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An Optimization of the Maintenance Assets Distribution Network in the Argentine Air Force

Santiago Hernandez

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Santiago Hernandez, Major, Argentine Air Force

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Major, Argentine Air Force

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Abstract

The Argentine Air Force Materiel General Directorate is responsible for the supply and distribution of reparable and consumable assets to support the operations of more than thirty different weapons systems. The Materiel General Directorate recently initiated an effort to assure logistic support and to gradually increase the productivity and efficiency of the related processes. The distribution of consumable and reparable assets was a key process identified as inefficient and targeted for improvement, and a recommendation was made to consider organic or private transportation and reduce transportation time in order to improve responsiveness and drive down logistic pipeline costs.

This thesis uses network flow modeling methods to analyze the spare parts flows between Argentine Air Force units to determine overall transportation demand and capacity required for a defined level of service, and to evaluate the tradeoffs between costs and service levels. The goal is to assist in the development of an effective and efficient maintenance assets distribution network.

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AN OPTIMIZATION OF THE MAINTENANCE ASSETS DISTRIBUTION NETWORK IN THE ARGENTINE AIR FORCE

I. Introduction

Background

The Argentine Air Force (AAF) Materiel General Directorate (MGD) is responsible for the supply and distribution of reparable and consumable parts from the Logistic Units and depots to the final user, which can be any Maintenance Group performing maintenance on a weapon system. Although some Maintenance Groups operate inside the Logistic Units, most of them are part of the Air Bases of the Readiness and Training Command and operate with functional relationship with the MGD.

Since 2007 the AAF is undertaking a broad effort to recover its capabilities and the MGD developed different plans to assure the airworthiness of aircraft and reparable parts, the recovery and certification of maintenance processes and the introduction of information technology. Once the goals of the initial plans were achieved, the MGD issued in 2014 the Director Plan to assure logistic support to the recovered capabilities and to gradually increase the productivity and efficiency of the related processes.

Among the processes identified as inefficient and targeted for improvement was the distribution of maintenance assets (consumable and reparable parts), stating that it should consider organic or private transportation and that reducing transportation time should simultaneously improve responsiveness and drive down the costs of the logistic pipeline.

In order to gain additional insight into their process, the MGD decided to sponsor an AFIT Argentine military student for a thesis research on this topic.

Problem Statement

According to AAF doctrine, feasibility is one of the three requirements for the solution of a problem. This is determined through a comparative analysis of the available resources and those factors whose opposition must be overcome, having also considered the characteristics of the environment where the problem exists. If the solution is not feasible, there are two possible actions to take: To adjust the desired effect of the problem so as to obtain a feasible solution or increase the required level of resources until the most convenient solution can be implemented. The decision maker will determine which of these options is acceptable and the final solution will be implemented.

As previously stated, the AAF distribution of reparable parts is an inefficient and fragmented operation that cannot satisfy the requirements of the Maintenance Groups with the level of service that the current low stock demands. Despite all the efforts being undertaken to recover maintenance capabilities to support flight operations, the desired effect will not be achieved if a feasible transportation system capable of providing an adequate level of service at a reasonable cost is not implemented.

There has been no formal research to determine the transportation capacity required or the trade-offs that network designs can have on the level of service and costs. Therefore, the objective of this study was to analyze the factors and models involved in a distribution network design and apply them to the AAF case.

Research Questions

To accomplish the research objective three research questions were addressed:

First research question: What is the capacity required to satisfy the current demand of transportation of maintenance assets?

Second research question: What are the network design and mode choices that fit the AAF distribution network needs?

Third research question: Which policies can be implemented to improve the performance of the network?

Research Focus

This thesis will analyze the characteristics of the current flows of maintenance assets between AAF units to determine the transportation demand, the capacity required for a defined level of service, analyze the network design and modes to evaluate the tradeoffs between costs and service level, and drive useful conclusions to assist in the development of an effective and efficient maintenance assets distribution network.

Investigative Questions

Four investigative questions will be used to answer these research questions:

1. What are the transportation demand characteristics at each unit?
2. What network optimization model can assist to determine the least costly way to satisfy the demand from each supplier?
3. Can a hub-and-spoke network design reduce costs and increase level of service?
4. What factors of the distribution network impedes further improvement and could be reasonably addressed?

Scope and Limitations

Given the time frame to complete this Thesis and the Master of Science in Logistics and Supply Chain Management, it is necessary to determine a reasonable scope for the broad areas of improvement that need to be addressed to implement the solution for this problem. Additionally, the availability of data will limit the analysis and conclusions derived by this research.

With respect to the data, they will be extracted from the AAF Logistic Information System (SIL). Although the SIL is currently a mandatory platform to register every movement of reparable parts between the Logistic Units and the Air Bases, the process of loading the total pipeline inventory and depot repair rate for each reparable part number is not finished and no reliable data base is available. Furthermore, the SIL reparable parts transaction records are designed to fulfill production and airworthiness needs and do not include transportation relevant data other than origin, destination and order date.

Consequently, this study will be based only upon the historical movements of reparable and consumable parts between AAF units and it will not include inventory level nor depot repair capacity in the analysis, assuming that the supplier will have stock to fulfill and order when it is placed by the requestor.

This historical data will be used to determine the transportation capacity required and study cost saving opportunities to achieve the goal with the least investment of resources.

Implications

This work will enhance the understanding of the dynamics of the distribution of reparable and consumable parts through the analysis of historical data and network flows in order to determine the transportation capacity needed on each transportation service. The insights from this research can be used for sensitivity analysis to assist in the formulation of policies and user-friendly procedures to improve the efficiency of the overall process. Additionally, it will address the cost-efficiency of intermodal transportation and cost reductions where possible.

It is important to state that this is the first time that the AAF MGD assigned a particular thesis research topic to an AFIT international military student related to a current logistic process improvement effort.

II. Literature Review

Chapter Overview

The deployment capability of the AAF depends mainly on the early definition and development of the transport capacity and the required network to support flight operations during peacetime. This capability includes the organization of AAF and third party resources, as well as the use of national infrastructure such as roads and airports. AAF doctrine defines the Cargo Transport System as all the resources required to move freight from one place to another satisfying time, place, quantity and quality requirements.

Before discussing an approach methodology to the problem, a comprehensive literature review was done to look over previous investigations and transportation network theories. This review begins with a general description of the AAF maintenance assets distribution process, discusses transportation network planning, modal choice and policies and the use of mathematical programming to solve network problems. Finally it describes the supply chain management framework and identifies the supply chain management processes involved in the distribution problem.

Description

Argentine Air Force Logistics System

Reparable assets are expensive items that can be fixed and used again, such as mission computers, hydraulic pumps, landing gears or jet engines. Every weapon system has an approved maintenance plan and for each reparable part there is an assigned depot shop or contractor who performs the required maintenance. Additionally, each weapon system has assigned depot warehouses for parts. Both the depot shops and warehouses are organized in the four Units of the MGD located in the cities of Quilmes, El Palomar, Río Cuarto and Córdoba. To support flight operations and maintenance activities, all the maintenance assets must be shipped from these locations to the Maintenance Groups and the reparable assets must be collected back after use for inspection or repair.

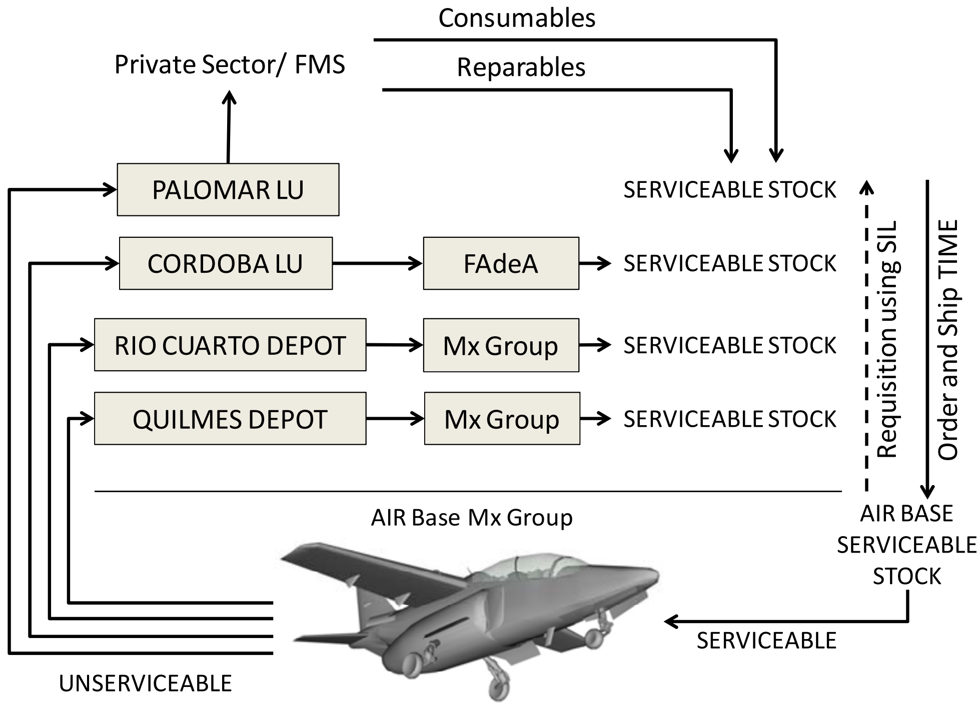


Figure 1. Conceptual maintenance assets pipeline.

Figure 1 shows the forward flow of serviceable assets and the retrograde flow of unserviceable assets in the pipeline. The reparable pipeline is essentially a closed loop system and although there are some unserviceable assets that cannot be repaired because of excessive wear or cost, most of them are conserved. This is true for all the depots except El Palomar Logistic Unit that additionally to its stable loop of reparables, introduces new assets to the pipeline from external suppliers. These new assets are mainly tires, filters and other consumables.

When a Maintenance Group requires a repairable or consumable part, the local warehouse checks first if there is stock available to satisfy the requirement. If the part is not in stock, the local warehouse places an order to the assigned Logistic Unit through the SIL, which is the information technology system established in 2007 by the MGD to improve the supply chain performance. This information system started as an operational level system to process data of routine operations such as aircraft status reports, fueling and movement of assets. Since then, it has been registering the movements of reparable parts with a slow learning curve, but since July 2012 it became mandatory to manage every single reparable part transaction.

Once the Logistic Unit responsible for supplying the required part checks its availability or repairs one for exchange, it places the part in its local air cargo terminal and informs the requestor that the part "has been made available". With no regular logistic flights, the part may wait there for days and sometimes weeks unless expediting action is taken, usually initiated by the requestor. This important part of the order fulfillment process has not been considered as part of the integrated logistic support that the MGD should offer. Some of the factors that contributed to this situation are:

- Airlift: The Douglas C-47 was grounded in 1990 and the IA-50 Guarani II in 1998 with no replacement (AAF, 2012). These medium and small transport airplanes were operated by the Air Bases and let them perform logistic flights in a decentralized way, picking up their reparable parts from the depots whenever they needed to. Furthermore, the fleet of Boeing

707 was grounded in 2005 and the Lockheed C-130 line considerably reduced. The flexibility that these cargo airplanes provided to the network was lost and since they were grounded, only one Squadron of C-130 Hercules and a couple of Fokker F-27 Friendship are available for this task. Some Fokker F-28 may be used for cargo but are mainly operated as passenger planes.

- Transportation Directorate: It is the Superior Logistics Agency for the transport function and with the assigned mission to plan, organize, manage and control all transportation activities. In the Director Plan 2014, the MGD observed that the Transportation Directorate was focused mostly on purchasing and supply management activities and consequently ordered the development of a transportation network and services as well as the associated processes.
- Information Technology: The SIL does not include yet a module for transportation management. An order placed in the SIL only affects the depot shop assigned to supply the part and it is considered closed once the depot places the part in its Air Cargo Terminal for shipping.

Although AAF air operations doctrine manuals describe the management of the airlift task and the logistics doctrine manuals describe the organization of transportation as a logistic function, these manuals apply for military conflict only. Among the subsidiary support tasks that the AAF performs in peace time, we have the Air Services for transportation of authorities, air transport between the units of the services, flights in support of declared emergency zones and required movement of police or security forces.

Regular air services are set when the frequency and nature of the airlift requirements justify scheduled flights and the success of the service is based on strict compliance with schedules on the same route, frequency, time and seat/ cargo hold offered. Special flights, instead, are unscheduled flights made upon request. If a special flight is required more frequently it can be changed to a regular flight.

Guidelines for AAF logistic management encourages thorough planning, flexibility to adapt to changing situations, centralized management and decentralized execution, continuous improvement and maximum system efficiency to achieve the goal with the least investment of resources (AAF, 2010). For example, a ground transport squadron of an Air Base is part of the logistics system and therefore is considered a decentralized executing agency of the transport logistic function, with functional relationship with the Transportation Directorate.

The AAF Logistics Management Manual (2010) states that the Transportation Directorate is responsible for the analysis of historical data and forecast of future demand, the planning and execution of transport activities, definition and specification of ground freight equipment and terminals, contracting of logistic services and technical advice for acquisition of future transport aircraft.

The decision of using organic transport capacity or for hire carriers must consider security, confidentiality, legal requirements, economy and efficiency. In planning transportation services, the Transportation Directorate should optimize the selection of routes, avoid empty backhauls and seek to operate at full load through cargo consolidation. However, the Logistics Management Manual (AAF, 2010) makes it clear that the search for efficiency in the transport services should not affect the effectiveness in meeting the requirements of users.

Although there are no air-express companies in Argentina, there are some third party logistics (3PL) companies with national coverage that operate motor carrier fleets and achieve high service levels, such as Andreani, Exologística, GEFCO, DHL and OCA. According to the Business Chamber of Logistics Operators (2014), 3PL companies have had a great impact in the growth of many manufacturing companies in Argentina, especially in the electronics, food and pharmaceutical industry and the e-commerce sector. The use of 3PL services boosted sales and market share of companies such as Hewlett-Packard, Brightstar Argentina, Merisant, Essen and the local Sarkany shoe brand.

Transportation Services

Crainic and Laporte (1997) identified some of the main issues in freight transportation and classified the levels of transportation planning as strategic, tactical and operational. The strategic level planning deals with general development policy decisions and broadly shapes the design and evolution of the physical network, the acquisition of major resources and the definition of services. The tactical level decisions involve the design of the service network while the operational lowest level implements and adjusts the schedules for services with the available resources. Planning also includes information and data flow that should follow the reverse hierarchical route with each level of planning supplying the essential information required at higher levels for decision making.

Strategic planning of freight transportation systems requires both demand and capacity measures to provide better accountability for transportation investment decisions. In general, the capacity of the system depends on the level of resources deployed and on the effectiveness at which these resources are utilized (Anupindi et al., 1012). Although capacity can have a broad interpretation, in transportation, it can be considered as the maximum flow rate (flow units per unit of time) that the system can move in a route or facility while capacity utilization is the ratio between used capacity (actual or forecasted flow rate) and practical capacity (capacity practically attainable). Park (2005) states that failure in many projects for capacity improvements can be attributed to a narrow view of capacity assessment. Underestimation of capacity can lead to excessive investment while overestimation can result in poor system performance. Consequently, the resulting transportation system will be effective if it supports the execution of the organization strategy and efficient if it operates at low cost.

At the tactical planning level, Crainic (2000) identified four issues that must be addressed by the decision maker:

1. Service selection: Routes serviced and characteristics of each service (Frequency and scheduling).
2. Traffic distribution: The itineraries used to move the traffic of each demand, including the terminals passed through and the operations performed in them.
3. Terminal policies: General rules that govern the consolidation activities performed in each terminal.

4. Empty balancing strategies: How to reposition empty vehicles and reset the service for the next planning period.

From a planning point of view, the long distance movement of parts is often referred as the service network design problem, while the short distance pick-up and delivery operations are usually identified as vehicle routing problems. In both cases, when the demand of several users is served by using the same vehicle, services cannot be customized for each user individually and thus, consolidation-type operations with regular services have to be established (Crainic and Laporte, 1997).

If we consider a low level demand route, consolidation results in a higher utilization of the equipment but creates additional unloading, consolidation and loading operations in some terminals and decreases the reliability of the service. On the other hand, more frequent direct services will be more responsive and reliable but will require additional resources and increase costs. To select the solution that better fits the user and the organization we need to simultaneously consider the routing of all demands and the costs and characteristics of each service offered on each arc. Additionally, trade-offs between operating costs and performance goals must be made (Crainic and Laporte, 1997).

The United States Air Force (USAF) Air Mobility Command (AMC) airlift is an example of an organic service network with consolidation-type operations. AMC channel services are monthly scheduled missions over a fixed route with capacity available to all customers and use a priority system to allocate airlift resources. On the other hand there are commercial air express carriers that showed to be more responsive to customer demands than organic airlift, being this one of the reason why the Department of Defense

(DoD) started to outsource shipping of all high priority cargo in the United States (less than 151 pounds) through air express small-parcel overnight carriers. According to Condon and Patterson´s (1997) research, when comparing military traditional organic transportation with Federal Express in the delivery of high priority cargo from United States to Germany, the private carrier showed to be faster in the ground transportation segments and in performing terminal activities.

In their review of the small package air freight industry in the United States, Chan et al. (1979) analyzed Federal Express operations in its early years and found that one of the factors that contributed to its competitive advantage was the hub-and-spoke concept with centralized operation in Memphis, allowing the carrier to operate in a rather intensive scale with a single break bulk and sorting facility. The initial low-density air freight between city pairs and the lack of available jet lift brought about the need to create an additional mini-hub in Pittsburgh and later another one in Salt Lake City. The hub-and-spoke concept (including the mini-hubs) showed to be economical for serving thin density markets by alleviating the pressure on the main hub while keeping a high system reliability and integrity with only one intermediate handling (at a hub) between the origin and destination.

Transportation Modal choice

When an organization relies on transportation to support lower inventory levels and faster cycle times or deal with shortage of reparable parts in the pipeline, modal choice becomes a critical management decision. It should find the lowest transportation cost that is still able to meet the requestor needs.

Each mode has its own characteristics, such as vehicle type, speed, capacity, reliability and cost and they can affect modal choice considerably. The decision maker has to weight each of their criteria to select the best value combination of modes for its transportation budget. According to Goulias (2003), all previous modal choice studies demonstrated the importance of understanding the nature not only of the freight, but also of the type of organizations and the geography involved in the problem.

To begin with, it is highly imperative to deeply understand the characteristics of the freight involved in the problem. Gradwell (2006) stated that there is a tendency to assume that most problems had a "normal" distribution and the bell-curve has become so much a part of our mental architecture that we tend to use it automatically. A thorough analysis of the complete range of part weight and volumes and their frequency of movements will reveal if we are dealing mainly with a small parcel problem with some infrequent heavy outliers, a bell-curve problem or vice versa.

As opposed to the private sector, military organizations weight service responsiveness and reliability heavier than cost when choosing a mode. This is mainly because effectiveness is more important than efficiency when dealing with mission accomplishment. However, current budgetary restrictions require supply chain managers to determine the optimal use of monetary resources for transportation. This does not imply that the norm should be to select always the most expensive air mode (organic or private air express) without considering the cost saving of using ground carriers able to meet the time standards required for delivery (Masciulli, 2001). Additionally, if the part is shipped by air and upon arrival is not used immediately or is stored for weeks, there is no logic behind paying a premium for expedited transportation.

There are a number of considerations that determine the mode an organization selects, which are summarized in Table 1.

Table 1. Key considerations in mode choice (Adapted from Chan et al., 1979).

Transport level of service attributes	Commodity attributes	Market attributes (as perceived at origin)	User attributes (at destination)
Wait time	Value	Price	Use rate
Travel time	Shelf life	Quality	Variability in use rate
Delivery reliability	Seasonality	Availability	Stockout situation
Loss and damage	Density	Production rate	Reorder cost
Cost	Perishability		Risk of stockout
Special services			
Packaging cost			
Handling costs			
Area served			
Convenience			
Tracking ability			

One of the more important reasons why an organization prefers to send their freight by air is time savings, especially for time sensitive or perishable packages. Chan et al. (1979) stated that much of this market was made up of critical items needed by requestors to solve stockage problems and almost 30% of all air freight was small in size and weight.

Although expedited shipping may justify a more expensive mode choice in the forward portion of the supply pipeline, speed may not be critical in the retrograde movement. Khaler (2004) evaluated if depot repair capacity should be used as a determinant of mode selection in the USAF retrograde transportation of parts. He found that USAF modal selection policy focuses only on the asset and directs expedited evacuation to the source of repair without considering depot repair capacity in the decision, which leads to over-expenditure of resources for premium air transportation when a slower and less expensive mode would have sufficed.

Prioritization policies

As previously described, the USAF uses a priority system to allocate airlift resources. The Uniform Materiel Movement and Issue Priority System (UMMIPS) is a structure that establishes time standards, based on the mission and urgency of need of the requestor, for the supply of materiel from the date of the requisition to date of physical receipt (DoDM 4140.01-V1, 2014). Priority designators are set accordingly to the force/activity designator (F/AD) assigned to the requestor unit and the relative urgency of need designator (UND) of the customer's requirement. Prioritization policy requires top leadership commitment, which is why the F/AD I is determined by the Chairman of the Joint Chiefs of Staff and approved by the Secretary of Defense while FA/D II through V are determined by the Chief of Staff of each service.

Additionally to these designators, a time definite delivery is defined for each pipeline segment in order to account for the time to meet customer requirements. Table 2 briefly describes the logic behind the UMMIPS. Time definite delivery codification may include letters, three digit numbers or a specific date to indicate special handling requirements:

1. 999: Expedited handling requirement for non mission capable supply overseas or customer deploying overseas within 30 days.
2. 555: Exception to mass requisition cancellation, expedited handling required.
3. N_: Expedited handling requirement for non mission capable supply customer.

4. E_: Expedited handling due to anticipated non mission capable supply requirement. Specific date indicates handling to meet that date of delivery.
5. 777: Expedited handling requirement for other than the above reasons.
6. Blank time definite delivery indicates routine handling.

Table 2. UMMIPS priority designator and time standards (Adapted from Condon and Patterson, 1997)

Priority Designator		UND		
		Cannot Perform Mission	Mission Capability Impaired	Firm Rqmt & Stock Replenishment
F/AD		A	B	C
COMBAT	I	1	4	11
COMBAT READINESS	II	2	5	12
DEPLOY READINESS	III	3	6	13
ACTIVE & RESERVE	IV	7	9	14
OTHER	V	8	10	15

PIPELINE SEGMENTS (Days)	Priority 1 (1-3)	Priority 2 (4-8)	Priority 3 (9-15)
Requisition Submission	1	1	2
Passing Action	0.5	1	1
Inventory Control Point Availability Determination	1	1	1
Depot/ Base Processing and Packaging	1	1	5
Transportation Hold and Intransit	1	4	10
Receipt take-up by Requisitioner	0.5	1	3
TOTAL	5	9	22

Although the AAF Logistic Management Manual (2010) mentions the need of prioritization criteria for the cargo, there is no formal procedure that describes how to do it. Furthermore, if a logistic flight arrives to an Air Cargo Terminal, the load master will load first what is stated in the Air Transport Order, and if there is still available space, he will load what the Air Cargo Terminal “has been made available” but with no prioritization identification whatsoever.

Mathematical Models

Modeling is an important part of most decision-making processes and in order to simplify the analysis, we must focus first on the core elements, their key relationships and the data that are available in order to understand as much as possible the current situation and how it may evolve in the future (Hensher et al., 2005). Although operational research-based models combined with modern computing power may assist in the analysis and decision making process, it is impossible to take into account every factor and influence.

The models for planning intercity freight operations usually take the form of network design formulations that are difficult to solve, requiring the use of mathematical programming or heuristics. Mathematical programming deals with the optimization of an objective function subject to a set of constraints while heuristic methods can provide good solutions quickly and can be combined with optimization models to solve complex problems. Linear Programming problems represent a special category of mathematical programming problems in which the contribution of any decision variable to the objective function or any constraint is directly proportional to its value and has no effect on the contribution of another decision variable, thus resulting in linear equations.

Ragsdale (2008) describes different applications of generalized network flow problems and how to formulate and solve them. Minimum cost network flow problems are useful to determine how many units of flow should be moved across each of the arcs of a network to minimize the total cost incurred to satisfy the demand.

