top-3 candidate with respect to transportation costs.

Table 12. Next Day by 10:30 a.m.

Base	Next Day by 10:30 a.m.
Keesler AFB	$ 3,622,050.42
Little Rock AFB	**$ 3,064,223.03**
Dyess AFB	$ 3,900,529.19
Cannon AFB	$ 3,900,264.55
Robins AFB	$ 4,423,939.56
Hurlburt Field	$ 3,914,243.16

Next day by 3 p.m.

For the Next Day by 3 p.m. service, Little Rock AFB is the cheapest option by $546K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 13. Next day by 3 p.m.

Base	Next day by 3 p.m.	
Keesler AFB	$	3,533,718.13
Little Rock AFB	**$**	**2,987,656.54**
Dyess AFB	$	3,781,064.25
Cannon AFB	$	3,797,732.41
Robins AFB	$	4,314,131.74
Hurlburt Field	$	3,798,204.81

2nd Day by 10:30 a.m.

For the 2nd Day by 10:30 a.m. service, Little Rock AFB is the cheapest option by $249K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 14. 2nd Day by 10:30 a.m.

Base	2nd Day by 10:30 a.m.	
Keesler AFB	$	2,166,945.46
Little Rock AFB	**$**	**1,918,096.84**
Dyess AFB	$	2,320,825.42
Cannon AFB	$	2,692,492.90
Robins AFB	$	2,822,762.25
Hurlburt Field	$	2,447,948.30

2nd Day by 4:30 p.m.

For the 2nd Day by 4:30 p.m. service, Little Rock AFB is the cheapest option by $220K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 15. 2nd Day by 4:30 p.m.

Base	2nd Day by 4:30 p.m.
Keesler AFB	$ 1,889,422.88
Little Rock AFB	**$ 1,669,427.24**
Dyess AFB	$ 2,023,864.64
Cannon AFB	$ 2,347,501.65
Robins AFB	$ 2,462,491.56
Hurlburt Field	$ 2,132,108.54

3rd Day by 4:30 p.m.

For the 3rd Day by 4:30 p.m. service, Little Rock AFB is the cheapest option by $199K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 16. 3rd Day by 4:30 p.m.

Base	3rd Day by 4:30 p.m.
Keesler AFB	$ 1,434,354.17
Little Rock AFB	**$ 1,234,945.76**
Dyess AFB	$ 1,533,445.07
Cannon AFB	$ 1,674,262.45
Robins AFB	$ 1,825,051.78
Hurlburt Field	$ 1,650,579.26

FedEx Overnight Freight

For the FedEx Overnight Freight service, Little Rock AFB is the cheapest option by $1.28M. Dyess AFB and Keesler AFB are 2nd and 3rd respectively. This service type is the only category in which Dyess AFB outperformed Keesler AFB with respect to transportation cost total.

Table 17. FedEx Overnight Freight

Base	FedEx Overnight Freight
Keesler AFB	$ 12,280,360.77
Little Rock AFB	**$ 10,954,706.06**
Dyess AFB	$ 12,238,722.65
Cannon AFB	$ 12,440,079.14
Robins AFB	$ 15,171,098.24
Hurlburt Field	$ 12,866,942.47

FedEx 1Day Freight

For the FedEx Overnight Freight service, Little Rock AFB is the cheapest option by $545K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 18. FedEx Overnight Freight

Base	FedEx 1Day Freight
Keesler AFB	$ 5,194,998.00
Little Rock AFB	**$ 4,649,830.93**
Dyess AFB	$ 5,380,883.42
Cannon AFB	$ 5,621,530.13
Robins AFB	$ 6,552,192.23
Hurlburt Field	$ 5,665,698.75

FedEx 2Day Freight

For the FedEx 2Day Freight service, Little Rock AFB is the cheapest option by $351K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 19. FedEx 2Day Freight

Base	FedEx 2Day Freight
Keesler AFB	$ 3,974,072.92
Little Rock AFB	**$ 3,622,796.56**
Dyess AFB	$ 4,016,126.76
Cannon AFB	$ 4,156,981.01
Robins AFB	$ 4,911,706.46
Hurlburt Field	$ 4,503,555.56

FedEx 3 Day Freight

For the FedEx 2Day Freight service, Little Rock AFB is the cheapest option by $256K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively.