As described by Crainic and Laporte (1997), the simplest version of a transportation network problem is the shortest spanning tree problem where the objective is to determine the minimal length tree that joins a graph G (N, A) of nodes N and arcs A. Similarly, minimum cost network flow model can be defined as G(N, A) containing a set of supply or demand nodes N and a set of arcs A on which transportation activities are carried out. Typically, these arcs are directed, representing the direction of flow from one node to the next. The movement of freight through an arc is the result of the supply from an origin node that is shipped to satisfy the demand of a destination node. Additionally, the movement from one node to another is subject to a penalty (distance, transit time or cost) and in some cases a capacity constraint. A minimum cost network flow formulation would be:

$$Minimize \sum_{(i,j) \in A} c_{i,j} x_{i,j}, \qquad (1)$$

Subject to:

$$\sum_{j \in N} x_{i,j} - \sum_{j \in N} x_{j,i} = d_i, \qquad i \in N, \qquad (2)$$

$$x_{i,j} \leq u_{i,j}, \qquad (i,j) \in A, \qquad (3)$$

$$x_{i,j} \geq 0, \qquad (i,j) \in A, \qquad (4)$$

In this model $x_{i,j}$ are real valued decision variables representing the flow of units of flow through arc *(i,j)*; $c_{i,j}$ the transportation cost per unit of flow on arc *(i,j)*; $u_{i,j}$ the capacity of the arc *(i,j)*; d_i the demand at node i. The objective function (1) selects arcs along with capacities in order to satisfy the demand at the lowest possible system cost. Constraint (2) assures that the balance-of-flow rule between inflow and outflow at each node is satisfied. Ragsdale (2008) states that in order to apply balance-of-flow rules correctly, we must first compare total supply (with negative sign in supply nodes) with total demand and then formulate the corresponding constraint for each case. In this particular minimization problem, the equality in the constraint implies that total supply equals total demand, but this is not always the case. Constraint (3) limits the flow in an included arc *(i,j)* to its capacity $u_{i,j}$ and the remaining constraints specify nonnegativity conditions for the decision variables. A simplified uncapacitated formulation can be made without constraint (3) or by setting a non binding capacity $u_{i,j}$ in the formula.

This basic model has been used as the basis for solving different network problems and offers flexibility to create different scenarios and conduct what-if analysis. Depending on the level of detail required, some nodes may be expanded with dummy nodes and arcs between these nodes to capture the related cost or delay of transshipments. With this layout, a path result from a set of feasible arcs between a source node and a demand node including directed arcs on one mode, a possible transshipment to another mode, directed arcs on the second mode and so on (Park, 2005).

The Supply Chain Management perspective

From a supply chain perspective, every organization exists as part of a supply chain network and the management of that network is Supply Chain Management. According to the Global Supply Chain Forum of the Ohio State University, managing a supply chain is a very challenging task and requires involvement of the six business functions which may include purchasing, production, finance, logistics, research and development, and marketing and sales. Corporate success requires cross-functional and cross-firm involvement, integrating relationships and activities into supply chain management processes with the goal of creating the most value not only for a firm but the supply chain network including the end customer. Implementing supply chain management involves identifying key organizations with which it is critical to link, the processes that need to be linked and the level of integration that each of these links requires (Lambert, 2014). Figure 2 shows the eight processes in the framework developed by The Global Supply Chain Forum.

Each of the eight supply chain management processes has a strategic and operational sub-process. The strategic level deals with implementation structure, design and integration with other members of the network, while the operational level deals with day-to-day activities with detailed steps for execution (Lambert, 2014).

In the case of the AAF, the design of a distribution network and the associated processes requires integration and coordination among different organizations, mainly through the development of the customer service management process, the demand management process and the order fulfillment process. The customer service management process focuses on the development of standardized response procedures to proactively identify situations that may affect the customers and minimize service failure.

The demand management process focuses on forecasting demand, finding ways to reduce demand variability, determining the level of flexibility needed to respond to the remaining variability and the implementation of contingency plans to efficiently and effectively react to unexpected situations (Lambert, 2014).

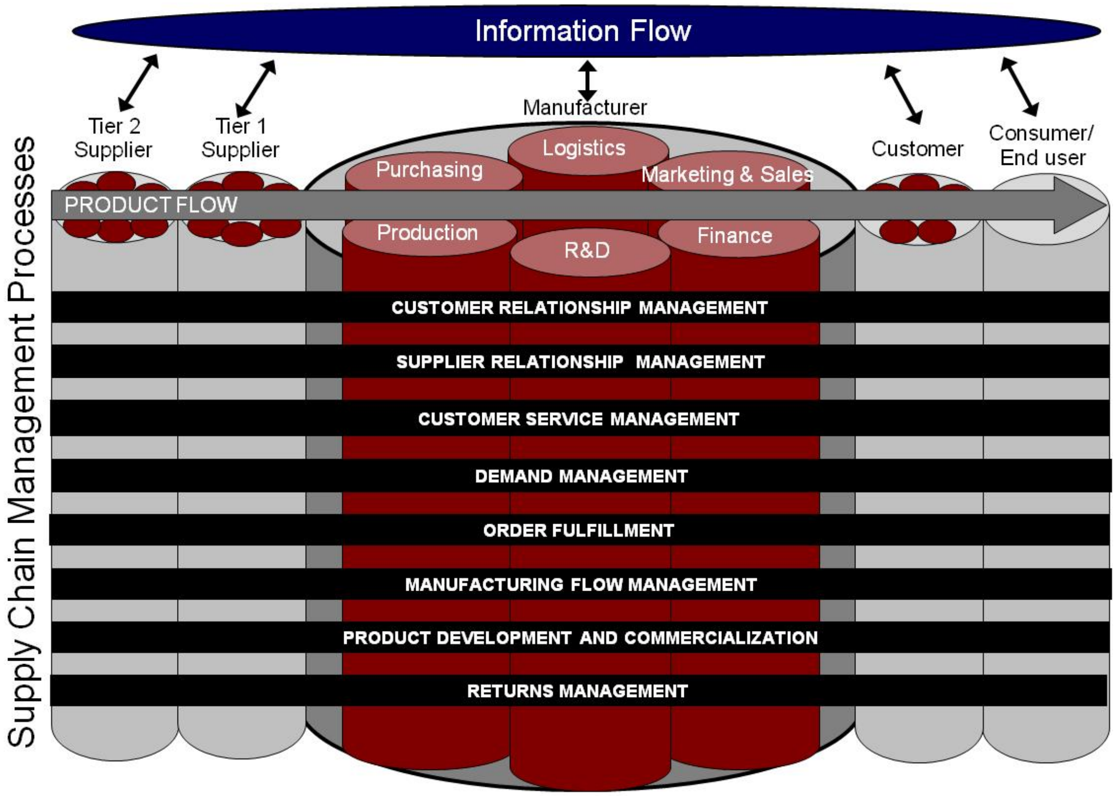


Figure 2. The Supply Chain Management framework.

Finally, the order fulfillment process deals with the design of the distribution network, modal choice, warehousing, transportation and order tracking to cost-effectively meet customer needs. Although this process is often viewed as a transactional logistics activity, it cannot be designed without the support of information technology and the input from other functional areas such as marketing, finance, purchasing and production (Lambert, 2014).

Conclusion

The AAF maintenance assets distribution process relied for many years in the use of small and medium transport aircraft that were operated by different units to perform logistic flights in a decentralized way. When these aircraft were grounded and the remaining fleet of bigger cargo planes was reduced, the distribution network lost flexibility and the lack of synchronization between the members of the supply chain resulted in a low customer service level.

This situation was observed in 2014 by the Materiel General Directorate and the maintenance assets distribution network was selected as one of the areas that required immediate improvement. The Transportation Directorate and the SIL information technology tool are two key players in the implementation of an efficient and effective distribution network. Nevertheless, according to the supply chain management framework, this endeavor will require cross-functional and cross-organization involvement of all the business functions to create the most value not only for the Transportation Directorate but the whole AAF and its supply chain, including the end user.

The design and implementation of the distribution network requires data from different areas of the AAF and the support of information technology. Among the data that is needed to implement the solution are the characteristics of the freight involved, the level of demand and its variability and the cost and characteristics of the service offered on each route. Policy making like prioritization codes can help in reducing the demand variability but decisions must be made to determine the customer service level, the level of flexibility needed to respond to the remaining variability, the contingency plans for unexpected situations and the mode choice to fulfill the orders in the required delivery time.

Previous research has shown that in low-level demand routes, consolidation results in higher utilization of equipment at the cost of additional terminal operations and reduction in service reliability. Other studies added that when the demand of several users is served by the same vehicle, regular consolidation-type operations have to be established. Network design such as the hub-and-spoke concept together with other mini hubs was found as one of the factors that contributed to the competitive advantage of air freight companies like Federal Express, when dealing with low available jet lift on low-density air freight routes. Finally, mathematical programming models and heuristics can help to minimize costs of network problems and can be customized to adapt to different scenarios and perform what-if analysis.

With all these factors influencing the solution we must keep in mind that, in designing military processes, the search for efficiency should not affect the effectiveness in meeting the requirements of the users. Nevertheless, trade-offs between operating costs and performance goals must be evaluated.

III. Methodology

Chapter Overview

The purpose of this chapter is to describe the steps followed to optimize the AAF maintenance assets distribution network. Using the investigative questions defined in Chapter I and the literature review as a guide, main subject areas were addressed individually to analyze the most significant factors influencing this research.

The chapter begins with a description of the organizations and the geography involved in the problem to determine infrastructure constraints that affect network design, modal choice and level of service. It continues with the analysis of the freight involved in the problem to deeply understand its physical characteristics and the way it shapes the transportation demand of each unit. Finally, the procedure used to determine the capacity for consolidated-type operations and evaluate costs is explained.

Characteristics of the network

This section analyzed the characteristics of the Units involved in the problem and the geographical and infrastructure constraints that affect the design of the distribution network. The Units included in this research are the following (codification in parenthesis):

- Materiel Command depot shops:
    - Quilmes depot (13ILM): Maintenance of electrical and radio/ navigation equipment, instruments, propellers and other. It also performs inspections on airframes of helicopters and DHC-6 transport aircraft. It has a Class A unpaved runway for small aircraft but most of the time is inoperative.

- Rio Cuarto depot (11TRC): Maintenance of avionics, hydraulic, fuel and mechanical equipment, piston engines, ejection seats and other. It also performs inspections on Mirage III/ V, A-4AR and EMB-312 Tucano aircraft. It has a paved runway.

- Materiel Command Logistic Units:
    - El Palomar Logistic Unit (14ALP): Manages consumables and reparable parts that are overhauled or repaired by private contractors or through Foreign Military Sales. It does not have a runway but it is adjacent to El Palomar Air Base.
    - Cordoba Logistic Unit (12ALC): Manages maintenance contracts with the local FAdeA (Fabrica Argentina de Aviones Brigadier San Martin), a national company that performs maintenance mainly on turbo-shaft engines, propellers, hydraulic, fuel and pneumatic parts, structural components and some instruments. It also performs some depot inspections on airframes of IA-58 and IA-63 attack aircraft and C-130, Fokker F-27 and F-28 transport aircraft. It does not have a runway but it is close to the Air Force Academy.
- Readiness and Training Command:
    - I Air Base El Palomar (1PAL): Operates C-130 Hercules transport aircraft.
    - II Air Base Parana (1PAR): Operates F-27 turboprop transport aircraft and Learjet 34A.
    - III Air Base Reconquista (3RTA): Operates IA-58 Pucara, a light attack twin-turboprop airplane.

- IV Air Base Mendoza (4DOZ): Operates IA-63 Pampa, a light attack and intermediate-advanced jet trainer and also SA-315B Lama helicopters for search and rescue (SAR) missions in the Andes.
- V Air Base Villa Reynolds (5RYD): Operates Lockheed A-4AR Fightinghawk fighter/ attack aircraft.
- VI Air Base Tandil (6DIL): Operates Mirage III and Mirage V jet aircraft.
- VII Air Base Moreno (7ENO): Operates Hughes-500D, Bell 212, Bell 412 and Mi-171E helicopters. (SAR/CSAR).
- IX Air Base Comodoro Rivadavia (9CRV): Operates DHC-6 Twin Otter turboprop light transport aircraft and Saab-340 regional passenger aircraft. It is the most extreme Unit in the network, requiring two days of driving time to be serviced from Buenos Aires, being a candidate for air service or outsourcing.
- VYCA Base Merlo (15VYCA): Headquarters of the Ground-controlled Interception System and warehouse of 3D radar spare parts.

- Education General Directorate
    - Moron Air Base (8MOR): Operates small piston engine airplanes for training of civil pilots.
    - Air Force Academy (10ESC): Operates the Grob-120 basic trainer and Embraer EMB-312 Tucano turboprop trainer.

With the exception of Comodoro Rivadavia Air Base, all the arcs of the network are less than 10 hours of driving time. Antarctic bases, anti-aircraft weapon systems units and bases used for training or operation deployments only were excluded for the analysis. Figure 3 shows the maintenance assets distribution network.

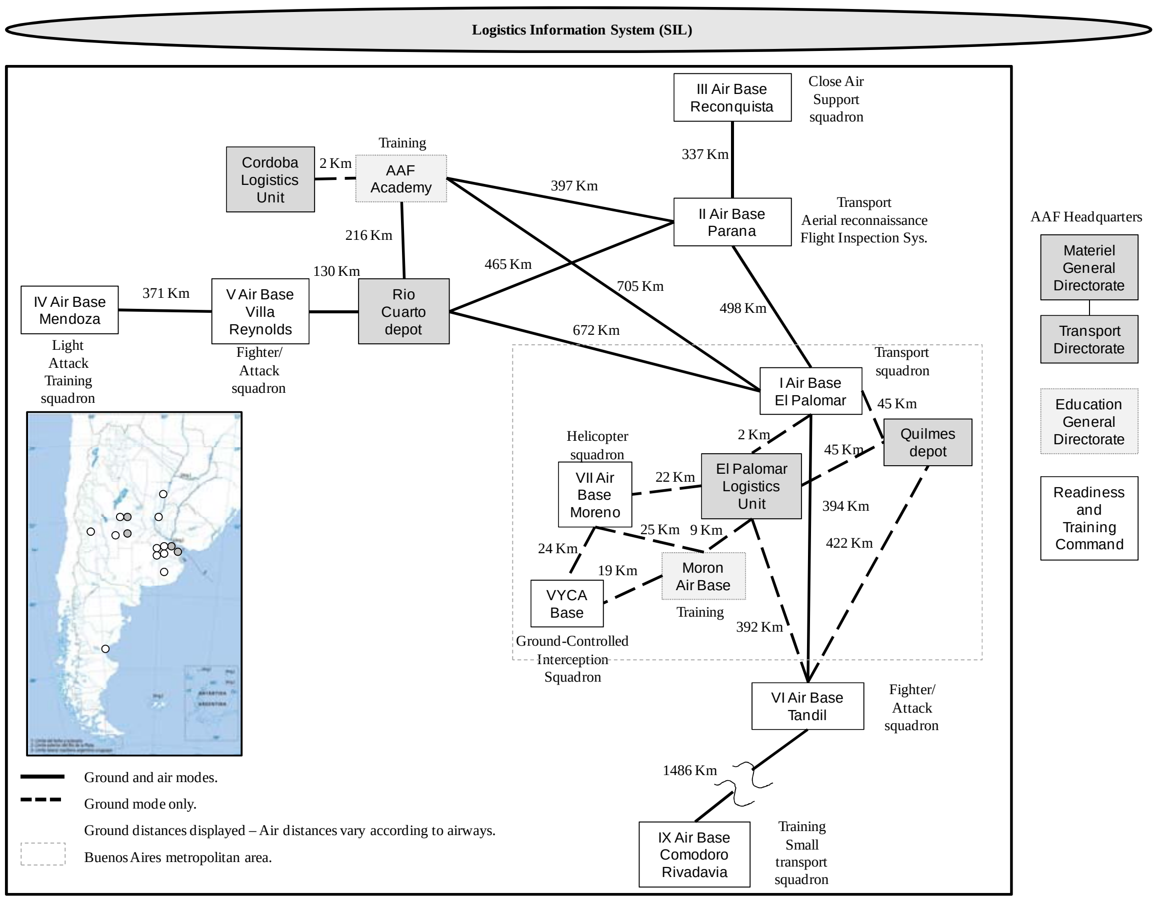


Figure 3. Maintenance Assets distribution network.

As shown in Figure 3, Quilmes depot and Merlo Base cannot be linked to the network by air because they do not have an operative runway. Although there is an unpaved runway in Quilmes it is not always operational. Therefore, due to the short distances between the depots and bases in the Buenos Aires city metropolitan area, these arcs were considered for the ground mode only.

Another particular characteristic of this network is that each base operates a different type of aircraft. Demand for a reparable part for an A-4AR for example, can only be generated by the V Air Base Villa Reynolds (user) and by the Maintenance Group of the depot that performs major inspections on the airframe (Rio Cuarto depot in this case). Similarly, the only supplier for that part will be the depot assigned to repair it. As there is no duplication of maintenance capacities, no other depot can satisfy that order.

The distances between bases were obtained using the Google Maps Directions function and whenever possible, highways were selected to increase transportation safety and reliability. Excluding the metropolitan areas of Buenos Aires and Cordoba, there are currently only four city pairs that are joined by highways: Buenos Aires-Parana, Buenos Aires-Cordoba, Rio Cuarto-Villa Reynolds and Villa Reynolds-Mendoza.

Flight distances between bases were provided by the AAF and were obtained from aeronautical charts and cartography, following the flight procedures and airways for each origin and destination.

Demand analysis

The demand data was extracted from the AAF Logistic Information System (SIL). As described in Chapter 1, every movement of reparable parts between the Logistic Units and the Maintenance Groups is registered in this database. The data from January 2008 to June 2014 inclusive was received in Microsoft Excel® format and required significant filtering to get to the usable records. The relevant columns used for the analysis included:

1. National Stock Number (NSN).
2. Description of the item.

3. Transaction number.
4. Class of transaction.
5. Origin.
6. Destination.
7. Date of transaction.

Considering that previous to 2012 the SIL was in a training and implementation phase and transaction records in the system were not mandatory, these early data was not considered representative of the real demand. This work was based on the analysis of the remaining 30 months from January 2012 to June 2014 inclusive.

Two important parameters needed for the analysis were missing: weight and volume of each of the 2130 NSN involved. Although this task may seem as simple as extracting the NSN weight and volume from the Federal Log, it became very difficult when dealing with parts of non-American equipment. Nevertheless, the MGD through its Planning Department coordinated and expedited the effort with all the Maintenance Groups to make the data available by November 2014. The weights and volumes provided included packaging and allowed to complete 77% of the 15,838 transaction lines in the data base. The remaining 23% of the data was approximated by alternative or similar assets, based on the description of the NSN and its weapon system applicability.

The process of getting to the usable records started out with filtering the forward from the retrograde movements out of the data. As shown in the Figure 4, the columns in grey represent the orders placed in the SIL by the Maintenance Groups to request a serviceable asset to the source of supply and at the same time the repair of the unserviceable one. Although this is the actual demand in the pipeline, it also represents the requirement for retrograde transportation of the unserviceable assets to the depots. On the other hand, the grey rows represent the forward supply of serviceable assets that the distribution network needs to move from the sources of supply to the final users. Considering that the forward flow of assets in the pipeline is affected by many factors including budgetary constraints at the production level, production delays due to backorder of higher indenture components or obsolescence issues, the data used to design the network was the demand from the Maintenance Groups.

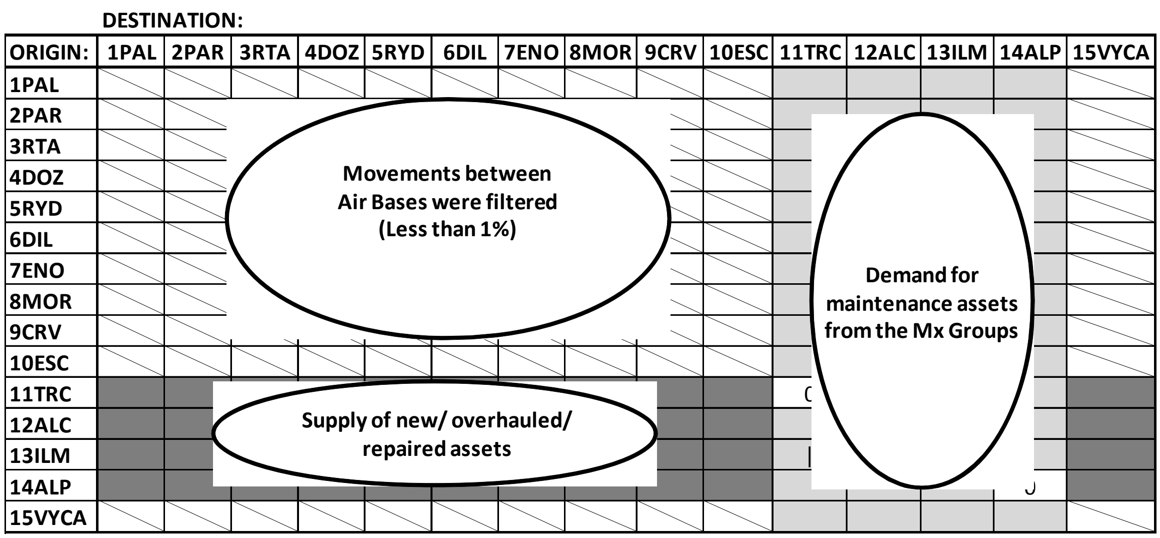


Figure 4. Filtering of data procedure.

To extract the individual demand from each Unit to each of the sources of supply, the data were filtered following the steps described herein. First, the transactions generated by Units other than the fifteen included in the analysis were deleted (some of these transactions were captured by combining them with those of the closest remaining Unit). The movements of assets between Air Bases were also discarded (only 171 movements). Then, using spreadsheet filtering formulas the requirements originated at each Unit were filtered by destination. In the case of the four sources of supply, daily aggregation of orders (or associated weight) was calculated and additional tables were made with the aggregation of orders in a weekly and monthly basis. After this, the demand of each Unit was analyzed individually to observe its variability in time and frequency. With the use of JMP® statistical software, histograms were plotted to observe the shape of the distribution and calculate descriptive statistics. Figure 5 shows the data analysis process.

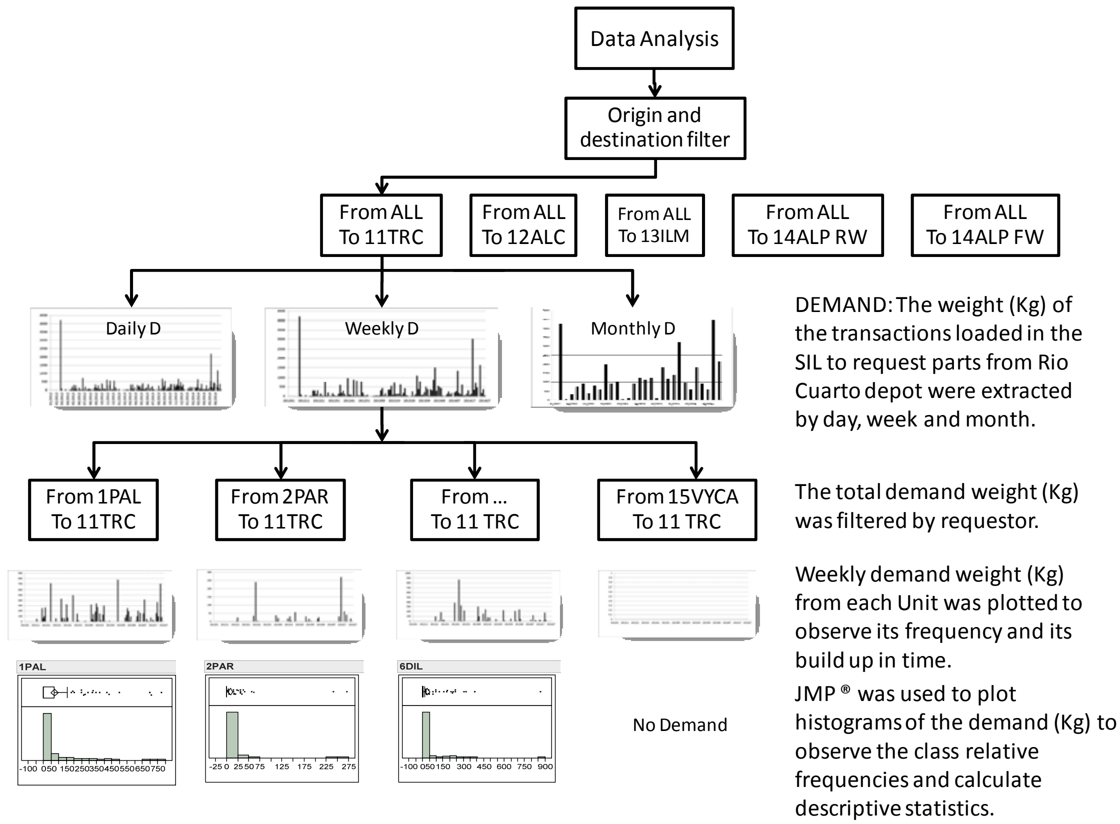


Figure 5. Data analysis.

Finally, descriptive statistics of the demand from each Unit to each source of supply was recorded in tables similar to the one in Figure 4 to calculate the input to be used to solve the minimum cost network flow problem of each supplier. The discussion about the numerical measures of central tendency and variability and the decision of which input to use in the model will be explained in Chapter 4.

Capacity assessment and cost analysis

The maintenance assets distribution network was designed based on a weekly regular service and consolidation-operations, based on the concepts discussed in the literature review. A weekly service was considered appropriate for the Argentine Air Force based on the low demand in the network. As a reference, Table 2 shows the time standards used by the United States Air Force to meet customer requirements being 5 to 9 days for priority designators 1 and 2, which makes a weekly distribution reasonable for the size, geographical spread and level of activity of the Argentine Air Force.

Considering the importance of developing the Argentine Air Force Transportation System, the network design considers the use of organic vehicles. The following steps describe the methodology used to determine the capacity required to satisfy the current demand of transportation of maintenance assets:

1. Filter and perform statistical analysis on the data to determine the DEMAND generated by each requestor to each of the suppliers.
2. Solve a Minimum Cost Network Flow Problem for each supplier individually.
3. Aggregate on all the arcs the resulting weight of assets flowing in the network to satisfy the demand of requestors from each supplier (Results of each Minimum Network Flow Problem).

4. Calculate the CAPACITY needed on each arc to support consolidated operations.
5. Evaluate the cost of assigning different vehicles to each arc and evaluate opportunities for cost savings.

The first step was already explained in the previous section, where the demand to load in the minimum cost network flow problem built for each supplier was calculated.

For the second step, five uncapacitated minimum cost network flow models were used. For Rio Cuarto depot, Cordoba Logistic Unit and Quilmes depot, the flow of reparable assets is a closed loop and for every asset shipped to fulfill an order, it is assumed that a defective asset will be collected back for repair, generating a balanced flow. That is not the case for El Palomar Logistic Unit that operates as an open loop with inflow of mainly consumable and some reparable assets from external suppliers, resulting in an unbalanced flow and requiring a separate analysis for the forward and retrograde movement of assets, being the fourth and fifth models.

Each minimum cost network flow problem was based on the equations presented in the literature review and used equation (1) for the objective function, equation (2) for the balance of flow constraints that determine the links between each supplier with its customers and equation (4) for non-negativity of the decision variables. The decision variables used represent the weight (Tons) of assets moved on each arc to satisfy the demand of the customers with the minimum cost, using the variable cost per ton Km of a truck. The goal of this step was to obtain the arcs used to satisfy the demand from each supplier and the flow (Tons) of assets on each of theses arcs.

The third step was the post processing of the results obtained from the models to aggregate in a spreadsheet the resulting flows of assets generated by each supplier on each arc of the network and the fourth step was the calculation of the capacity that the network must provide on each arc. Instead of solving a single aggregated network flow problem, the solution of individual models was considered to present a more realistic picture of the current network, which includes most of the arcs and where the opportunities and trade-offs of cost reduction could be detected and analyzed.

Finally, based on the capacity required on each arc, the cost of assigning different vehicles to each arc was calculated. Cost savings opportunities were analyzed as well as trade-offs between cost and in-transit-time when using aircraft in some arcs. These results can be used to assist in the development of policies to reduce variability of demand and procedures to determine transportation equipment specifications to add flexibility to the distribution process or make informed outsourcing decisions. The results will be presented in the next Chapter.

Assumptions

There are eight necessary assumptions that need to be made in order to model the maintenance assets distribution process as a deterministic event:

1. The data extracted from the SIL represent the total amount of the orders placed by the Maintenance Groups to the sources of supply.
2. Inventory at the local warehouses are at critical level, requiring weekly replenishments.

3. There is enough capacity or stock at the source of supply to fulfill an order when placed by the Maintenance Group.
4. The characteristics of the vehicles considered for the analysis are those in Table 3.
5. The cost structure of the vehicles considered for the analysis is defined in Table 4 and 5 (costs in dollars). The effect of product density in the variable cost is described in Table 6.
6. The product density is 54.745 Kg/m^3 (3.418 lbs/ft^2), based on the median density of all the weekly aggregated orders extracted from the data base.
7. For the post process cost calculations, the only costs incurred in the movement of assets are the vehicle variable and fixed costs. Fixed cost of terminals were not included.

Table 3. Vehicles considered in the model.

Vehicle characteristics	Truck with semitrailer 	Utility Vehicle 	Lockheed C-130H 	Cessna C-208B 
Speed (Km/h)	80	80	537	296
Speed urban area (Km/h)	40	40	-	-
Max. load (Ton)	26.900	1.465	20.400	1.466
Max. Volume (m^3)	67.08	14.00	41.87	12.70

The density of the commodity impacts the maximum weight that the vehicle can haul and consequently the shipment cost. To load a vehicle with low density products results in a filled truckload before reaching its maximum weight capacity and a higher cost per Ton. The opposite situation happens when loading a vehicle with high density products, where a greater amount of weight can be hauled resulting in a lower cost per Ton. Table 6 describes this effect on the variable cost of the vehicles.

In the case of the truck, if the product density is less than 0.401 Ton/m3 the maximum weight capacity of the vehicle (26.9 Tons) would not be reached causing the cost per Ton Km to increase. For products with a density of 0.055 Ton/m^3(3.418 lbs/ft^2), as assumed for the maintenance assets, the truck will be able to load only 3.672 Tons causing an increment of 28 cents in the variable cost per Ton Km. This will be considered for consolidation in the analysis of the results.

Table 4. Cost structure of motor carrier vehicles (dollars).

		Truck			Utility Vehicle		
	Cost Item	Annual	%	Per Km	Annual	%	Per Km
Fixed Cost	Depreciation on vehicle	9,777.8	5.04%	0.065	4,808.9	9.50%	0.048
	Interest on vehicle	4,496.0	2.32%	0.030	1,686.4	3.33%	0.017
	Management and overhead	1,500.0	0.77%	0.010	1,500.0	2.96%	0.015
	Total Fixed Costs	15,773.8	8.13%	0.105	7,995.3	15.79%	0.080
Variable Cost	Fuel-oil costs	96,666.7	49.82%	0.644	21,481.5	42.42%	0.215
	Repair and Maintenance	24,444.4	12.60%	0.163	5,000.0	9.87%	0.050
	Truck insurance	6,666.7	3.44%	0.044	2,444.4	4.83%	0.024
	Tires	21,467.0	11.06%	0.143	2,220.0	4.38%	0.022
	Drivers Per Diem	29,000.0	14.95%	0.193	11,500.0	5.93%	0.115
	Total Variable Costs	178,244.8	91.87%	1.188	42,645.9	84.21%	0.426
		Based on a Mercedes Benz Atron 1634 + semitrailer - 150,000 Km per			Based on a Mercedes Benz Sprinter 415 CDI 3665 - 100,000 Km per year		

Table 5. Cost structure of cargo aircraft (dollars)

		C-130				C-208B			
	Cost Item	Annual	%	Per FH	Per Km	Annual	%	Per FH	Per Km
Fixed Cost	Depreciation on aircraft	148,148.1	2.97%	269.36	0.910	65,000.0	20.02%	162.50	0.549
	Interest on aircraft	272,000.0	5.45%	494.55	1.671	74,800.0	23.04%	187.00	0.632
	Management and overhead	540,605.4	10.82%	982.92	3.321	13,200.0	4.07%	33.00	0.111
	Total Fixed Costs	960,753.5	19.23%	1746.82	5.901	153,000.0	47.12%	382.50	1.292
Variable Cost	Fuel-oil costs	1,842,825.5	36.89%	3350.59	11.320	147,400.0	45.40%	368.50	1.245
	Repair and Maintenance	2,162,421.5	43.29%	3931.68	13.283	12,800.0	3.94%	32.00	0.108
	Crew Per Diem	29,000.0	0.58%	52.73	0.178	11,500.0	3.54%	28.75	0.097
	Total Variable Costs	4,034,247.0	80.77%	7334.99	24.780	171,700.0	52.88%	429.25	1.450
		Based on AAF cost data - 550 flight hours per year.				Based on Aviaser S.A. cost data - 550 flight hours per year.			

Table 6. Impact of the density in transportation variable costs (dollars)

Product density - Effect on variable cost						
Vehicle	**Truck - Capacity of 26.9 m^3**			**Utility vehicle - Capacity of 1.465 m^3**		
Product density (Ton/m^3)	0.055	0.185	0.401	0.055	0.185	0.401
Shipment weight (Ton)	3.672	12.410	26.900	0.766	1.465	1.465
Variable Cost per Km	1.1880	1.188	1.188	0.4260	0.426	0.426
Variable Cost per Ton Km	0.3235	0.096	0.044	0.5558	0.291	0.291
Aircraft	**C-130H - Capacity of 41.87 m^3**			**C-208B - Capacity of 12.7 m^3**		
Product density (Ton/m^3)	0.055	0.185	0.487	0.055	0.185	0.487
Shipment weight (Ton)	2.292	7.746	20.400	0.695	1.466	1.466
Variable Cost per Km	24.7800	24.780	24.780	1.4500	1.450	1.450
Variable Cost per Ton Km	10.8107	3.199	1.215	2.0855	0.989	0.989

IV. Analysis and Results

Chapter Overview

This Chapter presents the statistical analysis of the freight involved in the problem, the resulting flows of assets obtained from the minimum cost network flow models and the post process made to calculate the capacity and costs of the network. The statistical analysis was made using JMP® V10 software and the linear programming model was developed in Microsoft Excel® and solved using the Premium Solver (for education) V70 platform.

The main contributions of this work are twofold. First, the relationships between the different factors involved in the distribution of maintenance assets were studied and analyzed to support the strategic processes required to design and manage the distribution network. Secondly, an optimization methodology was proposed to be integrated in the decision making, which is expandable to design large scale networks. Three subsections, each focusing on one of the following aspects, present the results:

1. Historical data was studied to determine the main suppliers and customers of the network and their comparative position. Additionally, the weight and volume of the weekly demand of assets to be shipped were analyzed in order to determine the capacity required to satisfy the current demand.
2. Based on the capacity required to support consolidation-type operations, the costs of assigning different types of vehicles was calculated for combination of vehicles and airlift with C-130 or C-208B Grand Caravan.

Finally, a hub-and-spoke network design was proposed and cost savings opportunities were studied to reduce costs where possible.

Results of data analysis

Applying the filtering methodology described in Chapter 3, the 15,838 transactions of the complete 30 months of data were divided into two main groups: 7,411 transactions (47%) for to the forward movement of assets and 8,427 transactions (53%) for the retrograde movements in the network. Considering the assumption made that there is stock at the source of supply to satisfy an order when placed by the customer and that the pipeline is a closed loop, we must consider that for each serviceable reparable asset moved forward, there is an equivalent unserviceable core collected back to be repaired or overhauled by the supplier. Nevertheless, as shown in Figure 1, there is an open loop through El Palomar Logistic Base with a considerable inflow of new consumable and reparable assets from external suppliers such as Foreign Military Sales.

Consequently, this open loop affects the balance between forward and retrograde transportation for this supplier requiring the analysis of this inflow as an individual flow in the forward portion of the network. Figure 6 shows the three flows of assets and the network; the transportation services must be designed with enough capacity to move the orders placed by the customers (53%), the inflow of new assets from El Palomar Logistic Unit (27%) and backhaul the unserviceable assets for repair.

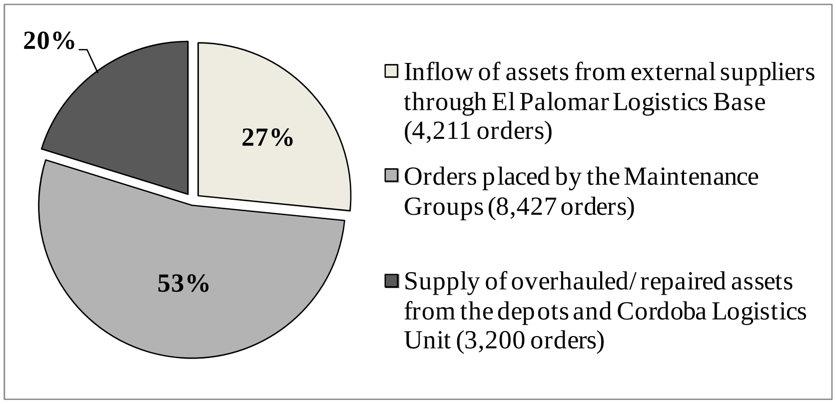


Figure 6. Three flow of assets in the network (30 months).

Given that customer relationship management and supplier relationship management form the framework for all linkages through the supply chain, it is important to visualize who are the customers and suppliers that are going to require more transportation resources. Figure 7 shows the percentage of orders placed by each of the units including the depots and Logistic Units while Figure 8 shows the percentage of orders placed to each supplier. .

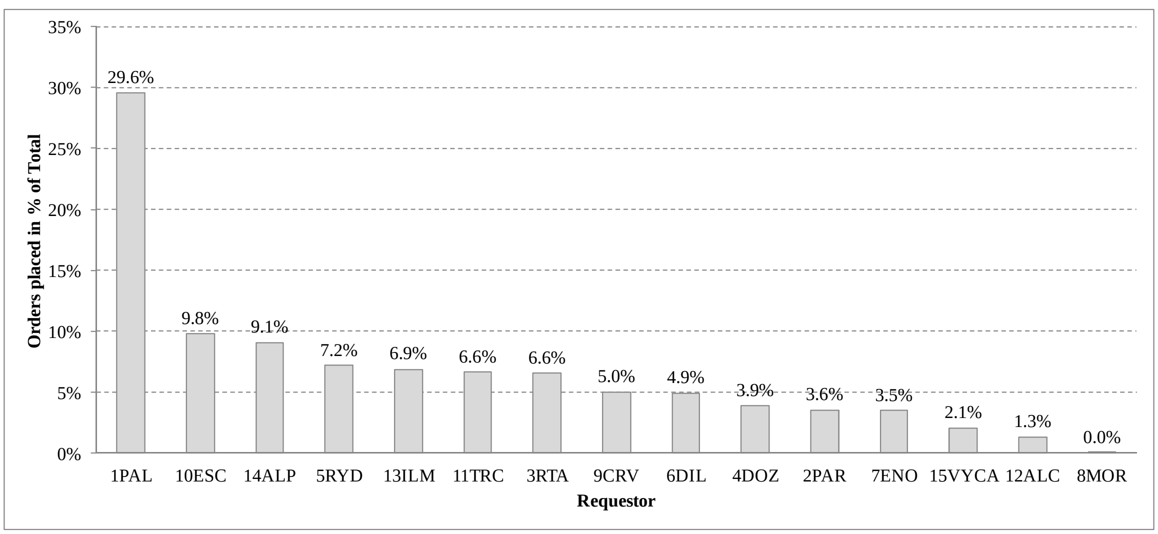


Figure 7. Orders placed by requestor in percentage of total.

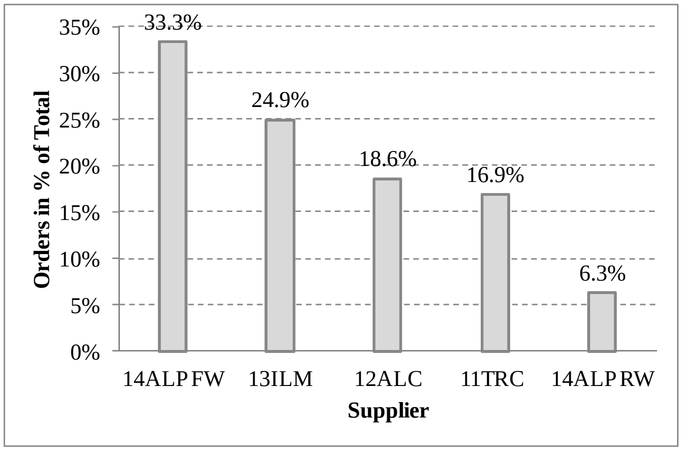
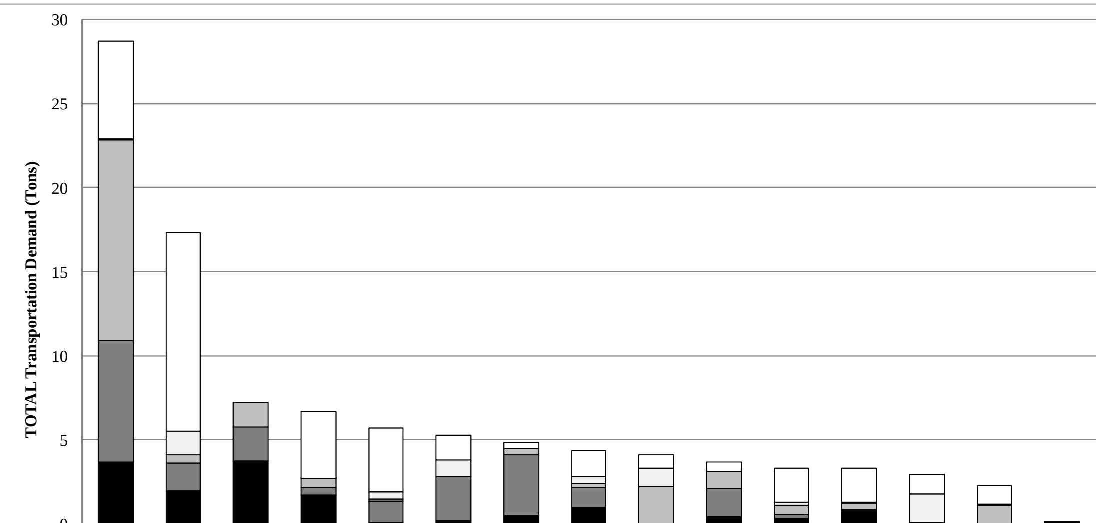


Figure 8. Orders placed to suppliers in percentage of total.

Based on the orders place by each unit, Figure 9 shows the annual average weight of the historic transportation demand by requestor and the contribution of each source of supply to it. When comparing it with Figure 7, El Palomar Air Base is still the unit with the highest demand in tonnage but other units shifted positions mainly affected by the inflow of assets from El Palomar Logistic Unit, showing the importance of analyzing this flow separately. Turbojet or turbo propeller engines are among the heaviest assets moved in the network and impact directly on tonnage demand for Villa Reynolds (A-4AR attack aircraft) and Tandil (Mirage Aircraft). Figure 10 shows the annual average weight of the historic transportation demand by supplier.

The frequency in which each unit places orders and the weights and volumes associated with each order were analyzed to determine the most appropriate numerical measures of central tendency and variability to use to describe the demand as a deterministic event. High variability in demand were observed across all the units as illustrated in Figure 11 that shows the weekly historical demand from all requestors to Quilmes depot, being the demand for assets produced by this depot the most stable.

Appendix II shows the bar charts of weekly historical demand from all requestors to each Logistic Unit.



	1PAL	5RYD	14ALP	6DIL	11TRC	13ILM	3RTA	4DOZ	9CRV	2PAR	10ESC	12ALC	15VYCA	7ENO	8MOR
14ALP FW	5.804	11.797	0.000	3.938	3.752	1.464	0.352	1.540	0.785	0.563	2.042	2.026	1.197	1.117	0.000
14ALP RW	0.070	1.374	0.000	0.032	0.428	1.009	0.000	0.417	1.094	0.000	0.203	0.021	1.709	0.076	0.000
13ILM	11.929	0.506	1.464	0.521	0.153	0.000	0.333	0.216	2.192	1.073	0.501	0.408	0.047	1.060	0.000
12ALC	7.257	1.680	2.026	0.431	1.312	2.634	3.669	1.198	0.000	1.653	0.283	0.000	0.000	0.006	0.000
11TRC	3.640	1.935	3.752	1.713	0.023	0.152	0.454	0.954	0.000	0.389	0.285	0.828	0.000	0.000	0.104

Figure 9. Annual average transportation demand by requestor (Tons).

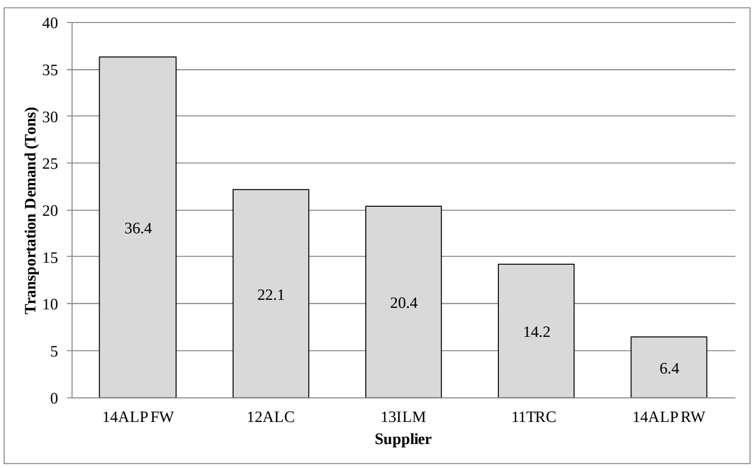


Figure 10. Annual average transportation demand weight by supplier (Tons).

When analyzing the weekly demand patterns, the low levels of demand cause the median to be zero for some users while few but extreme observations pull the mean away from the median towards the right with high standard deviations, resulting in extremely right skewed distributions.

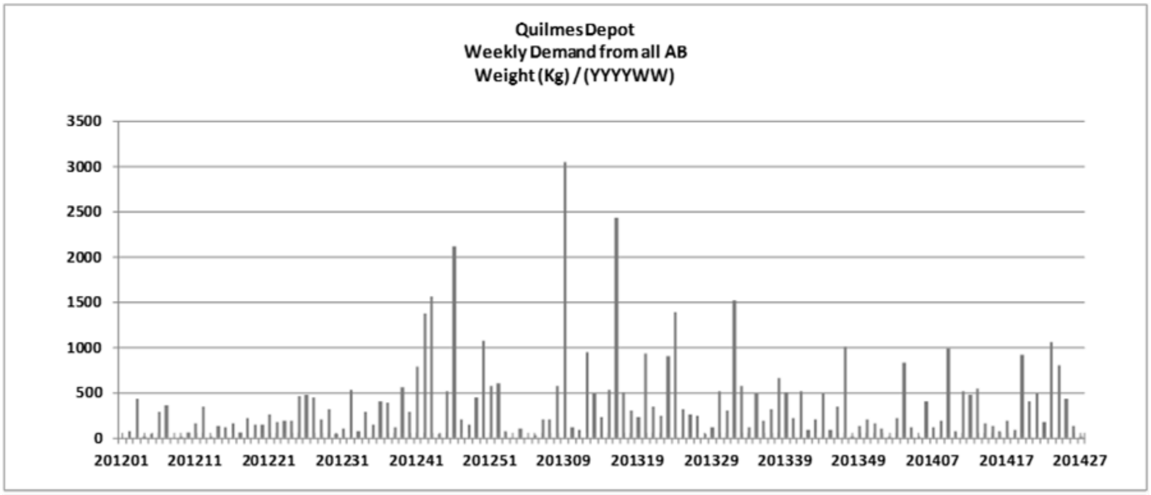
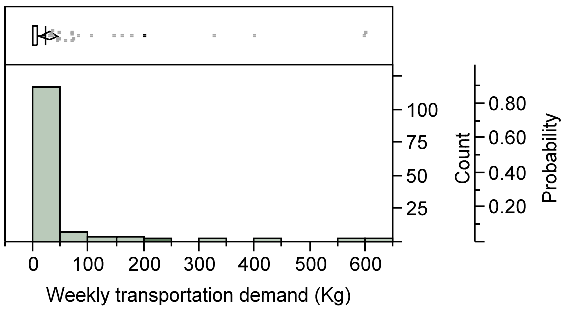


Figure 11. Weekly Demand from all requestors to Quilmes depot (Kg).