Table 20. FedEx 3 Day Freight

Base	FedEx 3 Day Freight
Keesler AFB	$ 2,832,389.07
Little Rock AFB	**$ 2,576,043.50**
Dyess AFB	$ 2,957,163.64
Cannon AFB	$ 3,067,748.61
Robins AFB	$ 3,532,393.34
Hurlburt Field	$ 3,308,820.84

Minimum Cost

For the minimum cost function service, Little Rock AFB is the cheapest option by $200K. Keesler AFB and Dyess AFB are 2nd and 3rd respectively. The minimum cost summation uses the least expensive method for each individual part. In some instances, especially with heavier items being shipped long distances, FedEx 3-Day Freight proved to be the least cost transport service. Although 3rd Day by 4:30 was the overall cheapest service (given every item shipped via this method), cost savings could still be recognized by using alternative service methods.

Table 21. Minimum Cost

Base	Min
Keesler AFB	$ 1,409,360.78
Little Rock AFB	**$ 1,209,701.92**
Dyess AFB	$ 1,503,988.04
Cannon AFB	$ 1,643,613.11
Robins AFB	$ 1,790,529.73
Hurlburt Field	$ 1,619,446.08

The results have shown that Little Rock AFB is the most effective option with respect to transportation costs across all service categories. This is due to the number of parts demanded (less items shipped) by Little Rock AFB and the high average weight of items shipped from Little Rock AFB. Additionally, it was shown in Figure 7 that an increase in item weight is relatively linear to an increase in cost. With more than 25% of items now being shipped organically (Little Rock ICP to Little Rock operational unit), it is clear why Little Rock AFB resulted as the clear favorite in all service categories since organic shipments are “zero cost” to the U.S. Air Force. For the remainder of the analysis, focus will be placed on Little Rock AFB as the only viable candidate site for the ICP. The only occurrence of estimated cost savings for a base other than Little Rock exists in the FedEx Overnight Freight service category. Given how expensive this service category is, Dyess AFB cannot be viewed as a viable option given the presented cost estimations.

Total Cost Time-Series

Now that total transportation costs were calculated for the respective service categories at Little Rock AFB, it can be shown how transportation cost totals relate to the number of parts shipped over the given time period. In order to visualize the trends, total costs and number of items shipped were broken out into monthly categories and overlaid in Figure 8 to show the part demand/shipments correlation with transportation cost fluctuations along a Log Scale. As mentioned in Chapter 2, quantity discounts can lead to cost savings for organizations, but each of the parts within the data set were shipped individually.

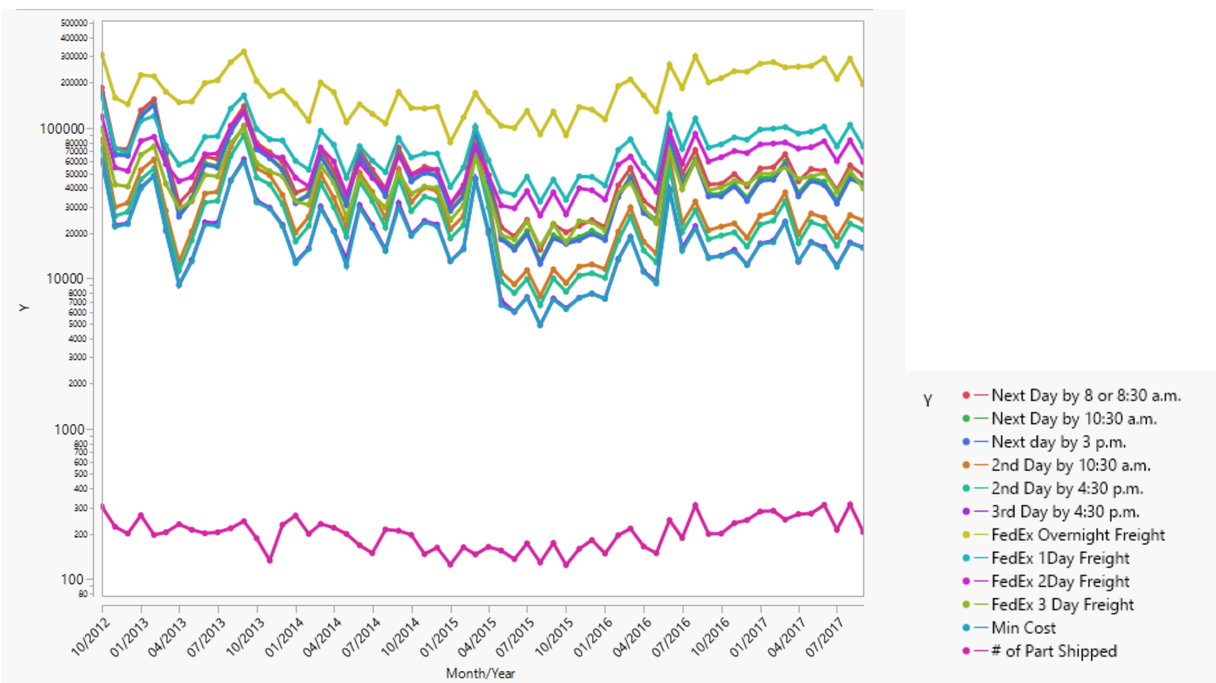


Figure 6. Log Scale Comparison of Parts Shipped v. Total Cost by Service

Average Cost per Item

With Given Weights

Table 22 outlines the average cost per item within the "minimum cost" service category and illustrate why Little Rock AFB is the most cost effective with respect to shipping costs. Table 22 shows the average shipping cost per item with the data presented "as is" at the respective candidate sites (recall that each base shipped a varying number of parts).

Table 22. Given Weights

Base	Average Shipping Price per Item
Keesler AFB	$113.98
Little Rock AFB	$97.84
Dyess AFB	$121.65
Cannon AFB	$132.95
Robins AFB	$144.83
Hurlburt Field	$123.14

In order to further understand how the number of aircraft, and subsequent variances in number of parts shipped, at a base can heavily affect part demand, the number of organic shipping costs were removed from the denominator in order to find the average of all parts which were physically shipped to other C-130J locations. Table 23 shows the total number of parts that would have been shipped by the candidate sites if the ICP were collocated. By changing the denominator from 12,363 to the number of parts shipped outlined in Table 23, one can understand the true effect of warehouse location on cost (Table 24).

Table 23. Part Demand/Number of Items Shipped by C-130J Candidate Sites

Base	Candidate Site Part Demand	Number of Items Physically shipped to C-130J CONUS bases
Keesler AFB	2,283	10,080
Little Rock AFB	**2,620**	**9,743**
Dyess AFB	1,730	10,633
Cannon AFB	1,574	10,789
Robins AFB	0	12,363
Hurlburt Field	1,453	10,910

Table 24. Average Shipping Price per Item Excluding On-base Organic Shipments

Base	Average Shipping Price per Item Excluding On-base Organic Shipments $\left(\frac{\mathit{Total\ Min\ Cost}}{\mathit{Items\ Phsyically\ Shipped}}\right)$
Keesler AFB	$139.80
Little Rock AFB	**$124.15**
Dyess AFB	$141.45
Cannon AFB	$152.34
Robins AFB	N/A
Hurlburt Field	$139.55

More occurrences of zeroes in the total cost, which are due to organic shipments, will further drive down the average. Removing those values, however, can help further validate which candidate site is the cheapest due to relative location from other C-130J bases. Upon removal of the “zero” values, Little Rock AFB was still the cheapest by $15.40/item; however, the variance of price lowered from $214.93 to $71.40.

Average Weight Applied

As mentioned previously in the chapter, several bases had substantially higher than average weights for items shipped. Unfortunately, it is impossible to determine the reason for these abnormalities without additional input on the 12,000+ items from the operational bases. Because of this, another technique was applied to analyze which candidate site is the optimal location with respect to transportation costs. One significant limitation is the data period length. Using five years of data to predict the location of a warehouse for the life cycle of an aircraft fleet may not be sufficient given the large amount of capital investment required for inventory movement, personnel relocation and warehouse construction.

Using mean reversion theory, the average weight of the items was applied to each part that was shipped assuming that, over time, the average weights by base will revert to some mean, thus lowering the variance across the base. By using this method, it accounts for those heavier items which significantly increase costs (i.e. - Little Rock AFB having shipped 12 of the 20 heaviest items). The new total transportation cost data is presented in Table 25.