To illustrate the demand pattern of a particular requestor, Figure 12 shows the frequency histogram generated with JMP® for the weekly demand of Quilmes depot to El Palomar Logistic Unit. The median numerical value of zero indicates that for more than one half of the weeks of the period studied the depot was ordering nothing. The presence of just a few heavy orders affected the mean pulling it to the right reaching 28 Kg, exceeding the majority of the measurements. Finally, the spread of the data set produces a large standard deviation in the order of 90 Kg. The whole set of demand histograms is in Appendix I.

Due to the highly skewed distributions of the demand in the network, different combinations of numerical measures of central tendency, relative standing and variability were analyzed to establish the deterministic values of weekly demand to load in the models, considering also that this input must provide a safety capacity to absorb the high variability of demand.



Quantiles		
100.0%	maximum	600
99.5%		600
97.5%		377.548
90.0%		69.974
75.0%	quartile	9.6
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	27.948397
Std Dev	90.142393
Std Err Mean	7.8757774
Upper 95% Mean	43.529681
Lower 95% Mean	12.367113
N	131
Median	0
Mode	0

Figure 12. Weekly Demand of Quilmes depot to El Palomar Logistic Unit (Kg).

Using the complete data set of demand (Kg) from each base to Rio Cuarto depot (11TRC), three alternatives were analyzed and compared with the total demand of the last six months of data:

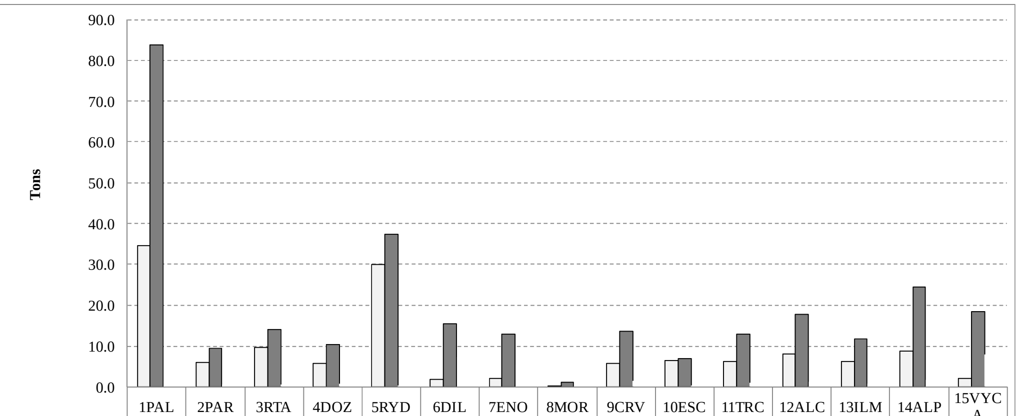
1. Mean + one standard deviation: This combination yielded the highest values of demand being 268% higher than the historical demand showing to be too conservative. Additionally, according to Chebyshef´s rule applied to any data set, at least 75% of the measurements will fall within two standard deviation of the mean but no estimations of percentage can be made within one standard deviation of the mean.
2. Median + one standard deviation: Being the median less sensitive than the mean to extremely large or small measurements, this combination yielded demand values 199% higher than historical data but due to the very low demand in the network, the median was zero for 28 of the 59 demands.
3. 90th percentile: A combination of the 90th percentile (if 90th percentile > 0) or one standard deviation (if 90th percentile = 0) was compared and yielded values of demand 107% higher than historical data to absorb variability of demand. Although using only the 90th percentile yielded was more conservative, some low

demand requestors had a value of zero. To be able to offer those requestors some capacity in the network, one standard deviation was used instead.

When comparing this measurements with demand from the last 12 months of the available data, the combination of the 90th percentile, covering for 90% of the possible demand values, with the one standard deviation to offer some capacity to very low demand requestors, showed to be the most convenient measurement to use as input for the models with a total 118% of safety capacity to absorb variability. Figure 13 shows the results of this comparison and Table 7 the input used in the models.

Table 7. Input of weekly demand used in the ILP model (Tons).

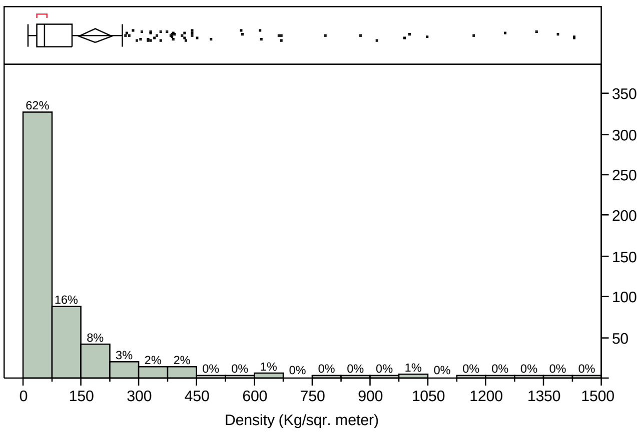
Origin:	ALL	1PAL	2PAR	3RTA	4DOZ	5RYD	6DIL	7ENO	8MOR	9CRV	10ESC	11TRC	12ALC	13ILM	14ALP	15VYCA
11TRC	**0.801**	0.258	0.019	0.043	0.084	0.072	0.115	0	0.021	0	0.026	0	0.009	0.018	0.137	0
12ALC	**1.238**	0.372	0.017	0.128	0.058	0.258	0.057	0.001	0	0	0.006	0.040	0	0.037	0.263	0
13ILM	**1.348**	0.717	0.080	0.023	0.021	0.038	0.042	0.062	0	0.152	0.050	0.018	0.065	0	0.070	0.010
14ALP RW	**0.753**	0.015	0	0	0.007	0.193	0.007	0.013	0	0.018	0.004	0.055	0.003	0.103	0	0.334
14ALP FW	**1.447**	0.248	0.066	0.077	0.028	0.158	0.075	0.173	0	0.094	0.046	0.137	0.263	0.070	0	0.012
TOTAL	**5.587**	**1.610**	**0.182**	**0.270**	**0.198**	**0.721**	**0.296**	**0.250**	**0.021**	**0.263**	**0.132**	**0.250**	**0.340**	**0.228**	**0.470**	**0.357**



	1PAL	2PAR	3RTA	4DOZ	5RYD	6DIL	7ENO	8MOR	9CRV	10ESC	11TRC	12ALC	13ILM	14ALP	15VYCA
□ Historical demand (Tons)	34.6	6.1	9.7	5.7	29.9	1.9	2.0	0.3	5.8	6.3	6.1	8.0	6.3	8.7	2.1
■ Deterministic demand (Tons)	83.7	9.4	14.0	10.3	37.5	15.4	13.0	1.1	13.7	6.8	13.0	17.7	11.9	24.4	18.6
Safety capacity to absorb variability	142%	56%	45%	82%	25%	729%	539%	321%	137%	8%	112%	122%	89%	179%	804%

Figure 13. Comparison of deterministic demand vs. last historic demand (Tons).

Finally, to address the impact of the product density on the capacity and the cost per Ton mile, the density of the product mix was computed based on the weights and volumes of the weekly demand from each requestor to each source of supply. Figure 14 shows the relative frequency histogram of the density of all the weekly demands showing again rightward skewed data with a high concentration of low density requirements. The median value was 54.75 Kg/m^3 (3.15 lbs/ft^3) and the mean was 185 Kg/m^3 (11.55 lbs/ft^3). Considering that the resulting median value is too low, the effect on costs of using the mean was analyzed to compare it with the median.



Quantiles		
100.0%	maximum	4375
99.5%		4005.67
97.5%		1376.95
90.0%		324.308
75.0%	quartile	125.004
50.0%	median	54.7449
25.0%	quartile	36.2238
10.0%		35.3017
2.5%		27.6938
0.5%		15.428
0.0%	minimum	12.7349

Summary Statistics	
Mean	185.00945
Std Dev	503.58647
Std Err Mean	21.957414
Upper 95% Mean	228.14463
Lower 95% Mean	141.87427
N	526
Median	54.744866
25% Trimmed Mean	62.196486

Figure 14. Density of the product mix computed from weekly demand (Kg/m^3).

Results of the optimization models

The goal of running the minimum cost network flow models was to determine the weights of freight to be shipped from each Logistic Unit or depot to fulfill the demand of the requestors with the least transportation cost. Table 8 shows the results of the models (Tons of serviceable assets shipped per arc to satisfy the demand) and includes the backhaul of unserviceable assets collected back from the requestor´s warehouses for repair, the consolidation of flow and the capacity that the network must provide on each arc. Figure 15 illustrates this table in a graph. These results can be used to design the transportation services to provide on each route by selecting the routing and the appropriate type of vehicle to reduce costs.

Table 8. Results of the LP models and capacity required on each route (Tons).

Arc		Supplier: Rio Cuarto depot	Supplier: Cordoba LU	Supplier: Quilmes depot	Supplier: El Palomar LU	TOTAL	Capacity Required
From	To	Tons	Tons	Tons	Tons	Tons	Tons
1PAL	2PAR			0.103	0.143	0.246	0.246
2PAR	1PAL			0.103		0.103	
1PAL	10ESC		0.730	0.115	0.309	1.154	1.154
10ESC	1PAL		0.730	0.115	0.007	0.852	
1PAL	11TRC	0.549		0.077	0.323	0.949	0.949
11TRC	1PAL	0.549		0.077	0.256	0.882	
1PAL	14ALP	0.290	0.359	1.012	0.227	1.888	2.683
14ALP	1PAL	0.290	0.359	1.012	1.022	2.683	
2PAR	3RTA	0.043	0.128	0.023	0.077	0.271	0.271
3RTA	2PAR	0.043	0.128	0.023		0.194	
2PAR	10ESC	0.062	0.145			0.207	0.207
10ESC	2PAR	0.062	0.145			0.207	
4DOZ	5RYD	0.084	0.058	0.021	0.007	0.170	0.191
5RYD	4DOZ	0.084	0.058	0.021	0.028	0.191	
5RYD	11TRC	0.156	0.316	0.060	0.200	0.732	0.732
11TRC	5RYD	0.156	0.316	0.060	0.187	0.719	
6DIL	9CRV			0.152	0.094	0.246	0.246
9CRV	6DIL			0.152	0.018	0.170	
6DIL	14ALP	0.115	0.057		0.025	0.197	0.341
14ALP	6DIL	0.115	0.057		0.169	0.341	
7ENO	14ALP		0.001	0.072	0.348	0.421	0.421
14ALP	7ENO			0.072	0.186	0.258	
7ENO	15VYCA			0.010	0.012	0.022	0.344
15VYCA	7ENO			0.010	0.334	0.344	
8MOR	14ALP	0.021				0.021	0.021
14ALP	8MOR	0.021				0.021	
10ESC	11TRC	0.097	0.356			0.453	0.453
11TRC	10ESC	0.097	0.356			0.453	
10ESC	12ALC	0.009	1.238	0.065	0.263	1.575	1.575
12ALC	10ESC	0.009	1.238	0.065	0.003	1.315	
13ILM	6DIL			0.193		0.193	0.193
6DIL	13ILM			0.193		0.193	
13ILM	14ALP	0.018	0.037	1.155	0.103	1.313	1.313
14ALP	13ILM	0.018	0.037	1.155	0.070	1.280	

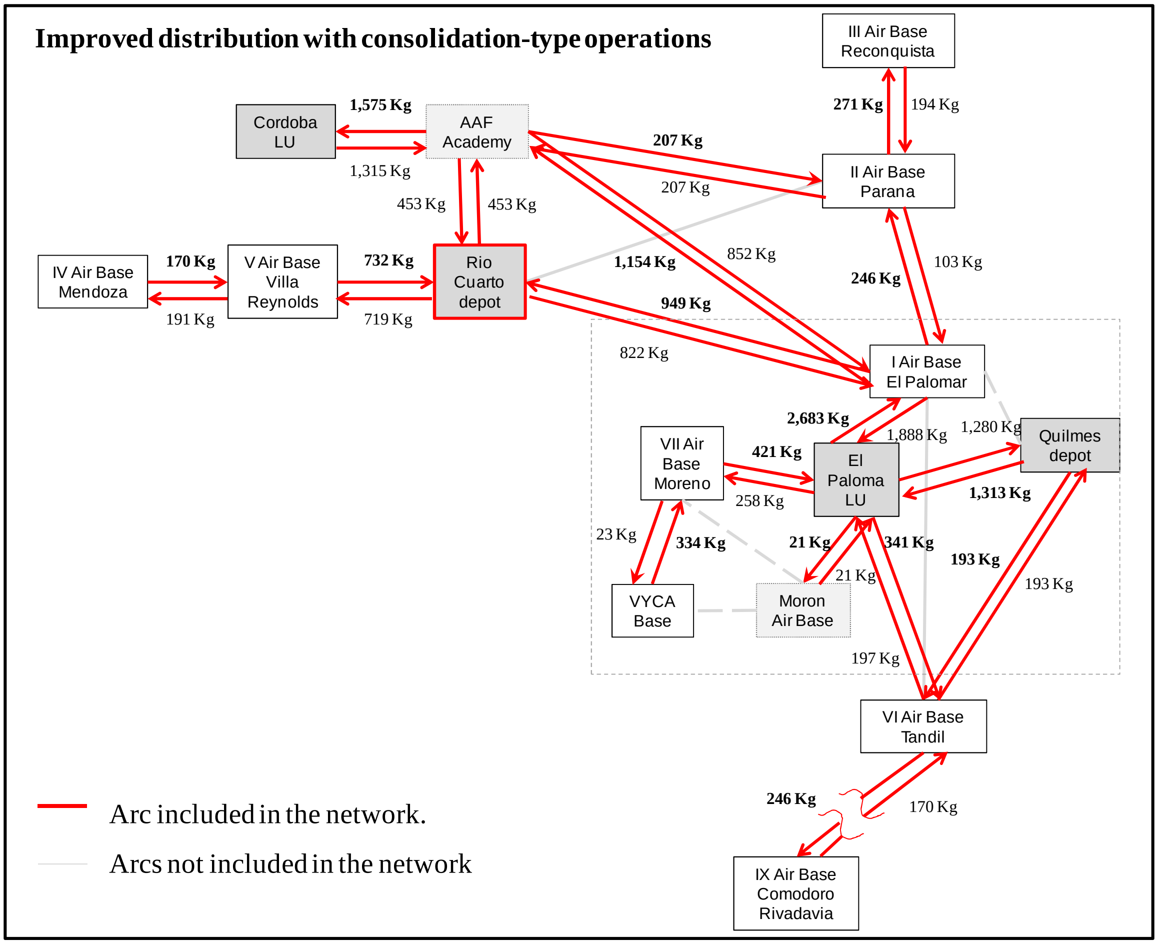


Figure 15. Consolidated flow of assets in the network (Kg).

As shown in Figure 15, there are three parts of the network where decision on routing of vehicles can reduce costs or improve level of service:

1. Central area: The link between the eastern and western part of the network is through arcs 1PAL-11TRC, 1PAL-10ESC and 2PAR-10ESC. Concentrating the freight in the route from El Palomar Air Base (1PAL) to Rio Cuarto depot (11TRC) can reduce costs serving one route instead of three. The additional capacity needed to make this main corridor is within the capacity of a truck load even with the low density assumed for the analysis. The potential cost saving of a hub-and-spoke network design,

with a main hub in El Palomar and a mini hub in Rio Cuarto was evaluated.

2. Route 13ILM – 6DIL: The route from Quilmes depot to Tandil Air Base can be cancelled and the freight redirected through El Palomar Logistic Unit using the excess capacity on those

3. The southern route: The route 6DIL - 9CRV, from Tandil Air Base to Comodoro Rivadavia Air Base, requires almost 19 driving hours or almost 2 days (potentially 3 days in case of any delay). The use of an aircraft to increase the level of service is worthy of consideration. With a very low demand of only 246 Kg per week, the use of a C-130 would be very inefficient. Although the Argentine Air Force does not operate the Cessna C-208B, the cost of operating it in this route was evaluated.

The cost of transportation was calculated for different vehicle combinations based on the basic network with consolidation-type operations of Figure 15 and the proposed hub-and-spoke design shown in Figure 16. Table 9 shows the costs for each case studied and Appendix 3 shows the tables used to calculate the cost of transportation with the vehicle assigned to each route.

Table 9. Comparison of costs of transportation.

Cost of transportation	Modes	Cost	Capacity utilization
Consolidation-type	Truck + UV + C-130	78,339	0.37
Consolidation-type	Truck +UV + C-208B	15,383	0.37
Consolidation-type	Truck only	14,818	0.16
Hub-and-spoke	Truck +UV + C-208B	10,676	0.39
Consolidation-type	Truck + UV	7,244	0.43
Hub-and-spoke	Truck + UV	5,709	0.39

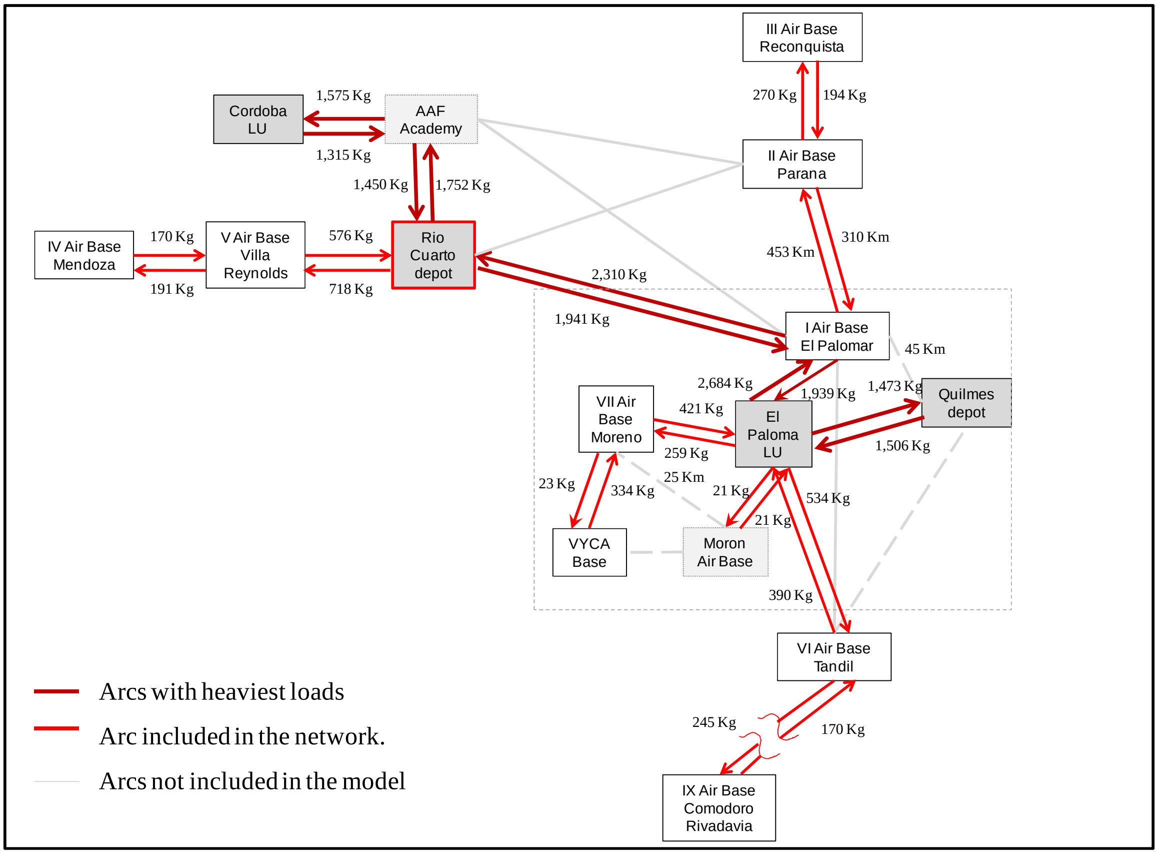


Figure 16. Hub-and-spoke network design.

The air mode was considered only to provide transportation service to Comodoro Rivadavia. It is the only Base with a driving time that exceeds 10 hours, which is considered the maximum service time for a driver. Air mode was not included in the routes that link the Units of Cordoba Province and Buenos Aires Province due to the fact that trucks or utility vehicles are frequently used by the Argentine Air Force on these routes to move personnel or freight.

The low demand in the network makes the use of C-130 unnecessarily expensive and compares poorly to cost of operating a smaller aircraft as the C-208B, which provides an 80% reduction in transportation cost when used instead. Including the

C-208B on this route, the network can deliver an order to Comodoro Rivadavia Air Base from Quilmes depot with a shipping time of 12 hours instead of 26 hours (potentially 3 days), assuming one hour of waiting in each terminal at El Palomar and Tandil.

As a consequence of the low demand in the system most of the routes could be served by utility vehicles. Additionally, when the capacity of the utility vehicle was exceeded, making two trips was still more economical than moving a truck. This can add flexibility to the network offering two services per week without increasing costs.

The results show that the hub-and-spoke network design using a combination of trucks and utility vehicles was the most efficient, producing cost saving of 21% when compared to the consolidated network. When the air mode is included to serve Comodoro Rivadavia, the total cost almost doubles reaching 10,676 dollar per week. Finally, Figure 17 shows the impact of product density in transportation costs, where when using the mean density of the aggregated weekly orders instead of the median, resulted in 24% to10% higher transportation costs. This is an incentive to assess the packaging policies and processes to determine if the low cargo density obtained from the data is a consequence of bad practices.

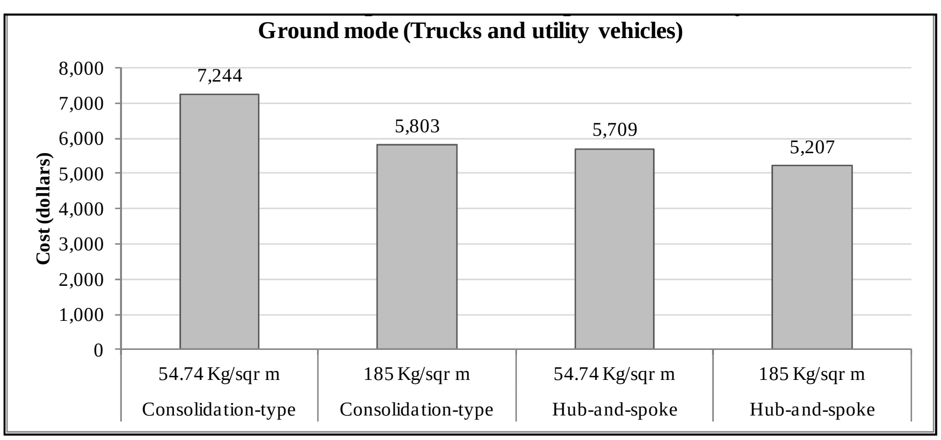


Figure 17. Effect on transportation cost of product density.

Summary

In this Chapter, the research addressed the basis for the design of the Argentine Air Force maintenance distribution network. The first investigative question examined the demand characteristics at each Unit, which was addressed by filtering the data by requestor and supplier and building frequency histograms of the aggregated weight of the weekly demand to extract statistical measurements (The complete set of demand histograms can be found in Appendix II)

The second investigative question asked what network optimization model can help in to determine the least costly way to satisfy the demand from each supplier. The minimum cost network flow problem was selected with the decision variables being the amount of weight of freight to be moved on each arc to minimize transportation cost. Because the network has four different suppliers and demand nodes with specific requirements to be fulfilled by specific suppliers, the models were run for each supplier and then aggregated in a spreadsheet to determine the flows of assets in the network.

The third investigative examined the cost savings that a hub-and-spoke design can produce on the total transportation cost of the network. According to the literature review, consolidation of freight and hub-and-spoke design showed to be economical for serving thin density markets. A hub-and-spoke design was proposed linking the most important supplier at the east of the network with the closest depot at the west. Although other operational consideration will support the idea of building a hub in Rio Cuarto depot, the network design showed a 21% cost savings when compared with the consolidated network.

The last investigative question asked about factors that impedes further improvement and can be easily addressed. One of them is the uncertainty on the product density, due to the low value obtained from the given data set. Adequate packaging policies and supplies to apply them at the warehouses can reduce the cubic volume of the freight by hauling more tons per truckload before filling the vehicle, thus driving down transportation costs. The effect of different product densities on the cost of the network showed potential saving from 10% to 24%. Another factor that can improve the performance of the network is an adequate prioritization policy. With a policy in place and historical data of the amount of aircraft-on-ground orders requiring expedite shipping, the transportation resources can be assigned where they can create more value to the requestors and reduce shipping time.