Table 25. Mean Reversion Cost

Base	Mean Reversion Minimum Cost	Original Cost	Percentage Change
Keesler AFB	$1,413,343.84	$1,409,360.78	+ 0.283%
Little Rock AFB	$1,250,539.84	$1,209,701.92	+ 3.376%
Dyess AFB	$1,364,728.51	$1,503,988.04	- 9.259
Cannon AFB	$1,447,507.24	$1,643,613.11	- 11.931%
Robins AFB	$1,720,610.03	$1,790,529.73	- 3.905%
Hurlburt Field	$1,558,810.65	$1,619,446.08	- 3.744

Both Keesler AFB and Little Rock AFB saw an increase when applying the mean reversion method. This is due in part to the “increase” of average weight for bases located further west and northeast. Cannon, Channel Islands, Davis-Monthan, Harrisburg Keesler, Kirtland, Moody, and Quonset Point, on average, shipped items which were below the mean weight. Reference Figure 1 and Table 5 for relative base locations and average shipping weights. Table 26 displays the results for average shipping price per item using the average weight method. Additionally, the same process of excluding the number of organic shipments (totaling $0) for determining the average was then applied to the new "average weight" transportation cost method (Table 27).

Table 26. Average Shipping Price per Item using Average Weight

Base	Average Shipping Price per Item using Average Weight (53 lbs.)
Keesler AFB	$114.32
Little Rock AFB	**$101.15**
Dyess AFB	$110.39
Cannon AFB	$117.08
Robins AFB	$139.17
Hurlburt Field	$126.09

Table 27. Average Shipping Price per Item Excluding On-base Organic Shipments using Average Weight

Base	Average Shipping Price per Item Excluding On-base Organic Shipments using Average Weight (53 lbs.)
Keesler AFB	$140.21
Little Rock AFB	**$128.35**
Dyess AFB	**$128.35**
Cannon AFB	$134.17
Robins AFB	$139.17
Hurlburt Field	$142.88

The results of the mean reversion theory method showed that Dyess AFB is now a viable option with respect to average price per item shipped. Under the current structure at the respective C-130J bases, Little Rock AFB is the least expensive with Keesler AFB coming in at a close 2nd; however, flying squadrons have relocated and/or bases have closed in years past. For this reason, the results above can offer great insight while also accounting for item weight variations and relative aircraft numbers. It was determined that Dyess AFB and Little Rock AFB had equal average shipping costs for the "Exclusion of On-Base Organic Shipment using Average Weight" method. With that being said, other factors besides cost should be used to compare the candidate sites.

Additional Consideration Factors

Warehouse Cost Estimation

This cost was not provided for this analysis; however, cost estimations for a 40,000 sq. ft. warehouse built in Little Rock AFB were available via buildingjounal.com. Assumptions included 10% overhead, 5% profit, and 1% bonding per the website calculator. Figure 7 displays the output for the estimation.

		Commercial Cost Estimate
Type of Building		Warehouse
Project Location		Arkansas-Little Rock
Type of Work		Lump Sum
Cost Index		Median
Square Feet		40,000.00
Subtotal		1,526,452.90
Overhead	10.00%	152,645.29
Profit	5.00%	76,322.65
Bonding	1.00%	15,264.53
Total Budget		1,770,685.36
Per Square Foot		44.27

Figure 7. Warehouse Cost Estimation ("Commerical Cost Estimator," n.d.)

One-Time shipment of Items to Candidate Sites

This cost was not provided for the analysis, nor can an estimate be formulated since the current inventory at the Keesler AFB ICP is unknown to the researcher.

Permanent Change of Station/Relocation of Lockheed Martin Employees

This cost was not provided for the analysis, nor could it be estimated for contracted personnel.

Return on Investment

Figure 8 displays the projected payoff period for differing FedEx service categories given the required investment of $1.77M for warehouse investment. The payoff periods would realistically be pushed further out; however, the additional cost considerations were not able to be obtained.

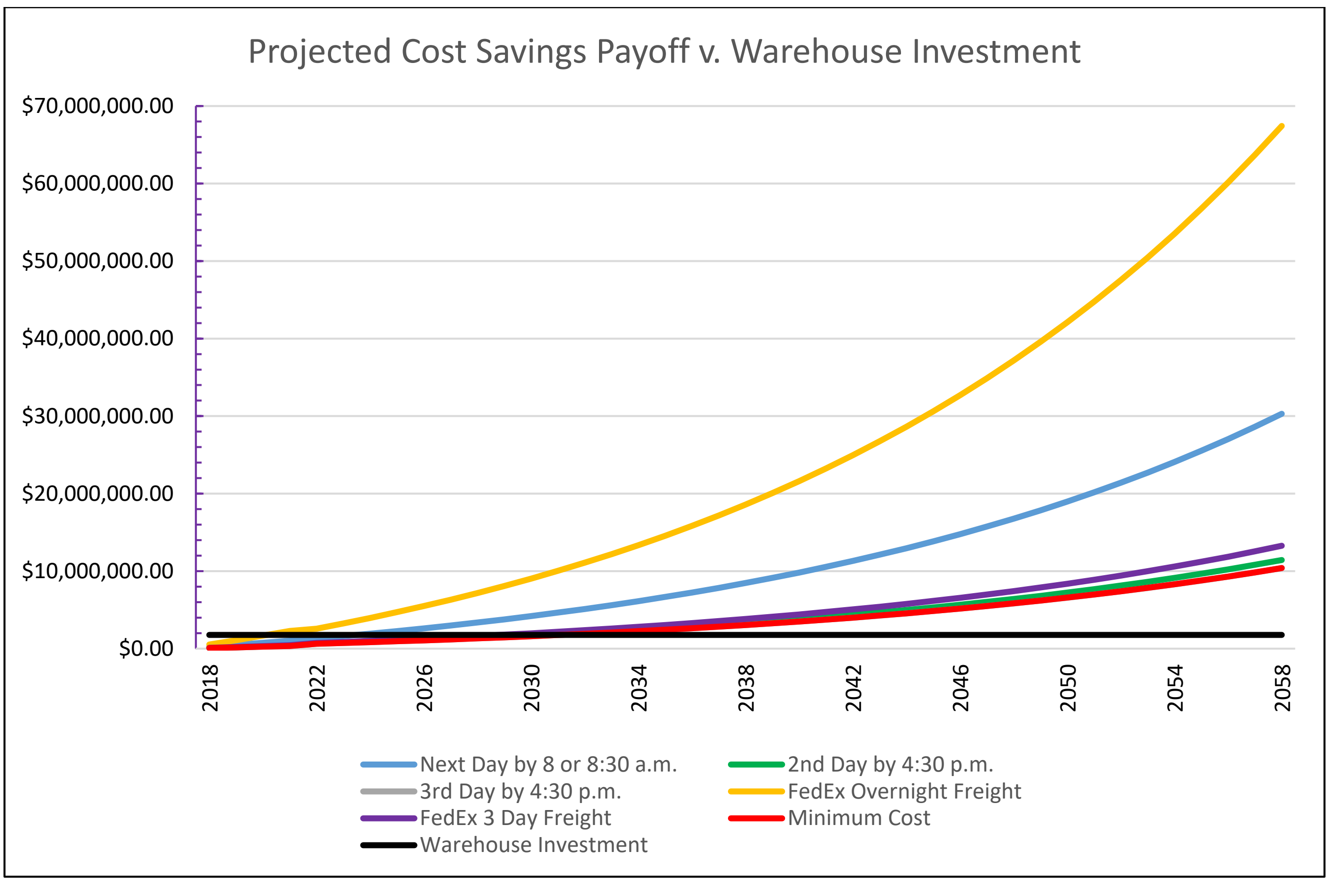


Figure 8. Return on Investment for Little Rock AFB Relocation

Summary

This chapter presents the results of the different model set runs developed in Chapter 3. The model formulated accounted for the transportation costs associated with shipping 12,363 items from the C-130J candidate sites. Utilizing the total transportation cost savings, average price per item shipped (all items and excluding organic), and mean reversion technique, it was shown that Little Rock AFB is optimal location with respect to transportation costs. Given these projected cost savings, the payoff period for relocating the personnel/inventory and building a new warehouse at Little Rock AFB is 13 years (2031). In Chapter 5, the managerial implications, recommendations, and limitations of this research are presented along with recommendations for further study.

V. Conclusions and Recommendations

Introduction

Chapter 1 provided the basis for this research effort by outlining the background of C-130J sustainment strategy and how the warehouse location problem can assist decision making processes. Next, Chapter 2 outlined relevant literature to the warehouse location, or Weber problem. The history of location analysis along with modeling taxonomies were used to build upon the methodological approach for this research topic. In Chapter 3, the detailed methodology, including the data collection process and the model parameters, were used to develop sound results. Thereafter, Chapter 4 summarized the results from the chosen model. Within the results and analysis, several candidate sites and other service categories were compared in order to determine a true optimal location with respect to transportation costs. The remainder of this research document will be dedicated to summarizing the findings, discussing the managerial implications, making recommendations based on the research, and outlining future research in order to improve upon the model's validity.