V. Conclusions and Recommendations

Chapter Overview

This chapter summarizes the conclusions of the research and provides recommendations for future data collection and the development of management processes required to efficiently meet the requestor's needs.

Conclusions of Research

The goals of this research project were to enhance the understanding of the maintenance assets distribution network through the analysis of historical data to determine the transportation demand, the capacity needed on each route and the network design that best fits the needs of the Argentine Air Force.

The capacity calculated in this research cover for 90% of the demand values observed from historical data, providing the network with a 118% safety capacity if the demand data from July 2013 to June 2014 is typical of normal operations. The demand at each Unit showed right skewed distributions with high variability, requiring considerable safety capacity in all the arcs. Nevertheless, the low demand in the network caused the average capacity utilization of the vehicles included in the analysis to be lower than 43% in the different combinations evaluated. Even with the low product density used in the analysis, most arcs were served by utility vehicles, being trucks required only to serve the routes joining El Palomar Logistic Unit with Rio Cuarto depot and from there to Cordoba Logistic Unit. With the hub-and-spoke design, a truck was required to serve the route from Rio Cuarto to Cordoba Logistic Unit too, being convenient for this category of vehicle to be placed in these three Units.

The second research question investigates the network design and mode choice that best fits the needs of the AAF. This research found that the most efficient network design was the hub-and-spoke design with a main hub at El Palomar and a second hub in Rio Cuarto. This layout is in the order of 21% less expensive than the consolidated network. Nevertheless, from the strategic point of view, this design could be vulnerable to disruptions while the consolidated network might remain more flexible and resilient, offering more responsiveness particularly to the Units at the north-east of the country. The results of this research provide useful information for the decision maker to determine the cost benefits of each design, given that both perform in a very economic way with the use of ground transportation mode. Finally, the use of air mode for the network is considered unnecessary between the hubs, but the level of service to the more distant Comodoro Rivadavia Air Base requires special consideration. Given the high fixed cost of the C-130 and the low volumes involved, the option of a small and economical aircraft such as the C-208B can considerably increase the level of service with a cost per flight hour ten times smaller than the Hercules.

Finally, with regards to the policies that can be implemented to improve the performance of the network, one is prioritization in order to allocate capacity in a more efficient way and add flexibility to the transportation services. Second policy should develop a transportation planning module for the SIL information system, combining the ordering process with generation of transport orders, tags for tracking and demand management. Finally, a well defined packaging policy and procedure can have a positive impact in transportation costs if it can reduce package volumes while adequately protecting the assets from damage.

Recommendations for Action

To succeed in the development of the distribution network, it is important to view it as part of a broad process that requires integration and coordination among different organizations, in which information technology can help to enable process effectiveness, systems integration and data accuracy. The development of the customer service management process, the demand management process and the order fulfillment process must be considered as part of the same problem. There are potential cost savings of having reliable sources of data to forecast demand, finding ways to reduce demand variability and building flexibility in the network.

Recommendations for Future Research

As previously described, the USAF uses a priority system to allocate airlift resources. The Uniform Materiel Movement and Issue Priority System establish time standards based on the mission and urgency of need of the requestor. The implementation of such a system, including time definite delivery for the pipeline segments, can assist in reduce the variability in demand for transportation and streamline the order fulfillment process associated with the operation of the network.

Appendix I

Weekly historical demand from all requestors to each Logistic Unit

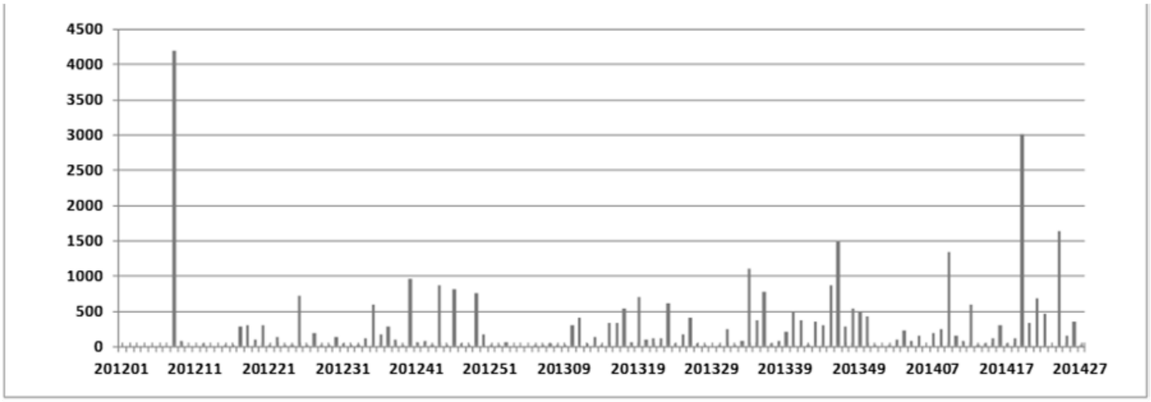


Figure I.1. Weekly (YYYYWW) demand from all Units to Rio Cuarto depot (Kg).

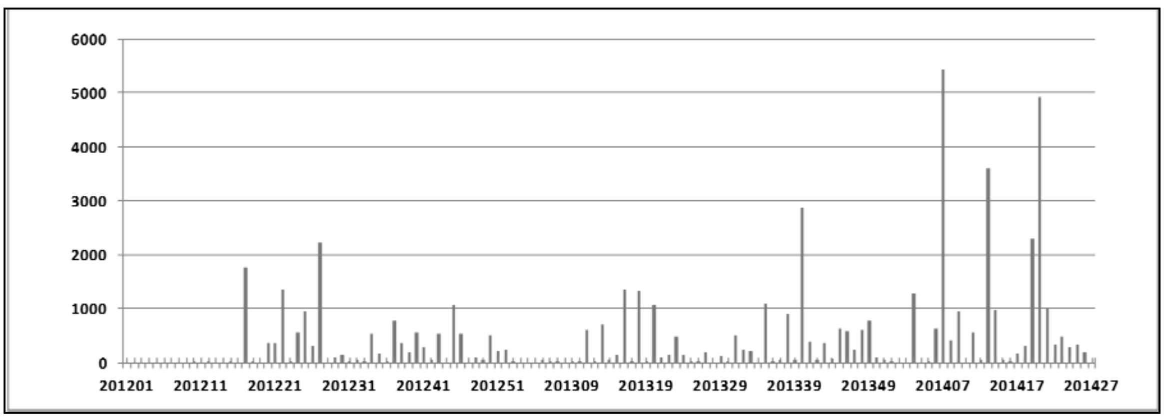


Figure I.2. Weekly (YYYYWW) demand from all Units to Cordoba depot (Kg).

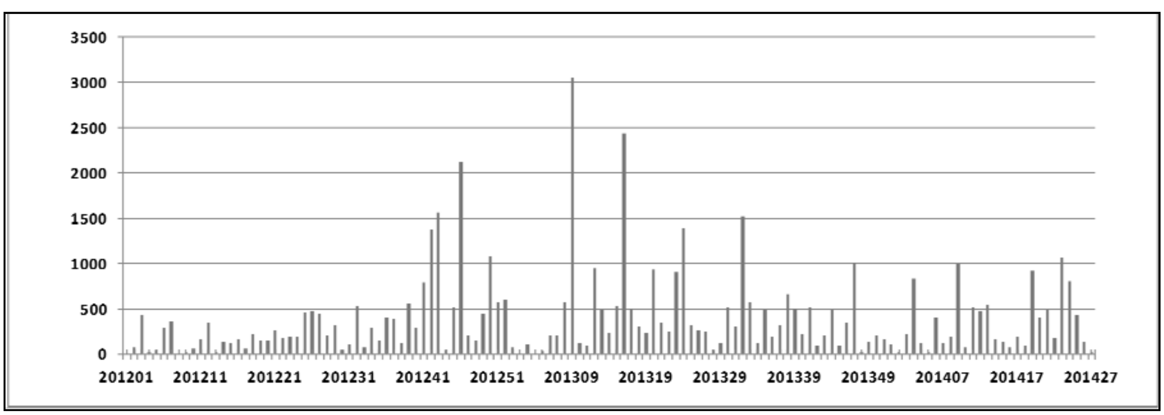


Figure I.3. Weekly (YYYYWW) demand from all Units to Quilmes depot (Kg).

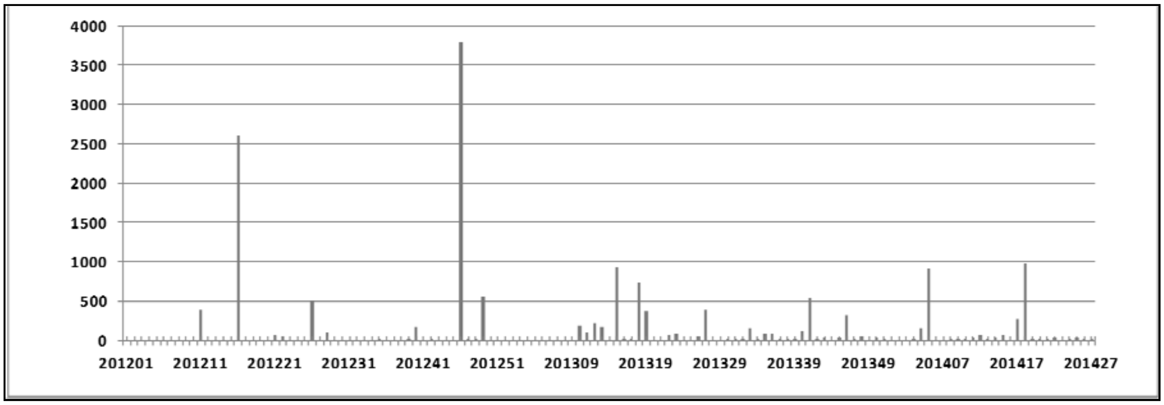


Figure I.4. Weekly (YYYYWW) retrograde collection from all Units to El Palomar depot (Kg).

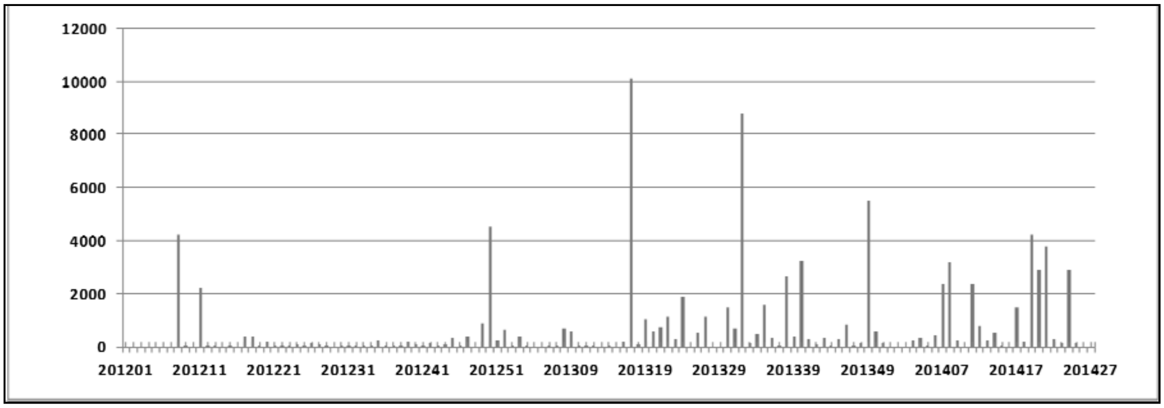


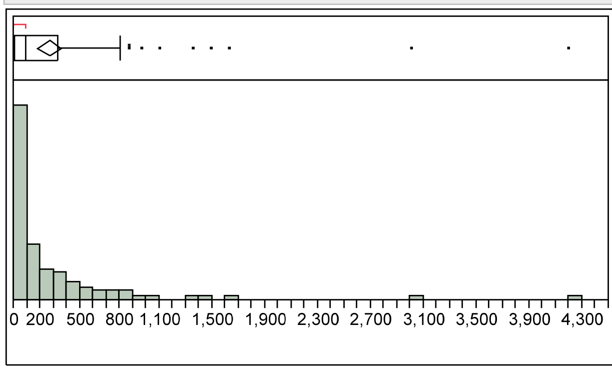
Figure I.5. Weekly (YYYYWW) forward demand from all Units to El Palomar depot (Kg).

Appendix II

Relative frequency histograms of weekly demand

<u>Origin: 11TRC (Rio Cuarto Depot)</u>

TOTAL



Quantiles

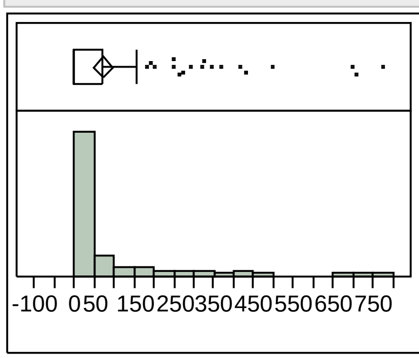
100.0%	maximum	4200
99.5%		4200
97.5%		1586.68
90.0%		723.848
75.0%	quartile	332.3
50.0%	median	90.41
25.0%	quartile	10
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	271.53771
Std Dev	524.96937
Std Err Mean	45.866787
Upper 95% Mean	362.27966
Lower 95% Mean	180.79576
N	131

Figure II.1. Weekly demand from all Units (Kg).

1PAL



Quantiles

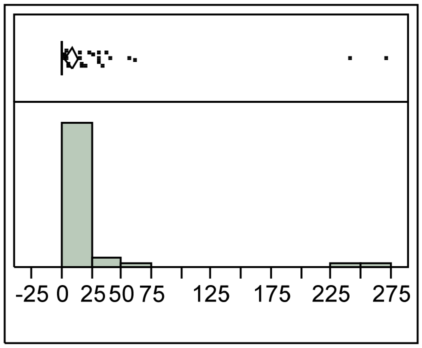
100.0%	maximum	774.34
99.5%		774.34
97.5%		637.273
90.0%		258.412
75.0%	quartile	70.31
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	69.470534
Std Dev	144.47389
Std Err Mean	12.622742
Upper 95% Mean	94.44312
Lower 95% Mean	44.497948
N	131

Figure II.2. Weekly demand from El Palomar Air Base (Kg).

2PAR



Quantiles

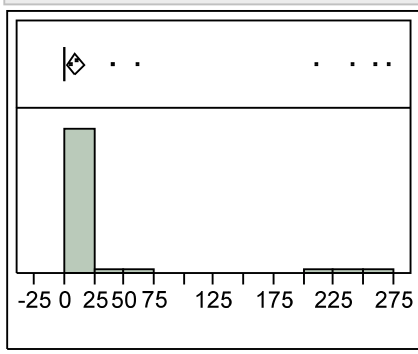
100.0%	maximum	270
99.5%		270
97.5%		58.662
90.0%		18.932
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	7.4269466
Std Dev	32.724882
Std Err Mean	2.8591862
Upper 95% Mean	13.083505
Lower 95% Mean	1.7703886
N	131

Figure II.3. Weekly demand from Parana Air Base (Kg).

3RTA



Quantiles

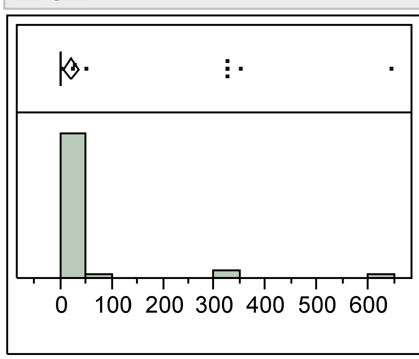
100.0%	maximum	270
99.5%		270
97.5%		231
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	8.6732824
Std Dev	42.907673
Std Err Mean	3.7488608
Upper 95% Mean	16.089955
Lower 95% Mean	1.2566096
N	131

Figure II.4. Weekly demand from Reconquista Air Base (Kg).

4DOZ



Quantiles

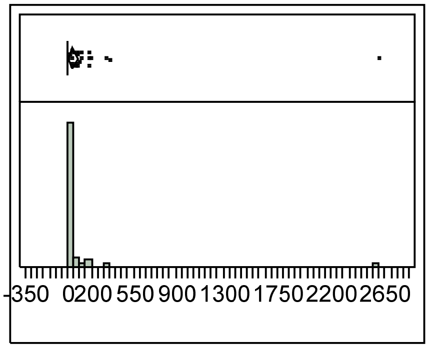
100.0%	maximum	643.2
99.5%		643.2
97.5%		323.2
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	18.21374
Std Dev	83.830746
Std Err Mean	7.3243263
Upper 95% Mean	32.704044
Lower 95% Mean	3.7234369
N	131

Figure II.5. Weekly demand from Mendoza Air Base (Kg).

5RYD



Quantiles

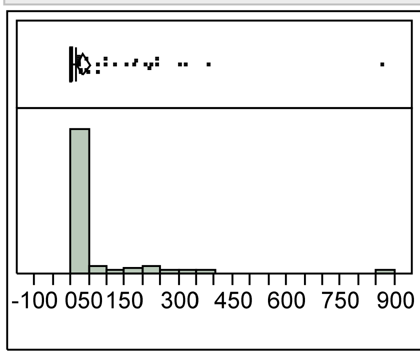
100.0%	maximum	2590.84
99.5%		2590.84
97.5%		275.792
90.0%		71.89
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	36.93458
Std Dev	231.21777
Std Err Mean	20.20159
Upper 95% Mean	76.90101
Lower 95% Mean	-3.03185
N	131

Figure II.6. Weekly demand from Villa Reynolds Air Base (Kg).

6DIL



Quantiles

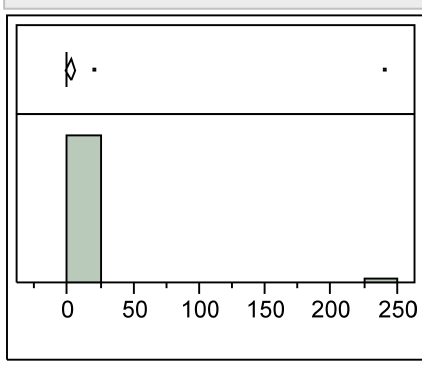
100.0%	maximum	862.55
99.5%		862.55
97.5%		313.849
90.0%		114.684
75.0%	quartile	6.35
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	32.687863
Std Dev	101.25965
Std Err Mean	8.8470966
Upper 95% Mean	50.190785
Lower 95% Mean	15.18494
N	131

Figure II.7. Weekly demand from Tandil Air Base (Kg).

8MOR



Quantiles

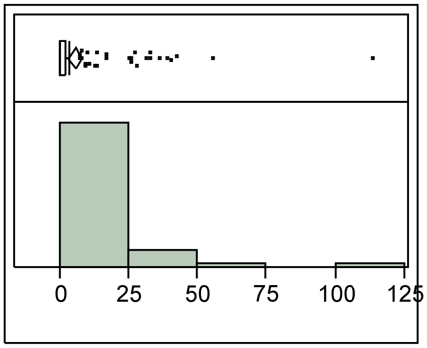
100.0%	maximum	240
99.5%		240
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	1.9847328
Std Dev	21.028181
Std Err Mean	1.8372407
Upper 95% Mean	5.6194938
Lower 95% Mean	-1.650028
N	131

Figure II.8. Weekly demand from Moron Air Base (Kg).

10ESC

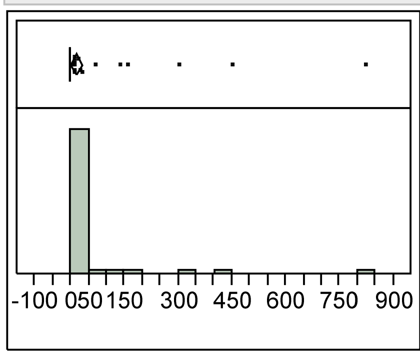


Quantiles		
100.0%	maximum	113.22
99.5%		113.22
97.5%		41.4
90.0%		25.64
75.0%	quartile	2
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	5.430916
Std Dev	14.254324
Std Err Mean	1.245406
Upper 95% Mean	7.894803
Lower 95% Mean	2.9670291
N	131

Figure II.9. Weekly demand from the Air Force Academy (Kg).

12ALC

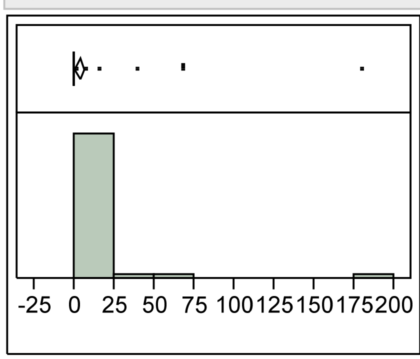


Quantiles		
100.0%	maximum	822.5
99.5%		822.5
97.5%		257.81
90.0%		9.08
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	15.792366
Std Dev	87.154505
Std Err Mean	7.6147245
Upper 95% Mean	30.857188
Lower 95% Mean	0.7275447
N	131

Figure II.10. Weekly demand from Cordoba Logistic Base (Kg).

13ILM

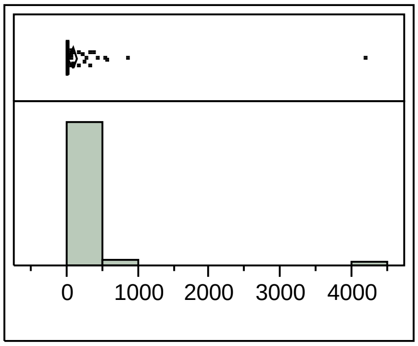


Quantiles		
100.0%	maximum	180
99.5%		180
97.5%		59.48
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	2.8924427
Std Dev	18.060878
Std Err Mean	1.5779862
Upper 95% Mean	6.0142997
Lower 95% Mean	-0.229414
N	131

Figure II.11. Weekly demand from Quilmes depot (Kg).

14ALP



Quantiles

100.0%	maximum	4200
99.5%		4200
97.5%		545.74
90.0%		136.64
75.0%	quartile	11.04
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

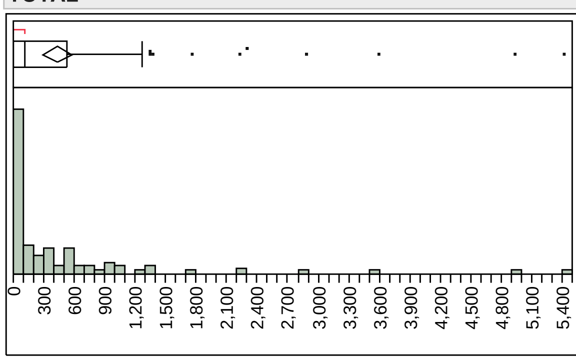
Mean	71.594962
Std Dev	382.71952
Std Err Mean	33.438359
Upper 95% Mean	137.74876
Lower 95% Mean	5.4411667
N	131

Figure II.12. Weekly demand from Palomar Logistic Unit (Kg).

End of Demand Histograms for 11TRC – No demand from 7ENO, 15VYCA and 9CRV.

Origin: 12ALC (Cordoba Depot)

TOTAL



Quantiles

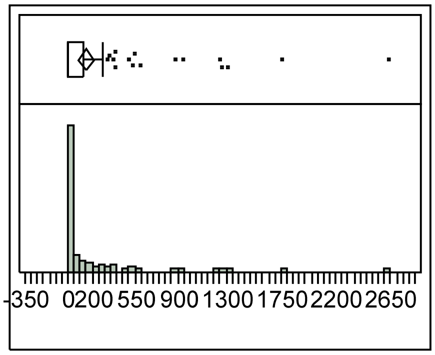
100.0%	maximum	5420.53
99.5%		5420.53
97.5%		3381.23
90.0%		1063.56
75.0%	quartile	527.35
50.0%	median	107.32
25.0%	quartile	5
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	422.70405
Std Dev	824.23962
Std Err Mean	72.01415
Upper 95% Mean	565.17543
Lower 95% Mean	280.23266
N	131

Figure II.13. Weekly demand from all requestors (Kg).