Findings

Six C-130J candidate sites were used to develop a transportation cost model which would determine the least cost alternative for the C-130J Inventory Control Point. Using Keesler AFB as the status quo model, it was found that only one candidate site consistently outperformed the current ICP location in all analysis areas: Little Rock AFB. Relocation of the ICP to Little Rock AFB can lead to an estimated costs savings of $79K/year, assuming the least cost transportation method is utilized and a one-for-one swap occurs. With the projected annual savings for relocation, it would take 13 years to realize a return on investment, chiefly due to the costs of inventory/personnel relocation and warehouse construction. In addition to the estimated cost savings, it was shown that Little Rock AFB's average shipping price/item was the least cost alternative with respect to the average shipping price/item when using historical data. Lastly, applying mean reversion theory shows both Little Rock AFB and Dyess AFB are viable relocation options, but the expected cost savings decreased, making it more difficult to provide justification for relocation.

Managerial Implications

Decision makers within the DoD's acquisition community need to understand the importance of location analysis theory when determining where to locate warehouses that support military aircraft and support equipment. Based on the findings of this research, one can conclude that transportation costs do not have a substantial impact on warehouse relocation determination for the C-130J fleet. Projected annual savings of $79K/year will lead to a return on investment period of # years, which shows that a relocation effort should not be determined based solely on cost. Literature within Chapter 2 has shown that cost should be included in all location determination problems, but with a prolonged return on investment, other factors would carry a higher weight. Some of those factors include accessibility to transportation networks, qualified workforce present, customer service rates, response time, and customer preference. Establishing the weight factors for these measures can prove to be difficult, but subject matter expert input would prove beneficial.

Military leaders determining warehouse location should not only include current network infrastructure within the decision making process, but should also have the foresight to understand that these networks grow and change. Keesler AFB was chosen as the site for the ICP since it was the first base to field the C-130J, but the aircraft is now located at 16 bases across the globe. Though the transportation costs were effectively $0 to the Air Force in the early years of the aircraft's life cycle, we can now see that these "cost savings" are not realized for sustained operations across multiple new locations. In all, location analysis should be applied prior to location determination and shouldn't be treated as an afterthought. Cost savings could be recognized over a long timeframe, but several unknowns make it difficult to up-end the current operations and move the ICP to Little Rock AFB.

Warehouse relocation can be catastrophic to an organization's supply chain. For the U.S. Air Force, C-130J flying operations will have to continue even if the ICP were to be relocated. The operational units could utilize spares currently located at the bases, but a substantial pause in the supply chain would lead to backfills in inventory ordering. Closing down a warehouse, packing/shipping the current inventory, and then unpacking the items at the end location could turn out to be a logistics nightmare. Several companies do specialize in industrial warehouse relocation, but that service would come at an additional cost to the Air Force, further driving out the payback period of relocation. In the end, cost savings are always a positive outcome, but the numerous negative effects could far outweigh the benefits.

Recommendations

Given the high cost of warehouse construction, warehouse relocation, and potential delays in the supply chain, the researcher's recommendation is to leave the ICP at Keesler AFB. Additionally, the payoff period is projected too far out to make a sound recommendation of relocation. As mentioned previously, the relocation effort would be too risky given the projected cost savings, even if more parts were shipped via MICAP (requires expedited service). With the current supply structure, Lockheed Martin handles all warehousing management of the C-130J parts; however, the USAF usually manages the supply chain organically for those aircraft that are far along in the life cycle. With “Full Operational Capability” since 2013, and the first aircraft delivery in 1999, organic supply management seems to be a viable option. Costs savings could be recognized through organic supply management, no matter the ICP/warehouse location. Finally, benefits of economies of scale storage could be realized. The C-130H and C-130J share similar parts; therefore, having a single warehouse for both airframes could be a feasible option. Further research would need to be conducted in order to validate this recommendation, but one large warehouse is often less expensive than operating two.

Limitations

With large data sets, limitations of the research are often produce invalid results. Over the 5-year period, 12,363 unserviceable items were shipped back to Keesler AFB from all other continental United States C-130J bases. The first limitation of this data set was the one-way shipping data without information on items shipped from Keesler AFB to the other locations. This limitation was previously listed in the assumptions, but significant differences in one-for-one swap data can cause significant cost variations when compared to the final results. Additionally, data integrity can cause skewed final results. All shipping data (nomenclature, control number, NSN, and weight) are input manually into CMOS; therefore, there is a strong probability that some of the data was input incorrectly, which evident in some cases across the data set (i.e.- varying weights for the same item). The data was not manipulated in any way to account for these possible errors since 12,000+ items were shipped, making it difficult to correct all errors. Each item shipped would have to be researched individually in order to validate its accuracy which would take far too long.