1PAL



Quantiles

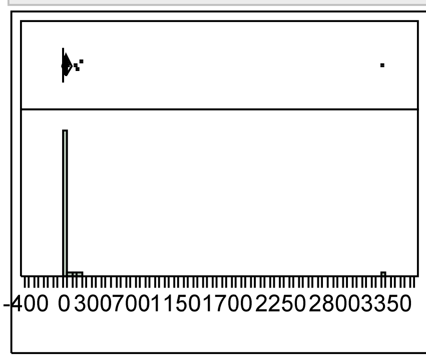
100.0%	maximum	2629.04
99.5%		2629.04
97.5%		1292.44
90.0%		371.736
75.0%	quartile	120
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	138.4913
Std Dev	356.09151
Std Err Mean	31.11186
Upper 95% Mean	200.04239
Lower 95% Mean	76.940204
N	131

Figure II.14. Weekly demand from El Palomar Air Base (Kg).

2PAR



Quantiles

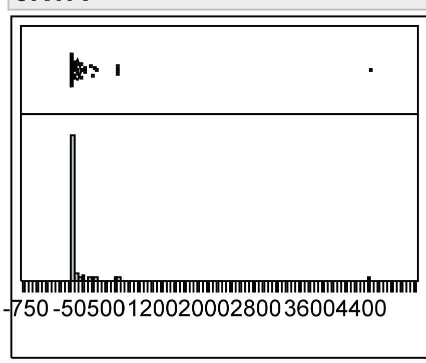
100.0%	maximum	3300
99.5%		3300
97.5%		135.5
90.0%		17.168
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	31.548092
Std Dev	288.74266
Std Err Mean	25.227563
Upper 95% Mean	81.457808
Lower 95% Mean	-18.36162
N	131

Figure II.15. Weekly demand from Parana Air Base (Kg).

3RTA



Quantiles

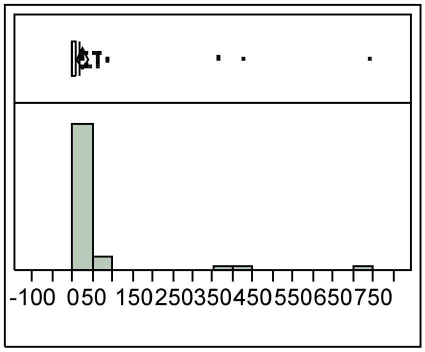
100.0%	maximum	4535.79
99.5%		4535.79
97.5%		699.127
90.0%		127.536
75.0%	quartile	1.25
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	70.021069
Std Dev	411.11145
Std Err Mean	35.918975
Upper 95% Mean	141.08246
Lower 95% Mean	-1.040327
N	131

Figure II.16. Weekly demand from Reconquista Air Base (Kg).

4DOZ

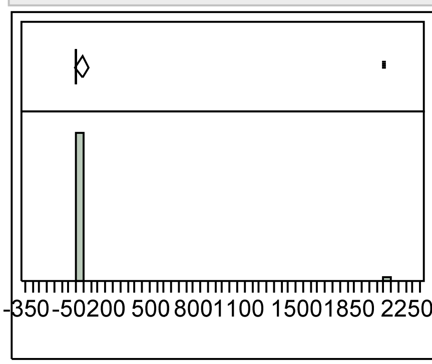


Quantiles		
100.0%	maximum	738.25
99.5%		738.25
97.5%		364
90.0%		57.936
75.0%	quartile	8.3
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	22.858397
Std Dev	86.718532
Std Err Mean	7.5766333
Upper 95% Mean	37.84786
Lower 95% Mean	7.8689341
N	131

Figure II.17. Weekly demand from Mendoza Air Base (Kg).

5RYD

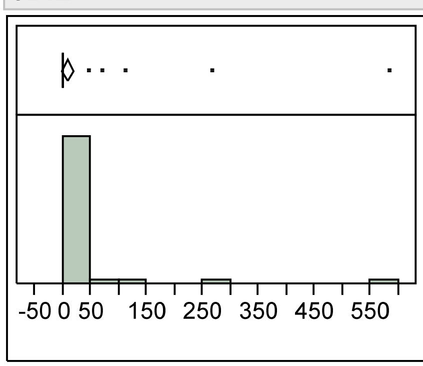


Quantiles		
100.0%	maximum	2100
99.5%		2100
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	32.061069
Std Dev	258.47695
Std Err Mean	22.583236
Upper 95% Mean	76.739301
Lower 95% Mean	-12.61716
N	131

Figure II.18. Weekly demand from Villa Reynolds Air Base (Kg).

6DIL

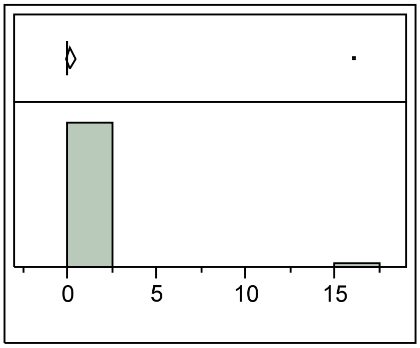


Quantiles		
100.0%	maximum	582.96
99.5%		582.96
97.5%		99.248
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	8.2287023
Std Dev	56.946462
Std Err Mean	4.9754355
Upper 95% Mean	18.072006
Lower 95% Mean	-1.614602
N	131

Figure II.19. Weekly demand from Tandil Air Base (Kg).

7ENO



Quantiles

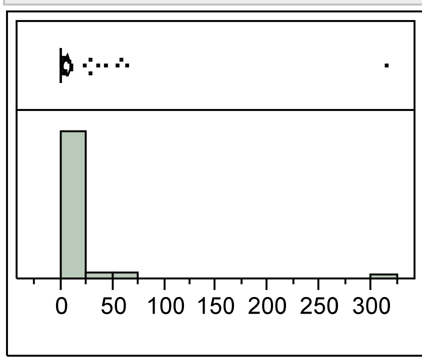
100.0%	maximum	16
99.5%		16
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.1221374
Std Dev	1.3979265
Std Err Mean	0.1221374
Upper 95% Mean	0.3637717
Lower 95% Mean	-0.119497
N	131

Figure II.20. Weekly demand from Moreno Air Base (Kg).

10ESC



Quantiles

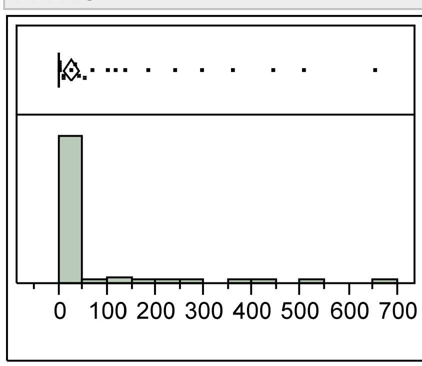
100.0%	maximum	314.27
99.5%		314.27
97.5%		57.678
90.0%		6.202
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	5.4091603
Std Dev	29.22799
Std Err Mean	2.5536613
Upper 95% Mean	10.461274
Lower 95% Mean	0.3570467
N	131

Figure II.21. Weekly demand from the Air Force Academy (Kg).

11TRC



Quantiles

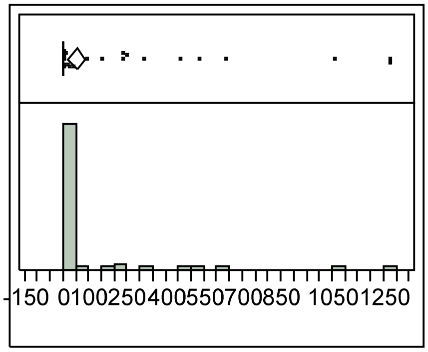
100.0%	maximum	654.8
99.5%		654.8
97.5%		417.057
90.0%		40.08
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	25.032901
Std Dev	94.348905
Std Err Mean	8.2433021
Upper 95% Mean	41.341288
Lower 95% Mean	8.7245135
N	131

Figure II.22. Weekly demand from Rio Cuarto depot (Kg).

13ILM



Quantiles

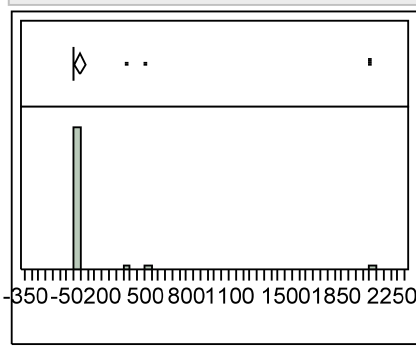
100.0%	maximum	1270.52
99.5%		1270.52
97.5%		928.812
90.0%		37.04
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	50.274733
Std Dev	200.05915
Std Err Mean	17.479249
Upper 95% Mean	84.855336
Lower 95% Mean	15.69413
N	131

Figure II.23. Weekly demand from Quilmes depot (Kg).

14ALP



Quantiles

100.0%	maximum	2100
99.5%		2100
97.5%		459.2
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

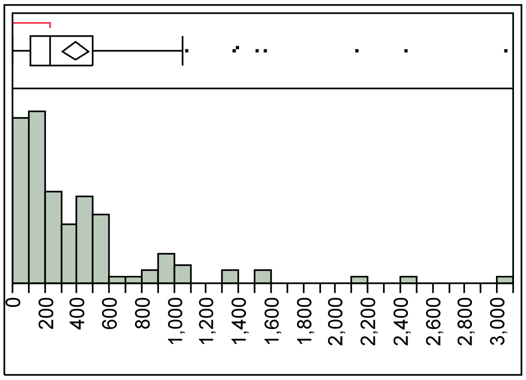
Mean	38.656489
Std Dev	263.2159
Std Err Mean	22.99728
Upper 95% Mean	84.153857
Lower 95% Mean	-6.84088
N	131

Figure II.24. Weekly demand from El Palomar Logistic Unit (Kg).

End of Demand Histograms for 12ALC – No demand from 8MOR, 9CRV and 15VYCA.

Origin: 13ILM (Quilmes Depot)

TOTAL



Quantiles

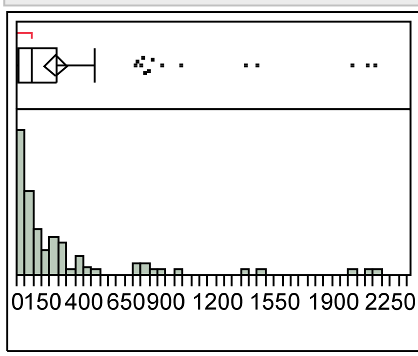
100.0%	maximum	3049.18
99.5%		3049.18
97.5%		1954.06
90.0%		929.768
75.0%	quartile	495.64
50.0%	median	230.89
25.0%	quartile	112.04
10.0%		43.838
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	389.37985
Std Dev	465.79687
Std Err Mean	40.696862
Upper 95% Mean	469.89372
Lower 95% Mean	308.86597
N	131

Figure II.25. Weekly demand from all requestors (Kg).

1PAL



Quantiles

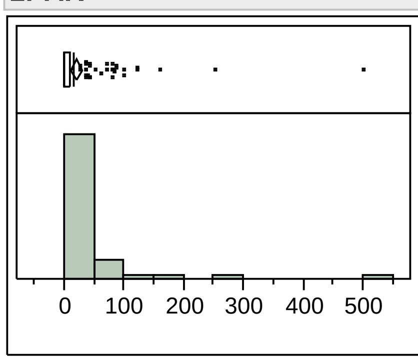
100.0%	maximum	2155.98
99.5%		2155.98
97.5%		1844.84
90.0%		717.288
75.0%	quartile	236.77
50.0%	median	96.16
25.0%	quartile	12.23
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	227.65366
Std Dev	385.6802
Std Err Mean	33.697036
Upper 95% Mean	294.31922
Lower 95% Mean	160.98811
N	131

Figure II.26. Weekly demand from El Palomar Air Base (Kg).

2PAR



Quantiles

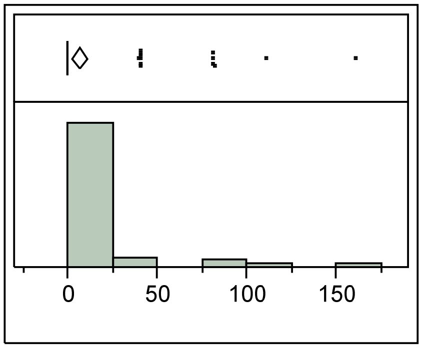
100.0%	maximum	500
99.5%		500
97.5%		148.18
90.0%		80
75.0%	quartile	9.08
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	20.471527
Std Dev	56.170143
Std Err Mean	4.9076082
Upper 95% Mean	30.180643
Lower 95% Mean	10.762411
N	131

Figure II.27. Weekly demand from Parana Air Base (Kg).

3RTA



Quantiles

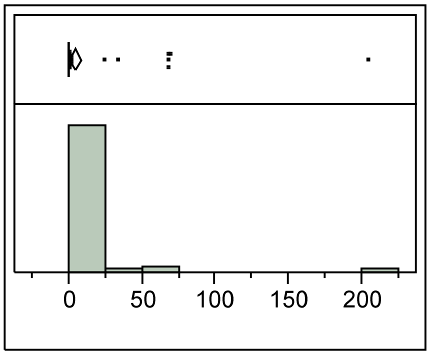
100.0%	maximum	160
99.5%		160
97.5%		81.26
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	6.3457252
Std Dev	22.861407
Std Err Mean	1.9974104
Upper 95% Mean	10.297363
Lower 95% Mean	2.3940875
N	131

Figure II.28. Weekly demand from Reconquista Air Base (Kg).

4DOZ



Quantiles

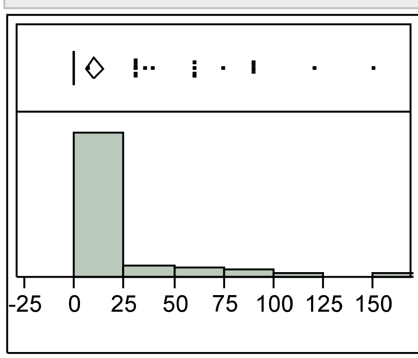
100.0%	maximum	204
99.5%		204
97.5%		68
90.0%		0.42
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	4.1129008
Std Dev	21.415441
Std Err Mean	1.8710758
Upper 95% Mean	7.8146004
Lower 95% Mean	0.4112011
N	131

Figure II.29. Weekly demand from Mendoza Air Base (Kg).

5RYD



Quantiles

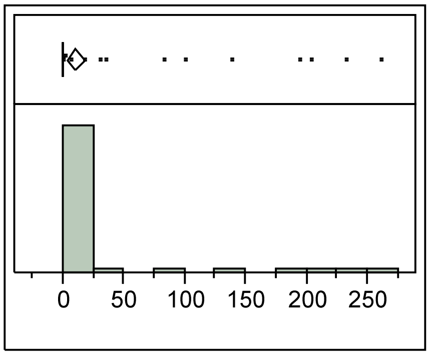
100.0%	maximum	150
99.5%		150
97.5%		90
90.0%		38.208
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	9.6549618
Std Dev	26.130841
Std Err Mean	2.2830621
Upper 95% Mean	14.171727
Lower 95% Mean	5.1381964
N	131

Figure II.30. Weekly demand from Villa Reynolds Air Base (Kg).

6DIL



Quantiles

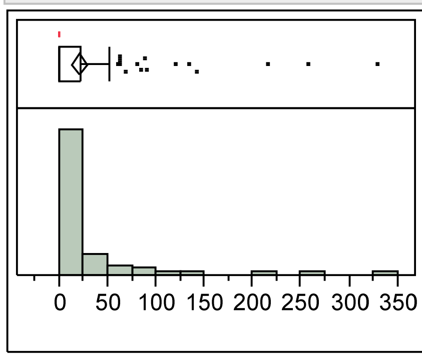
100.0%	maximum	261.78
99.5%		261.78
97.5%		200.856
90.0%		0.064
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	9.9516031
Std Dev	41.824049
Std Err Mean	3.6541842
Upper 95% Mean	17.180969
Lower 95% Mean	2.7222367
N	131

Figure II.31. Weekly demand from Tandil Air Base (Kg).

7ENO



Quantiles

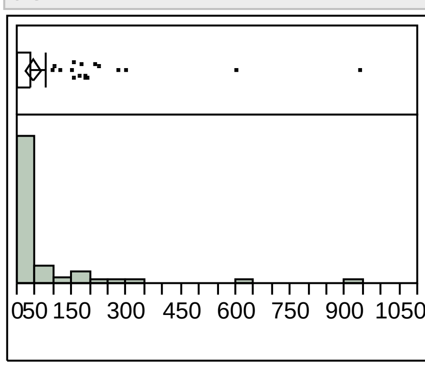
100.0%	maximum	328.47
99.5%		328.47
97.5%		192.997
90.0%		61.924
75.0%	quartile	22.39
50.0%	median	0.8
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	20.236641
Std Dev	47.318415
Std Err Mean	4.1342291
Upper 95% Mean	28.415719
Lower 95% Mean	12.057563
N	131

Figure II.32. Weekly demand from Moreno Air Base (Kg).

9CRV



Quantiles

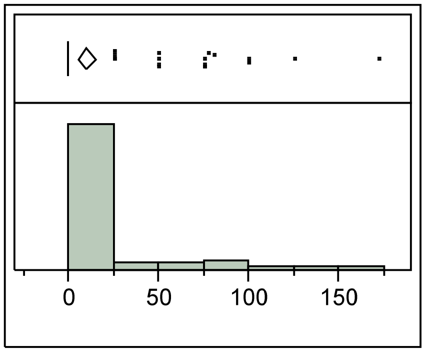
100.0%	maximum	941.42
99.5%		941.42
97.5%		293.512
90.0%		151.556
75.0%	quartile	35
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	41.823359
Std Dev	111.61785
Std Err Mean	9.7520966
Upper 95% Mean	61.116716
Lower 95% Mean	22.530002
N	131

Figure II.33. Weekly demand from Comodoro Rivadavia Air Base (Kg).

10ESC



Quantiles

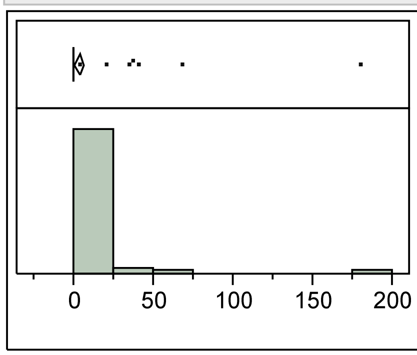
100.0%	maximum	171.32
99.5%		171.32
97.5%		100
90.0%		50
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	9.5673282
Std Dev	27.778467
Std Err Mean	2.4270159
Upper 95% Mean	14.368889
Lower 95% Mean	4.7657675
N	131

Figure II.34. Weekly demand from the Air Force Academy (Kg).

11TRC



Quantiles

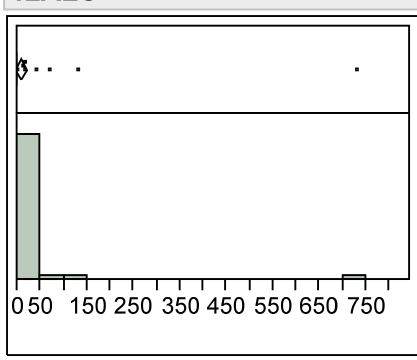
100.0%	maximum	180
99.5%		180
97.5%		39.471
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	2.9205344
Std Dev	17.641745
Std Err Mean	1.5413664
Upper 95% Mean	5.9699434
Lower 95% Mean	-0.128875
N	131

Figure II.35. Weekly demand from Rio Cuarto depot (Kg).

12ALC



Quantiles

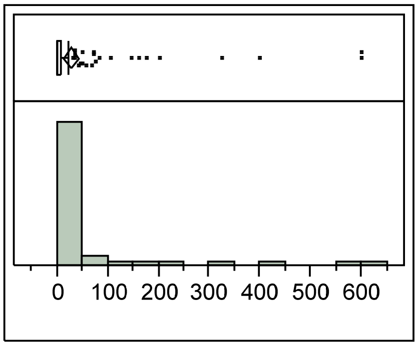
100.0%	maximum	730.52
99.5%		730.52
97.5%		60.462
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	7.789542
Std Dev	65.060148
Std Err Mean	5.6843315
Upper 95% Mean	19.035312
Lower 95% Mean	-3.456228
N	131

Figure II.36. Weekly demand from Cordoba Logistic Base (Kg).

14ALP

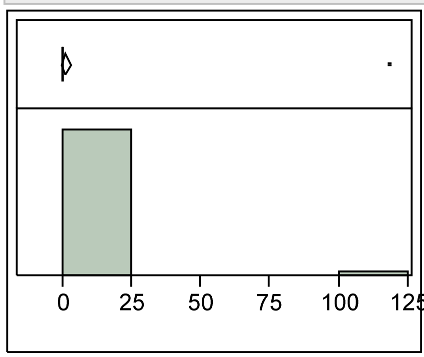


Quantiles		
100.0%	maximum	600
99.5%		600
97.5%		377.548
90.0%		69.974
75.0%	quartile	9.6
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	27.948397
Std Dev	90.142393
Std Err Mean	7.8757774
Upper 95% Mean	43.529681
Lower 95% Mean	12.367113
N	131

Figure II.37. Weekly demand from Palomar Logistic Base (Kg).

15VYCA



Quantiles		
100.0%	maximum	118.38
99.5%		118.38
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

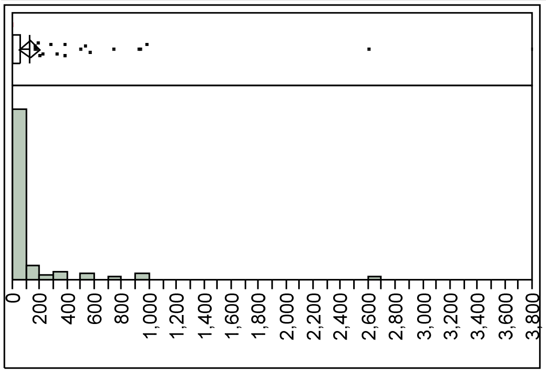
Summary Statistics	
Mean	0.9036641
Std Dev	10.342909
Std Err Mean	0.9036641
Upper 95% Mean	2.6914555
Lower 95% Mean	-0.884127
N	131

Figure II.38. Weekly demand from Ground-Controlled Interception System Unit (Kg).

End of Demand Histograms for 13ILM – No demand from 8MOR.

Origin: 14ALP RW (El Palomar Depot) for retrograde only

TOTAL



Quantiles

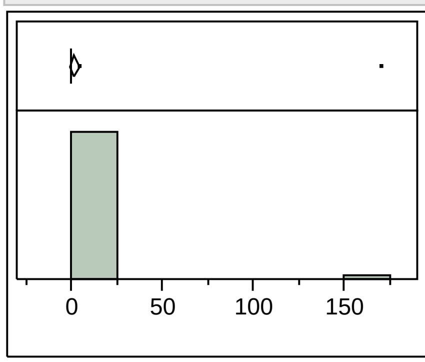
100.0%	maximum	3800
99.5%		3800
97.5%		967.856
90.0%		316.348
75.0%	quartile	59.26
50.0%	median	0.96
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	122.77046
Std Dev	431.74056
Std Err Mean	37.721348
Upper 95% Mean	197.39763
Lower 95% Mean	48.143282
N	131

Figure II.39. Weekly demand from all requestors (Kg).

1PAL



Quantiles

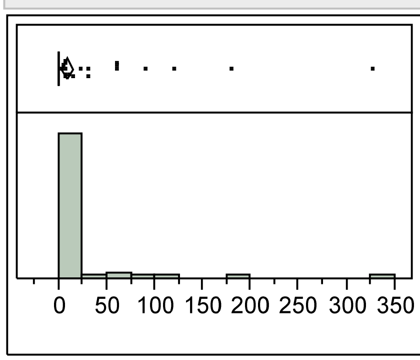
100.0%	maximum	170.1
99.5%		170.1
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	1.3291603
Std Dev	14.863154
Std Err Mean	1.2985998
Upper 95% Mean	3.8982848
Lower 95% Mean	-1.239964
N	131

Figure II.40. Weekly demand from Palomar Air Base (Kg).

4DOZ



Quantiles

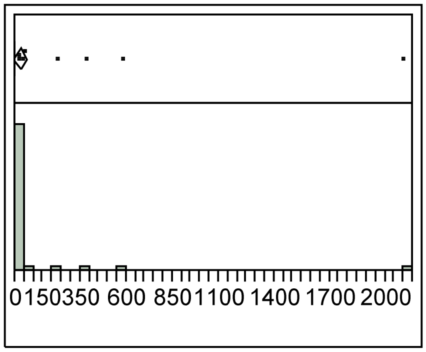
100.0%	maximum	327
99.5%		327
97.5%		111
90.0%		7
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	7.9587786
Std Dev	35.856953
Std Err Mean	3.1328365
Upper 95% Mean	14.156721
Lower 95% Mean	1.7608363
N	131

Figure II.41. Weekly demand from Mendoza Air Base (Kg).