Another significant limitation to the data set is that historical data was used. A 5-year snapshot of part demand can offer significant information and/or findings for decision makers, but it comes at a price. Relative to the rest of the USAF aircraft inventory, the C-130J is a “new” aircraft. The 5 years of data include a range of NSNs that have been ordered; however, many of the parts on the aircraft haven’t failed yet. One could see a significant spike in part demand data which would further expand the potential cost savings at Little Rock AFB; however, manufacturer mean time between failures (MTBF) may not be resemble true failure data. Also, expanding upon the increased part demand would possibly provide a need for increased storage capacity. The current warehouse structure at Keesler AFB includes two separate buildings totaling 28K sq. ft. Potential growth of the inventory due to increased demand could potentially cause high utilization of storage space with no excess capacity available.

Significant change in demand data is not the only concern with respect to results validity. There is always the potential for the aircraft network to significantly change which can lead to repositioning of the supply and demand nodes. The DoD has closed bases in the past through Base Realignment and Closing (BRAC), leading logistics professionals to relocate all resources at that installation. If a flying squadron were to be relocated to another C-130J base, the results could shift away from Little Rock AFB being the “cost optimal” alternative for the ICP. Although unlikely given each C-130J base provides significant mission contribution, it is still something that should be considered by decision makers and leaders within the USAF.

Future Research

With a data set this large, a number of other methodologies can be applied to further validate the results and findings. This research does not utilize forecasting techniques, which could be used to project demand data by time and by base. By incorporating MTBF rates, more accurate measures of future costs could be established, and though limitations exist with manufacturer MTBF rates, it would further validate the relocation effort. Knowing forecasts will also give a better understanding of demand frequency which could be relayed to manufacturers for better inventory policy management. Another technique that could be used is a mixed integer program (IP). As mentioned previously in Chapter 2, several IP methodologies exist. The use of the p-median problem or capacitated warehouse location model with risk pooling (CLMRP) could produce a true optimal (v. discrete/local optimal) location w/ established inventory policies.

In addition to the above methodologies, incorporating other service carrier data and rates would be beneficial to acquisitions leaders. Only public FedEx service rates were used to calculate transportation costs, but use of other carriers could provide additional cost savings. Some carriers may cover regions more efficiently from a cost and customer service standpoint which would pay dividends to the USAF. In relation to regionalized carrier choice, repositioning of assets to multiple locations versus one warehouse could reduce the total part movement, and in turn, reduce transportation costs. Air Force Bases often order parts at different frequencies, and although each has the same aircraft, certain climates and/or flying mission sets can drive varying demands for different parts. Knowing these high demand parts specific to locations and/or regions could help with the inventory repositioning efforts. Similarly, further research into the USAF's use of rented warehouse space versus organic, on-base storage could provide more viable candidate sits. Though security concerns would exist for parts stored outside of the DoD's controlled areas, the cost benefits may far outweigh those concerns.

To finish, further research into the C-130H supply chain strategy could offer insight into better management of the C-130 fleet. The use of C-130H demand data over a longer timeframe could assist forecasting techniques and validation of changing demand (number of parts and average weight) over the life cycle of the C-130J. The use of the methodologies listed previously would benefit tremendously from a Delphi study. Though the quantitative models would produce more accurate cost measures, senior military leaders' inputs would provide the necessary feedback for those factors, other than cost, related to warehouse location determination. Relating the input of senior leaders to what literature defines as important to warehouse location could further assist the USAF and other branches of service when determining "optimal" inventory locations.

Summary of Findings

From the start of this research effort, the main objective was to determine the optimal location of the C-130J ICP with respect to transportation costs. The model generated indicated Little Rock AFB is the most cost effective option for relocation; however, high relocation and construction costs make it difficult to justify the extended payoff period and assumed risks of shutting down/delaying the supply chain. Additionally, it was shown that number of aircraft, part demand, and part weights significantly affect the final cost estimations. In all, further research in the areas previously listed will help validate this investigation's findings.

Bibliography

Baumol, W. J., & Wolfe, P. (1958). A Warehouse-Location Problem. *Institute of Operations Research and Management Sciences*, *6*(2), 252–263. Retrieved from https://doi.org/10.1287/opre.6.2.252

C-130J PS BCA Final Report V2. (2016). Wright Patterson AFB, OH.