5RYD

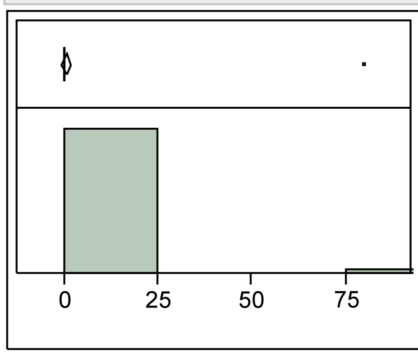


Quantiles		
100.0%	maximum	2100
99.5%		2100
97.5%		336.501
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	26.21458
Std Dev	193.4994
Std Err Mean	16.906121
Upper 95% Mean	59.661319
Lower 95% Mean	-7.232159
N	131

Figure II.42. Weekly demand from Villa ReynoldsAir Base (Kg).

6DIL

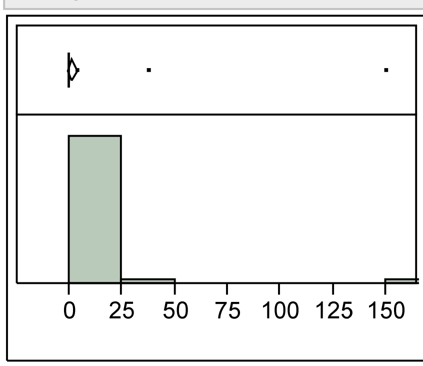


Quantiles		
100.0%	maximum	80
99.5%		80
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	0.610687
Std Dev	6.9896325
Std Err Mean	0.610687
Upper 95% Mean	1.8188583
Lower 95% Mean	-0.597484
N	131

Figure II.43. Weekly demand from Tandil Air Base (Kg).

7ENO

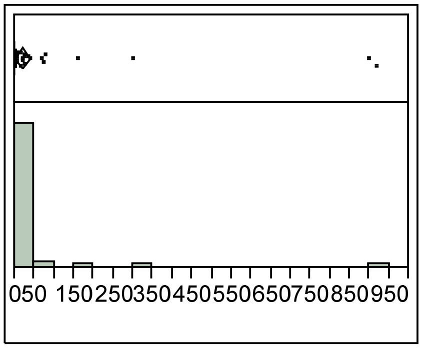


Quantiles		
100.0%	maximum	150
99.5%		150
97.5%		2.429
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	1.4572519
Std Dev	13.483567
Std Err Mean	1.1780647
Upper 95% Mean	3.7879121
Lower 95% Mean	-0.873408
N	131

Figure II.44. Weekly demand from Moreno Air Base (Kg).

9CRV



Quantiles

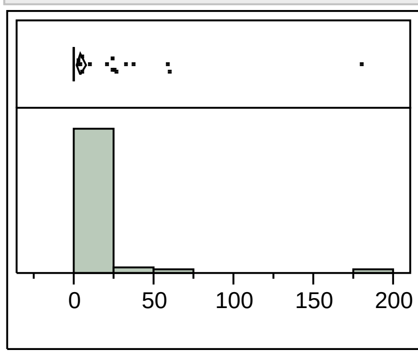
100.0%	maximum	917.44
99.5%		917.44
97.5%		257.154
90.0%		18.004
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	20.886565
Std Dev	115.36798
Std Err Mean	10.079747
Upper 95% Mean	40.828139
Lower 95% Mean	0.9449905
N	131

Figure II.45. Weekly demand from Comodoro Rivadavia Air Base (Kg).

10ESC



Quantiles

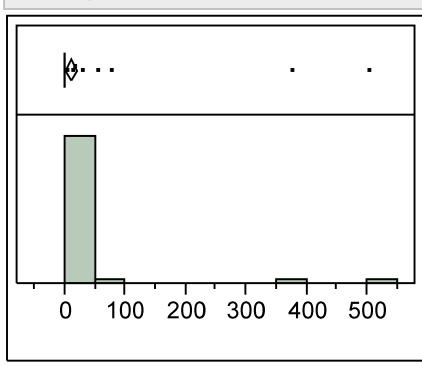
100.0%	maximum	180
99.5%		180
97.5%		51.651
90.0%		3.984
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	3.8723664
Std Dev	18.094846
Std Err Mean	1.5809541
Upper 95% Mean	7.0000949
Lower 95% Mean	0.7446379
N	131

Figure II.46. Weekly demand from the Air Force Academy (Kg).

11TRC



Quantiles

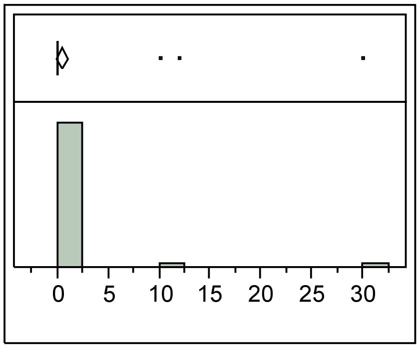
100.0%	maximum	504
99.5%		504
97.5%		68.829
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	8.1643511
Std Dev	55.175696
Std Err Mean	4.820723
Upper 95% Mean	17.701575
Lower 95% Mean	-1.372873
N	131

Figure II.47. Weekly demand from Rio Cuarto depot (Kg).

12ALC



Quantiles

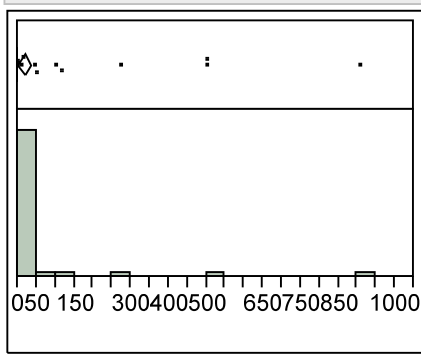
100.0%	maximum	30
99.5%		30
97.5%		7
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	0.3969466
Std Dev	2.9395954
Std Err Mean	0.2568336
Upper 95% Mean	0.9050612
Lower 95% Mean	-0.111168
N	131

Figure II.48. Weekly demand from El Palomar Logistic Base (Kg).

13ILM



Quantiles

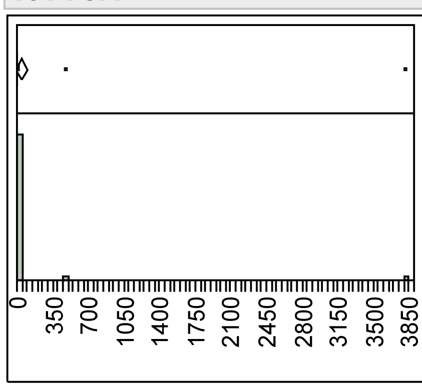
100.0%	maximum	909.08
99.5%		909.08
97.5%		431.882
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	19.255802
Std Dev	103.14776
Std Err Mean	9.0120616
Upper 95% Mean	37.085088
Lower 95% Mean	1.4265154
N	131

Figure II.49. Weekly demand from Quilmes depot (Kg).

15VYCA



Quantiles

100.0%	maximum	3800
99.5%		3800
97.5%		2.807
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

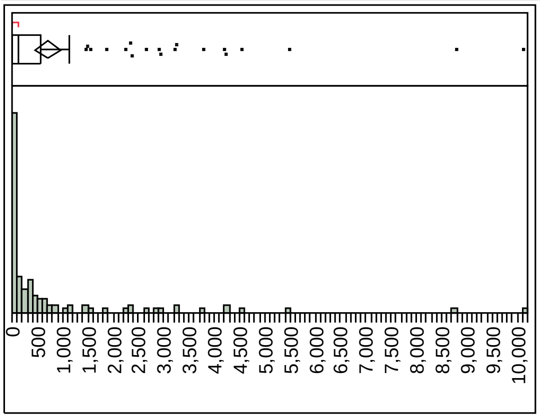
Mean	32.623969
Std Dev	334.21257
Std Err Mean	29.200288
Upper 95% Mean	90.393247
Lower 95% Mean	-25.14531
N	131

Figure II.50. Weekly demand from the Ground-Controlled Interception Sys Unit (Kg).

End of Demand Histograms for 14ALP RW – No demand from 2PAR, 3RTA and 8MOR.

Origin: 14ALP FW (El Palomar Depot) for forward (supply) side only

TOTAL



Quantiles

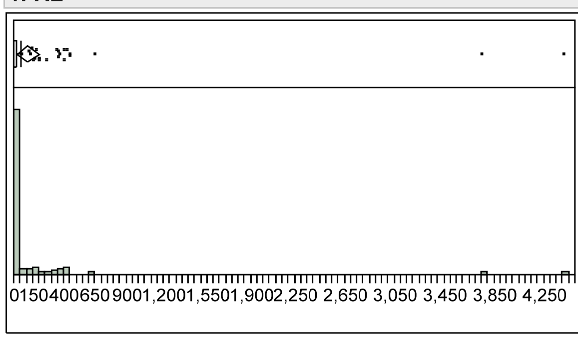
100.0%	maximum	10103
99.5%		10103
97.5%		5202.19
90.0%		2343.73
75.0%	quartile	561.41
50.0%	median	127.01
25.0%	quartile	5.83
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	694.19244
Std Dev	1518.5527
Std Err Mean	132.67656
Upper 95% Mean	956.67715
Lower 95% Mean	431.70773
N	131

Figure II.51. Weekly demand from all requestors (Kg).

1PAL



Quantiles

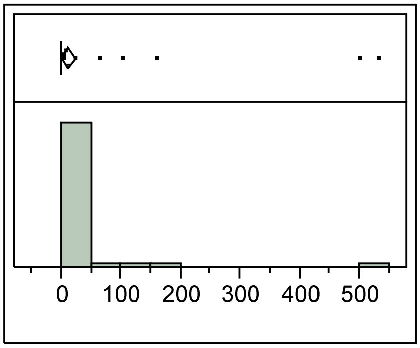
100.0%	maximum	4405.12
99.5%		4405.12
97.5%		584.622
90.0%		247.566
75.0%	quartile	24.04
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	110.76748
Std Dev	511.20521
Std Err Mean	44.664207
Upper 95% Mean	199.13027
Lower 95% Mean	22.40469
N	131

Figure II.52. Weekly demand from El Palomar Air Base (Kg).

2PAR

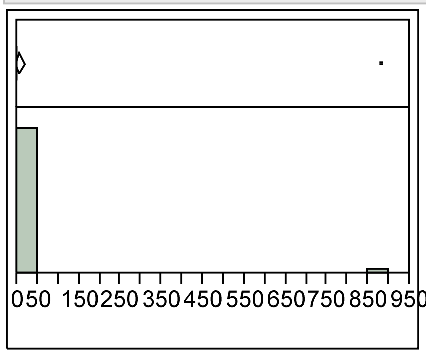


Quantiles		
100.0%	maximum	533.15
99.5%		533.15
97.5%		142.3
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	10.736183
Std Dev	65.618356
Std Err Mean	5.7331024
Upper 95% Mean	22.078441
Lower 95% Mean	-0.606074
N	131

Figure II.53. Weekly demand from Parana Air Base (Kg).

3RTA

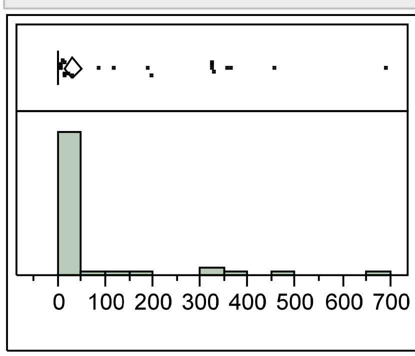


Quantiles		
100.0%	maximum	880
99.5%		880
97.5%		0
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	6.7175573
Std Dev	76.885957
Std Err Mean	6.7175573
Upper 95% Mean	20.007441
Lower 95% Mean	-6.572326
N	131

Figure II.54. Weekly demand from Reconquista Air Base (Kg).

4DOZ

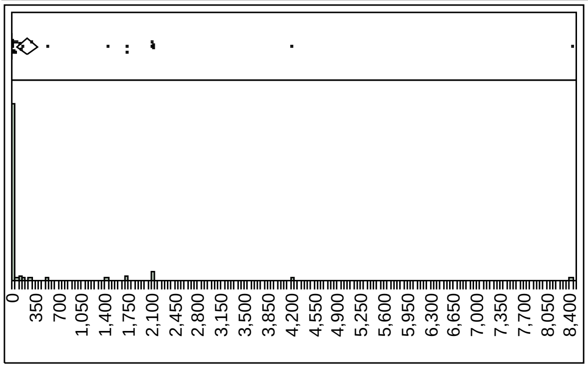


Quantiles		
100.0%	maximum	688.5
99.5%		688.5
97.5%		360.82
90.0%		28.2
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics	
Mean	29.383969
Std Dev	101.56278
Std Err Mean	8.873581
Upper 95% Mean	46.939288
Lower 95% Mean	11.828651
N	131

Figure II.55. Weekly demand from Mendoza Air Base (Kg).

5RYD



Quantiles

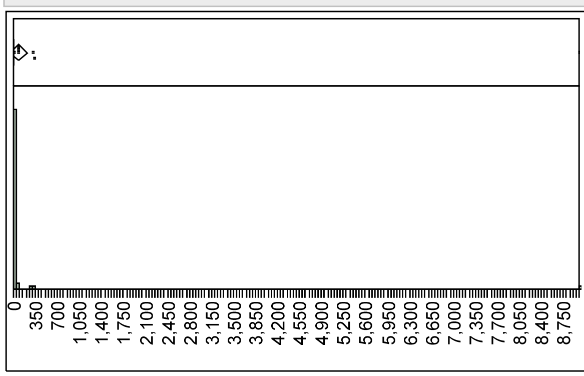
100.0%	maximum	8430
99.5%		8430
97.5%		2119.57
90.0%		158.482
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	225.13046
Std Dev	931.38489
Std Err Mean	81.375475
Upper 95% Mean	386.1221
Lower 95% Mean	64.138812
N	131

Figure II.56. Weekly demand from Villa Reynolds Air Base (Kg).

6DIL



Quantiles

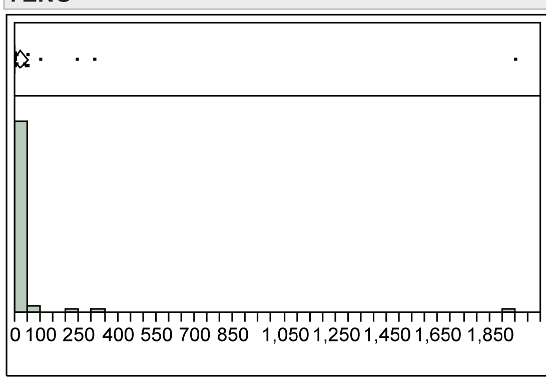
100.0%	maximum	9000
99.5%		9000
97.5%		230.36
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	75.146489
Std Dev	786.76097
Std Err Mean	68.739625
Upper 95% Mean	211.13962
Lower 95% Mean	-60.84664
N	131

Figure II.57. Weekly demand from Tandil Air Base (Kg).

7ENO



Quantiles

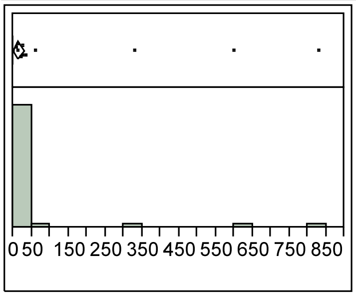
100.0%	maximum	1948.56
99.5%		1948.56
97.5%		197.025
90.0%		1
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	21.318015
Std Dev	173.39337
Std Err Mean	15.149449
Upper 95% Mean	51.289388
Lower 95% Mean	-8.653357
N	131

Figure II.58. Weekly demand from Moreno Air Base (Kg).

9CRV



Quantiles

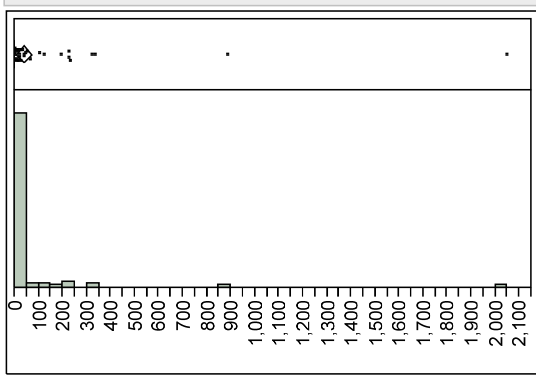
100.0%	maximum	831.52
99.5%		831.52
97.5%		249.351
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	14.983282
Std Dev	93.570281
Std Err Mean	8.1752734
Upper 95% Mean	31.157083
Lower 95% Mean	-1.190518
N	131

Figure II.59. Weekly demand from Comodoro Rivadavia Air Base (Kg).

10ESC



Quantiles

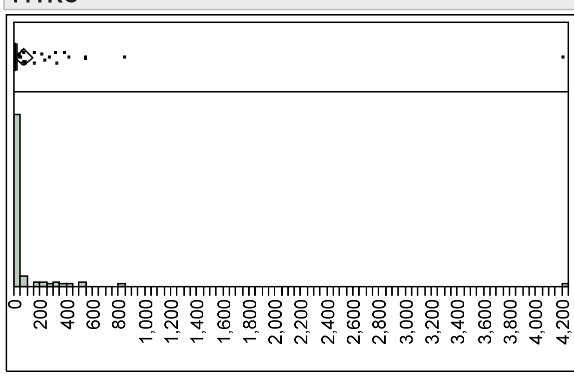
100.0%	maximum	2046.8
99.5%		2046.8
97.5%		328.018
90.0%		45.72
75.0%	quartile	0.22
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	38.967405
Std Dev	200.40619
Std Err Mean	17.50957
Upper 95% Mean	73.607996
Lower 95% Mean	4.3268135
N	131

Figure II.60. Weekly demand from the Air Force Academy (Kg).

11TRC



Quantiles

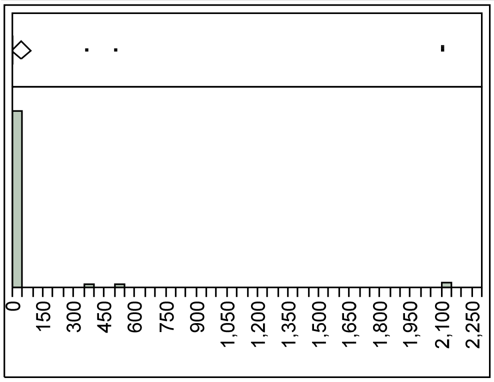
100.0%	maximum	4200
99.5%		4200
97.5%		545.74
90.0%		136.64
75.0%	quartile	11.04
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	71.594962
Std Dev	382.71952
Std Err Mean	33.438359
Upper 95% Mean	137.74876
Lower 95% Mean	5.4411667
N	131

Figure II.61. Weekly demand from Rio Cuarto depot (Kg).

12ALC



Quantiles

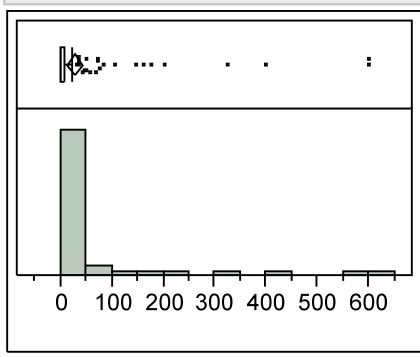
100.0%	maximum	2100
99.5%		2100
97.5%		459.2
90.0%		0
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	38.656489
Std Dev	263.2159
Std Err Mean	22.99728
Upper 95% Mean	84.153857
Lower 95% Mean	-6.84088
N	131

Figure II.62. Weekly demand from El Palomar Logistic Unit (Kg).

13ILM



Quantiles

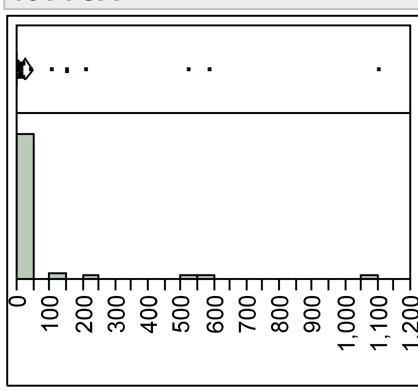
100.0%	maximum	600
99.5%		600
97.5%		377.548
90.0%		69.974
75.0%	quartile	9.6
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	27.948397
Std Dev	90.142393
Std Err Mean	7.8757774
Upper 95% Mean	43.529681
Lower 95% Mean	12.367113
N	131

Figure II.63. Weekly demand from Quilmes depot (Kg).

15VYCA



Quantiles

100.0%	maximum	1099.46
99.5%		1099.46
97.5%		428.535
90.0%		12.384
75.0%	quartile	0
50.0%	median	0
25.0%	quartile	0
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	22.841756
Std Dev	119.55414
Std Err Mean	10.445494
Upper 95% Mean	43.506916
Lower 95% Mean	2.1765952
N	131

Figure II.64. Weekly demand from Ground-Controlled Interception Sys. Unit (Kg).

End of Supply Histograms for 14ALP FW – No supply to 8MOR.

Appendix III

Tables of cost of transportation with product density of 55 Kg/m^3.

Table III.1. Transportation costs of consolidation-type operations including C-130

		Distance	Time	Mode	Resource	Rio Cuarto depot	Cordoba LU	Quilmes depot	El Palomar LU	TOTAL				
From	To	Km	Hs	Vehicle	Unit	Tons	Tons	Tons	Tons	Tons	Fixed Cost	Variable Cost	Capacity Utilization	TOTAL COST
1PAL	2PAR	498	6.23	UV	1			0.103	0.143	0.246	39.84	212.15	0.32	251.99
2PAR	1PAL	498	6.23	UV	1			0.103		0.103	39.84	212.15	0.13	251.99
1PAL	10ESC	580	8.81	Truck	1		0.730	0.115	0.309	1.154	60.90	689.04	0.31	749.94
10ESC	1PAL	580	8.81	Truck	1		0.730	0.115	0.007	0.852	60.90	689.04	0.23	749.94
1PAL	11TRC	572	8.40	Truck	1	0.549		0.077	0.323	0.949	60.06	679.54	0.26	739.60
11TRC	1PAL	572	8.40	Truck	1	0.549		0.077	0.256	0.882	60.06	679.54	0.24	739.60
1PAL	14ALP	2	0.05	Truck	1	0.290	0.359	1.012	0.227	1.888	0.21	2.38	0.51	2.59
14ALP	1PAL	2	0.05	Truck	1	0.290	0.359	1.012	1.022	2.683	0.21	2.38	0.73	2.59
2PAR	3RTA	337	4.21	UV	1	0.043	0.128	0.023	0.077	0.271	26.96	143.56	0.35	170.52
3RTA	2PAR	337	4.21	UV	1	0.043	0.128	0.023		0.194	26.96	143.56	0.25	170.52
2PAR	10ESC	397	4.96	UV	1	0.062	0.145			0.207	31.76	169.12	0.27	200.88
10ESC	2PAR	397	4.96	UV	1	0.062	0.145			0.207	31.76	169.12	0.27	200.88
4DOZ	5RYD	371	4.64	UV	1	0.084	0.058	0.021	0.007	0.170	29.68	158.05	0.22	187.73
5RYD	4DOZ	371	4.64	UV	1	0.084	0.058	0.021	0.028	0.191	29.68	158.05	0.25	187.73
5RYD	11TRC	130	1.63	UV	1	0.156	0.316	0.060	0.200	0.732	10.40	55.38	0.96	65.78
11TRC	5RYD	130	1.63	UV	1	0.156	0.316	0.060	0.187	0.719	10.40	55.38	0.94	65.78
6DIL	9CRV	1180	2.20	C-130	1			0.152	0.094	0.246	6963.18	29240.40	0.11	36203.58
9CRV	6DIL	1180	2.20	C-130	1			0.152	0.018	0.170	6963.18	29240.40	0.07	36203.58
6DIL	14ALP	392	4.90	UV	1	0.115	0.057		0.025	0.197	31.36	166.99	0.26	198.35
14ALP	6DIL	392	4.90	UV	1	0.115	0.057		0.169	0.341	31.36	166.99	0.45	198.35
7ENO	14ALP	22	0.55	UV	1		0.001	0.072	0.348	0.421	1.76	9.37	0.55	11.13
14ALP	7ENO	22	0.55	UV	1			0.072	0.186	0.258	1.76	9.37	0.34	11.13
7ENO	15VYCA	24	0.60	UV	1			0.010	0.012	0.022	1.92	10.22	0.03	12.14
15VYCA	7ENO	24	0.60	UV	1			0.010	0.334	0.344	1.92	10.22	0.45	12.14
8MOR	14ALP	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
14ALP	8MOR	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
10ESC	11TRC	218	2.73	UV	1	0.097	0.356			0.453	17.44	92.87	0.59	110.31
11TRC	10ESC	218	2.73	UV	1	0.097	0.356			0.453	17.44	92.87	0.59	110.31
10ESC	12ALC	2	0.05	Truck	1	0.009	1.238	0.065	0.263	1.575	0.21	2.38	0.43	2.59
12ALC	10ESC	2	0.05	Truck	1	0.009	1.238	0.065	0.003	1.315	0.21	2.38	0.36	2.59
13ILM	6DIL	422	5.28	UV	1			0.193		0.193	33.76	179.77	0.25	213.53
6DIL	13ILM	422	5.28	UV	1			0.193		0.193	33.76	179.77	0.25	213.53
13ILM	14ALP	45	1.13	UV	2	0.018	0.037	1.155	0.103	1.313	7.20	38.34	0.86	45.54
14ALP	13ILM	45	1.13	UV	2	0.018	0.037	1.155	0.070	1.280	7.20	38.34	0.84	45.54
										TOTAL:	14634.40	63705.07	0.37	78339.47
											19%	81%		

Table III.2. Transportation costs of consolidation-type operations including C-208B.