Church, R. L., & ReVelle, C. S. (1976). Theoretical and Computational Links between the p-Median, Location Set-covering, and the Maximal Covering Location Problem. *Geographical Analysis*, *8*(4), 406–415. https://doi.org/10.1111/j.1538-4632.1976.tb00547.x

Commerical Cost Estimator. (n.d.). Retrieved February 21, 2018, from http://www.buildingjournal.com/construction-estimating.html

Economides, S., & Fok, E. (1984). Warehouse Relocation or Modernization : Modeling the Managerial Dilemma, (December 2017). Retrieved from https://doi.org/10.1287/inte.14.3.62

Federal Express. (2017). Service Guide. Retrieved from fedex.com/serviceguide

Friedrich, C. J. (1929). Alfred Weber's Theory of the Location of Industries. *Materials for the Study of Business.* Chicago, IL: The University of Chicago Press.

Hakimi, S. L. (1964). Optimum Locations of Switching Centers and the Absolute Centers and Medians of a Graph. *Operations Research*, *12*(3), 450–459. https://doi.org/10.1287/opre.12.3.450

Kuehn, A. A., & Hamburger, M. J. (1963). A Heuristic Program for Locating Warehouses. *Management Science*, *9*(4), 643–646. Retrieved from https://doi.org/10.1287/mnsc.9.4.643

Masciulli, J. L., & William A. Cunningham. (2001). Air Force MICAP shipping policies : Are they optimal from a cost standpoint ? *Air Force Jounral of Logistics*, *25*(3), 2–5, 40–41.

Melachrinoudis, E., & Min, H. (2007). Redesigning a warehouse network. *European Journal of Operational Research*, *176*(1), 210–229. https://doi.org/10.1016/j.ejor.2005.04.034

Melkote, S., & Daskin, M. S. (2001). Capacitated facility location/network design problems. *European Journal of Operational Research*, *129*(3), 481–495. https://doi.org/10.1016/S0377-2217(99)00464-6

Owen, S. H., & Daskin, M. S. (1998). Strategic facility location: A review. *European Journal of Operational Research*, *111*(3), 423–447. https://doi.org/10.1016/S0377-2217(98)00186-6

Ozsen, L., Coullard, C. R., & Daskin, M. S. (2008). Capacitated warehouse location model with risk pooling. *Naval Research Logistics*, *55*(4), 295–312. https://doi.org/10.1002/nav.20282

Tellier, L. (1972). The Weber Problem: Solution and Interpretation. *Geographical Analysis*, 215–233.

Tsao, Y.-C., & Lu, J.-C. (2012). A supply chain network design considering transportation cost discounts. *Transportation Research Part E: Logistics and Transportation Review*, *48*(2), 401–414. https://doi.org/10.1016/j.tre.2011.10.004

U.S. Air Force. (2017). *AFI 24-203, Transportation: Preparation and Movement of Air Force Cargo*.

Wan, Y. W., Cheung, R. K., Liu, J., & Tong, J. H. (1998). Warehouse location problems for air freight forwarders: A challenge created by the airport relocation. *Journal of Air Transport Management*, *4*(4), 201–207. https://doi.org/10.1016/S0969-6997(98)00024-6

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14. ABSTRACT
Since the first C-130J delivery in 1999, Lockheed Martin has managed the USAF's C-130J "peculiar" parts inventory at Keesler AFB. Now with 193 aircraft assigned to 17 operating locations across the globe, effective supply chain management and recognized cost savings are essential components to mission success and fleet longevity. Previous research within the area of location analysis has shown that minimizing the average weighted distance of shipping products can assist in cost reduction efforts. Due to this, the goal of this study is to determine if alternative CONUS C-130J locations can be utilized as the Inventory Control Point to help reduce total transportation costs for the fleet's "peculiar" spares inventory. Using the 2017 FedEx Service Guide in conjunction with five years of historical shipping data, five alternative C-130J bases were evaluated in order to identify which of the locations could offer transportation cost savings. Additionally, inventory/personnel relocation and new infrastructure costs were collected to project pay-off periods for capital investment. Based on this analysis, Little Rock AFB is the only C-130J CONUS operating location which would reduce the total transportation costs. In conclusion, this research can drive cost effective warehousing prior to staging aircraft and establishing the full supply chain structure.

15. SUBJECT TERMS
Warehouse Location, C-130J, Warehouse Relocation, Transportation Cost, FedEx Service Guide

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