		Distance	Time	Mode	Resource	Rio Cuarto depot	Cordoba LU	Quilmes depot	El Palomar LU	TOTAL				
From	To	Km	Hs	Vehicle	Unit	Tons	Tons	Tons	Tons	Tons	Fixed Cost	Variable Cost	Capacity Utilization	TOTAL COST
1PAL	2PAR	498	6.23	UV	1			0.103	0.143	0.246	39.84	212.15	0.32	251.99
2PAR	1PAL	498	6.23	UV	1			0.103		0.103	39.84	212.15	0.13	251.99
1PAL	10ESC	580	8.81	Truck	2		0.730	0.115	0.309	1.154	121.80	1378.08	0.16	1499.88
10ESC	1PAL	580	8.81	Truck	2		0.730	0.115	0.007	0.852	121.80	1378.08	0.12	1499.88
1PAL	11TRC	572	8.40	Truck	2	0.549		0.077	0.323	0.949	120.12	1359.07	0.13	1479.19
11TRC	1PAL	572	8.40	Truck	2	0.549		0.077	0.256	0.882	120.12	1359.07	0.12	1479.19
1PAL	14ALP	2	0.05	Truck	1	0.290	0.359	1.012	0.227	1.888	0.21	2.38	0.51	2.59
14ALP	1PAL	2	0.05	Truck	1	0.290	0.359	1.012	1.022	2.683	0.21	2.38	0.73	2.59
2PAR	3RTA	337	4.21	UV	1	0.043	0.128	0.023	0.077	0.271	26.96	143.56	0.35	170.52
3RTA	2PAR	337	4.21	UV	1	0.043	0.128	0.023		0.194	26.96	143.56	0.25	170.52
2PAR	10ESC	397	4.96	UV	1	0.062	0.145			0.207	31.76	169.12	0.27	200.88
10ESC	2PAR	397	4.96	UV	1	0.062	0.145			0.207	31.76	169.12	0.27	200.88
4DOZ	5RYD	371	4.64	UV	1	0.084	0.058	0.021	0.007	0.170	29.68	158.05	0.22	187.73
5RYD	4DOZ	371	4.64	UV	1	0.084	0.058	0.021	0.028	0.191	29.68	158.05	0.25	187.73
5RYD	11TRC	130	1.63	UV	1	0.156	0.316	0.060	0.200	0.732	10.40	55.38	0.96	65.78
11TRC	5RYD	130	1.63	UV	1	0.156	0.316	0.060	0.187	0.719	10.40	55.38	0.94	65.78
6DIL	9CRV	1180	3.98	C-208B	1			0.152	0.094	0.246	1524.56	1711.00	0.35	3235.56
9CRV	6DIL	1180	3.98	C-208B	1			0.152	0.018	0.170	1524.56	1711.00	0.24	3235.56
6DIL	14ALP	392	4.90	UV	1	0.115	0.057		0.025	0.197	31.36	166.99	0.26	198.35
14ALP	6DIL	392	4.90	UV	1	0.115	0.057		0.169	0.341	31.36	166.99	0.45	198.35
7ENO	14ALP	22	0.55	UV	1		0.001	0.072	0.348	0.421	1.76	9.37	0.55	11.13
14ALP	7ENO	22	0.55	UV	1			0.072	0.186	0.258	1.76	9.37	0.34	11.13
7ENO	15VYCA	24	0.60	UV	1			0.010	0.012	0.022	1.92	10.22	0.03	12.14
15VYCA	7ENO	24	0.60	UV	1			0.010	0.334	0.344	1.92	10.22	0.45	12.14
8MOR	14ALP	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
14ALP	8MOR	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
10ESC	11TRC	218	2.73	UV	1	0.097	0.356			0.453	17.44	92.87	0.59	110.31
11TRC	10ESC	218	2.73	UV	1	0.097	0.356			0.453	17.44	92.87	0.59	110.31
10ESC	12ALC	2	0.05	Truck	1	0.009	1.238	0.065	0.263	1.575	0.21	2.38	0.43	2.59
12ALC	10ESC	2	0.05	Truck	1	0.009	1.238	0.065	0.003	1.315	0.21	2.38	0.36	2.59
13ILM	6DIL	422	5.28	UV	1			0.193		0.193	33.76	179.77	0.25	213.53
6DIL	13ILM	422	5.28	UV	1			0.193		0.193	33.76	179.77	0.25	213.53
13ILM	14ALP	45	1.13	UV	2	0.018	0.037	1.155	0.103	1.313	7.20	38.34	0.86	45.54
14ALP	13ILM	45	1.13	UV	2	0.018	0.037	1.155	0.070	1.280	7.20	38.34	0.84	45.54
										TOTAL:	3999.080	11383.424	0.37	15382.50
											26%	74%		

Table III.3. Transportation costs of consolidation-type operations using only trucks.

		Distance	Time	Mode	Resource	Rio Cuarto depot	Cordoba LU	Quilmes depot	El Palomar LU	TOTAL				
From	To	Km	Hs	Vehicle	Unit	Tons	Tons	Tons	Tons	Tons	Fixed Cost	Variable Cost	Capacity Utilizatio	TOTAL COST
1PAL	2PAR	498	6.23	Truck	1			0.103	0.143	0.246	52.29	591.62	0.07	643.91
2PAR	1PAL	498	6.23	Truck	1			0.103		0.103	52.29	591.62	0.03	643.91
1PAL	10ESC	705	8.81	Truck	1		0.730	0.115	0.309	1.154	74.03	837.54	0.31	911.57
10ESC	1PAL	705	8.81	Truck	1		0.730	0.115	0.007	0.852	74.03	837.54	0.23	911.57
1PAL	11TRC	672	8.40	Truck	1	0.549		0.077	0.323	0.949	70.56	798.34	0.26	868.90
11TRC	1PAL	672	8.40	Truck	1	0.549		0.077	0.256	0.882	70.56	798.34	0.24	868.90
1PAL	14ALP	2	0.05	Truck	1	0.290	0.359	1.012	0.227	1.888	0.21	2.38	0.51	2.59
14ALP	1PAL	2	0.05	Truck	1	0.290	0.359	1.012	1.022	2.683	0.21	2.38	0.73	2.59
2PAR	3RTA	337	4.21	Truck	1	0.043	0.128	0.023	0.077	0.271	35.39	400.36	0.07	435.74
3RTA	2PAR	337	4.21	Truck	1	0.043	0.128	0.023		0.194	35.39	400.36	0.05	435.74
2PAR	10ESC	397	4.96	Truck	1	0.062	0.145			0.207	41.69	471.64	0.06	513.32
10ESC	2PAR	397	4.96	Truck	1	0.062	0.145			0.207	41.69	471.64	0.06	513.32
4DOZ	5RYD	371	4.64	Truck	1	0.084	0.058	0.021	0.007	0.170	38.96	440.75	0.05	479.70
5RYD	4DOZ	371	4.64	Truck	1	0.084	0.058	0.021	0.028	0.191	38.96	440.75	0.05	479.70
5RYD	11TRC	130	1.63	Truck	1	0.156	0.316	0.060	0.200	0.732	13.65	154.44	0.20	168.09
11TRC	5RYD	130	1.63	Truck	1	0.156	0.316	0.060	0.187	0.719	13.65	154.44	0.20	168.09
6DIL	9CRV	1486	18.58	Truck	1			0.152	0.094	0.246	156.03	1765.37	0.07	1921.40
9CRV	6DIL	1486	18.58	Truck	1			0.152	0.018	0.170	156.03	1765.37	0.05	1921.40
6DIL	14ALP	392	4.90	Truck	1	0.115	0.057		0.025	0.197	41.16	465.70	0.05	506.86
14ALP	6DIL	392	4.90	Truck	1	0.115	0.057		0.169	0.341	41.16	465.70	0.09	506.86
7ENO	14ALP	22	0.55	Truck	1		0.001	0.072	0.348	0.421	2.31	26.14	0.11	28.45
14ALP	7ENO	22	0.55	Truck	1			0.072	0.186	0.258	2.31	26.14	0.07	28.45
7ENO	15VYCA	24	0.60	Truck	1			0.010	0.012	0.022	2.52	28.51	0.01	31.03
15VYCA	7ENO	24	0.60	Truck	1			0.010	0.334	0.344	2.52	28.51	0.09	31.03
8MOR	14ALP	7	0.18	Truck	1	0.021				0.021	0.74	8.32	0.01	9.05
14ALP	8MOR	7	0.18	Truck	1	0.021				0.021	0.74	8.32	0.01	9.05
10ESC	11TRC	218	2.73	Truck	1	0.097	0.356			0.453	22.89	258.98	0.12	281.87
11TRC	10ESC	218	2.73	Truck	1	0.097	0.356			0.453	22.89	258.98	0.12	281.87
10ESC	12ALC	2	0.05	Truck	1	0.009	1.238	0.065	0.263	1.575	0.21	2.38	0.43	2.59
12ALC	10ESC	2	0.05	Truck	1	0.009	1.238	0.065	0.003	1.315	0.21	2.38	0.36	2.59
13ILM	6DIL	422	5.28	Truck	1			0.193		0.193	44.31	501.34	0.05	545.65
6DIL	13ILM	422	5.28	Truck	1			0.193		0.193	44.31	501.34	0.05	545.65
13ILM	14ALP	45	1.13	Truck	1	0.018	0.037	1.155	0.103	1.313	4.73	53.46	0.36	58.19
14ALP	13ILM	45	1.13	Truck	1	0.018	0.037	1.155	0.070	1.280	4.73	53.46	0.35	58.19
										TOTAL:	1203.30	13614.48	0.16	14817.78
											8%	92%		

Table III.4. Cost of hub-and-spoke operations using including C-208B.

		Distance	Time	Mode	Resource	Rio Cuarto depot	Cordoba LU	Quilmes depot	El Palomar LU	TOTAL				
From	To	Km	Hs	Vehicle	Unit	Tons	Tons	Tons	Tons	Tons	Fixed Cost	Variable Cost	Capacity Utilization	TOTAL COST
1PAL	2PAR	498	6.23	UV	1	0.062	0.145	0.103	0.143	0.453	39.84	212.15	0.59	251.99
2PAR	1PAL	498	6.23	UV	1	0.062	0.145	0.103		0.310	39.84	212.15	0.40	251.99
1PAL	10ESC	705	8.81							0.000				
10ESC	1PAL	705	8.81							0.000				
1PAL	11TRC	672	8.40	Truck	1	0.611	0.875	0.192	0.632	2.310	70.56	798.34	0.63	868.90
11TRC	1PAL	672	8.40	Truck	1	0.611	0.875	0.192	0.263	1.941	70.56	798.34	0.53	868.90
1PAL	14ALP	2	0.05	Truck	1	0.290	0.359	1.012	0.227	1.888	0.21	2.38	0.51	2.59
14ALP	1PAL	2	0.05	Truck	1	0.290	0.359	1.012	1.022	2.683	0.21	2.38	0.73	2.59
2PAR	3RTA	337	4.21	UV	1	0.043	0.128	0.023	0.077	0.271	26.96	143.56	0.35	170.52
3RTA	2PAR	337	4.21	UV	1	0.043	0.128	0.023		0.194	26.96	143.56	0.25	170.52
2PAR	10ESC	397	4.96											
10ESC	2PAR	397	4.96											
4DOZ	5RYD	371	4.64	UV	1	0.084	0.058	0.021	0.007	0.170	29.68	158.05	0.22	187.73
5RYD	4DOZ	371	4.64	UV	1	0.084	0.058	0.021	0.028	0.191	29.68	158.05	0.25	187.73
5RYD	11TRC	130	1.63	UV	1	0.156	0.316	0.060	0.200	0.732	10.40	55.38	0.96	65.78
11TRC	5RYD	130	1.63	UV	1	0.156	0.316	0.060	0.187	0.719	10.40	55.38	0.94	65.78
6DIL	9CRV	1180	3.98	C-208B	1			0.152	0.094	0.246	1524.56	1711.00	0.35	3235.56
9CRV	6DIL	1180	3.98	C-208B	1			0.152	0.018	0.170	1524.56	1711.00	0.24	3235.56
6DIL	14ALP	392	4.90	UV	1	0.115	0.057	0.193	0.025	0.390	31.36	166.99	0.51	198.35
14ALP	6DIL	392	4.90	UV	1	0.115	0.057	0.193	0.169	0.534	31.36	166.99	0.70	198.35
7ENO	14ALP	22	0.55	UV	1		0.001	0.072	0.348	0.421	1.76	9.37	0.55	11.13
14ALP	7ENO	22	0.55	UV	1			0.072	0.186	0.258	1.76	9.37	0.34	11.13
7ENO	15VYCA	24	0.60	UV	1			0.010	0.012	0.022	1.92	10.22	0.03	12.14
15VYCA	7ENO	24	0.60	UV	1			0.010	0.334	0.344	1.92	10.22	0.45	12.14
8MOR	14ALP	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
14ALP	8MOR	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
10ESC	11TRC	218	2.73	Truck	1	0.097	1.231	0.115	0.007	1.450	22.89	258.98	0.39	281.87
11TRC	10ESC	218	2.73	Truck	1	0.097	1.231	0.115	0.309	1.752	22.89	258.98	0.48	281.87
10ESC	12ALC	2	0.05	Truck	1	0.009	1.238	0.065	0.263	1.575	0.21	2.38	0.43	2.59
12ALC	10ESC	2	0.05	Truck	1	0.009	1.238	0.065	0.003	1.315	0.21	2.38	0.36	2.59
13ILM	6DIL	422	5.28							0.000				
6DIL	13ILM	422	5.28							0.000				
13ILM	14ALP	45	1.13	UV	2	0.018	0.037	1.348	0.103	1.506	7.20	38.34	0.98	45.54
14ALP	13ILM	45	1.13	UV	2	0.018	0.037	1.348	0.070	1.473	7.20	38.34	0.96	45.54
										TOTAL:	3536.22	7140.24	0.39	10676.46
											33%	67%		

Table 5. Transportation costs of consolidation-type operations using only trucks and utility vehicles.

		Distance	Time	Mode	Resource	Rio Cuarto depot	Cordoba LU	Quilmes depot	El Palomar LU	TOTAL				
From	To	Km	Hs	Vehicle	Unit	Tons	Tons	Tons	Tons	Tons	Fixed Cost	Variable Cost	Capacity Utilizatio	TOTAL COST
1PAL	2PAR	498	6.23	UV	1			0.103	0.143	0.246	39.84	212.15	0.32	251.99
2PAR	1PAL	498	6.23	UV	1			0.103		0.103	39.84	212.15	0.13	251.99
1PAL	10ESC	705	8.81	UV	2		0.730	0.115	0.309	1.154	112.80	600.66	0.75	713.46
10ESC	1PAL	705	8.81	UV	2		0.730	0.115	0.007	0.852	112.80	600.66	0.56	713.46
1PAL	11TRC	672	8.40	UV	2	0.549		0.077	0.323	0.949	107.52	572.54	0.62	680.06
11TRC	1PAL	672	8.40	UV	2	0.549		0.077	0.256	0.882	107.52	572.54	0.58	680.06
1PAL	14ALP	2	0.05	Truck	1	0.290	0.359	1.012	0.227	1.888	0.21	2.38	0.51	2.59
14ALP	1PAL	2	0.05	Truck	1	0.290	0.359	1.012	1.022	2.683	0.21	2.38	0.73	2.59
2PAR	3RTA	337	4.21	UV	1	0.043	0.128	0.023	0.077	0.271	26.96	143.56	0.35	170.52
3RTA	2PAR	337	4.21	UV	1	0.043	0.128	0.023		0.194	26.96	143.56	0.25	170.52
2PAR	10ESC	397	4.96	UV	1	0.062	0.145			0.207	31.76	169.12	0.27	200.88
10ESC	2PAR	397	4.96	UV	1	0.062	0.145			0.207	31.76	169.12	0.27	200.88
4DOZ	5RYD	371	4.64	UV	1	0.084	0.058	0.021	0.007	0.170	29.68	158.05	0.22	187.73
5RYD	4DOZ	371	4.64	UV	1	0.084	0.058	0.021	0.028	0.191	29.68	158.05	0.25	187.73
5RYD	11TRC	130	1.63	UV	1	0.156	0.316	0.060	0.200	0.732	10.40	55.38	0.96	65.78
11TRC	5RYD	130	1.63	UV	1	0.156	0.316	0.060	0.187	0.719	10.40	55.38	0.94	65.78
6DIL	9CRV	1486	18.58	UV	1			0.152	0.094	0.246	118.88	633.04	0.32	751.92
9CRV	6DIL	1486	18.58	UV	1			0.152	0.018	0.170	118.88	633.04	0.22	751.92
6DIL	14ALP	392	4.90	UV	1	0.115	0.057		0.025	0.197	31.36	166.99	0.26	198.35
14ALP	6DIL	392	4.90	UV	1	0.115	0.057		0.169	0.341	31.36	166.99	0.45	198.35
7ENO	14ALP	22	0.55	UV	1		0.001	0.072	0.348	0.421	1.76	9.37	0.55	11.13
14ALP	7ENO	22	0.55	UV	1			0.072	0.186	0.258	1.76	9.37	0.34	11.13
7ENO	15VYCA	24	0.60	UV	1			0.010	0.012	0.022	1.92	10.22	0.03	12.14
15VYCA	7ENO	24	0.60	UV	1			0.010	0.334	0.344	1.92	10.22	0.45	12.14
8MOR	14ALP	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
14ALP	8MOR	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
10ESC	11TRC	218	2.73	UV	1	0.097	0.356			0.453	17.44	92.87	0.59	110.31
11TRC	10ESC	218	2.73	UV	1	0.097	0.356			0.453	17.44	92.87	0.59	110.31
10ESC	12ALC	2	0.05	Truck	1	0.009	1.238	0.065	0.263	1.575	0.21	2.38	0.43	2.59
12ALC	10ESC	2	0.05	Truck	1	0.009	1.238	0.065	0.003	1.315	0.21	2.38	0.36	2.59
13ILM	6DIL	422	5.28	UV	1			0.193		0.193	33.76	179.77	0.25	213.53
6DIL	13ILM	422	5.28	UV	1			0.193		0.193	33.76	179.77	0.25	213.53
13ILM	14ALP	45	1.13	UV	2	0.018	0.037	1.155	0.103	1.313	7.20	38.34	0.86	45.54
14ALP	13ILM	45	1.13	UV	2	0.018	0.037	1.155	0.070	1.280	7.20	38.34	0.84	45.54
										TOTAL:	1144.52	6099.60	0.43	7244.12
											16%	84%		

Table 6. Transportation costs of hub-and-spoke operations using only trucks and utility vehicles.

		Distance	Time	Mode	Resource	Rio Cuarto depot	Cordoba LU	Quilmes depot	El Palomar LU	TOTAL				
From	To	Km	Hs	Vehicle	Unit	Tons	Tons	Tons	Tons	Tons	Fixed Cost	Variable Cost	Capacity Utilization	TOTAL COST
1PAL	2PAR	498	6.23	UV	1	0.062	0.145	0.103	0.143	0.453	39.84	212.15	0.59	251.99
2PAR	1PAL	498	6.23	UV	1	0.062	0.145	0.103		0.310	39.84	212.15	0.40	251.99
1PAL	10ESC	705	8.81							0.000				
10ESC	1PAL	705	8.81							0.000				
1PAL	11TRC	672	8.40	Truck	1	0.611	0.875	0.192	0.632	2.310	70.56	798.34	0.63	868.90
11TRC	1PAL	672	8.40	Truck	1	0.611	0.875	0.192	0.263	1.941	70.56	798.34	0.53	868.90
1PAL	14ALP	2	0.05	Truck	1	0.290	0.359	1.012	0.227	1.888	0.21	2.38	0.51	2.59
14ALP	1PAL	2	0.05	Truck	1	0.290	0.359	1.012	1.022	2.683	0.21	2.38	0.73	2.59
2PAR	3RTA	337	4.21	UV	1	0.043	0.128	0.023	0.077	0.271	26.96	143.56	0.35	170.52
3RTA	2PAR	337	4.21	UV	1	0.043	0.128	0.023		0.194	26.96	143.56	0.25	170.52
2PAR	10ESC	397	4.96											
10ESC	2PAR	397	4.96											
4DOZ	5RYD	371	4.64	UV	1	0.084	0.058	0.021	0.007	0.170	29.68	158.05	0.22	187.73
5RYD	4DOZ	371	4.64	UV	1	0.084	0.058	0.021	0.028	0.191	29.68	158.05	0.25	187.73
5RYD	11TRC	130	1.63	UV	1	0.156	0.316	0.060	0.200	0.732	10.40	55.38	0.96	65.78
11TRC	5RYD	130	1.63	UV	1	0.156	0.316	0.060	0.187	0.719	10.40	55.38	0.94	65.78
6DIL	9CRV	1486	18.58	UV	1			0.152	0.094	0.246	118.88	633.04	0.32	751.92
9CRV	6DIL	1486	18.58	UV	1			0.152	0.018	0.170	118.88	633.04	0.22	751.92
6DIL	14ALP	392	4.90	UV	1	0.115	0.057	0.193	0.025	0.390	31.36	166.99	0.51	198.35
14ALP	6DIL	392	4.90	UV	1	0.115	0.057	0.193	0.169	0.534	31.36	166.99	0.70	198.35
7ENO	14ALP	22	0.55	UV	1		0.001	0.072	0.348	0.421	1.76	9.37	0.55	11.13
14ALP	7ENO	22	0.55	UV	1			0.072	0.186	0.258	1.76	9.37	0.34	11.13
7ENO	15VYCA	24	0.60	UV	1			0.010	0.012	0.022	1.92	10.22	0.03	12.14
15VYCA	7ENO	24	0.60	UV	1			0.010	0.334	0.344	1.92	10.22	0.45	12.14
8MOR	14ALP	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
14ALP	8MOR	7	0.18	UV	1	0.021				0.021	0.56	2.98	0.03	3.54
10ESC	11TRC	218	2.73	Truck	1	0.097	1.231	0.115	0.007	1.450	22.89	258.98	0.39	281.87
11TRC	10ESC	218	2.73	Truck	1	0.097	1.231	0.115	0.309	1.752	22.89	258.98	0.48	281.87
10ESC	12ALC	2	0.05	Truck	1	0.009	1.238	0.065	0.263	1.575	0.21	2.38	0.43	2.59
12ALC	10ESC	2	0.05	Truck	1	0.009	1.238	0.065	0.003	1.315	0.21	2.38	0.36	2.59
13ILM	6DIL	422	5.28							0.000				
6DIL	13ILM	422	5.28							0.000				
13ILM	14ALP	45	1.13	UV	2	0.018	0.037	1.348	0.103	1.506	7.20	38.34	0.98	45.54
14ALP	13ILM	45	1.13	UV	2	0.018	0.037	1.348	0.070	1.473	7.20	38.34	0.96	45.54
										TOTAL:	724.86	4984.31	0.39	5709.17
											13%	87%		

Appendix IV

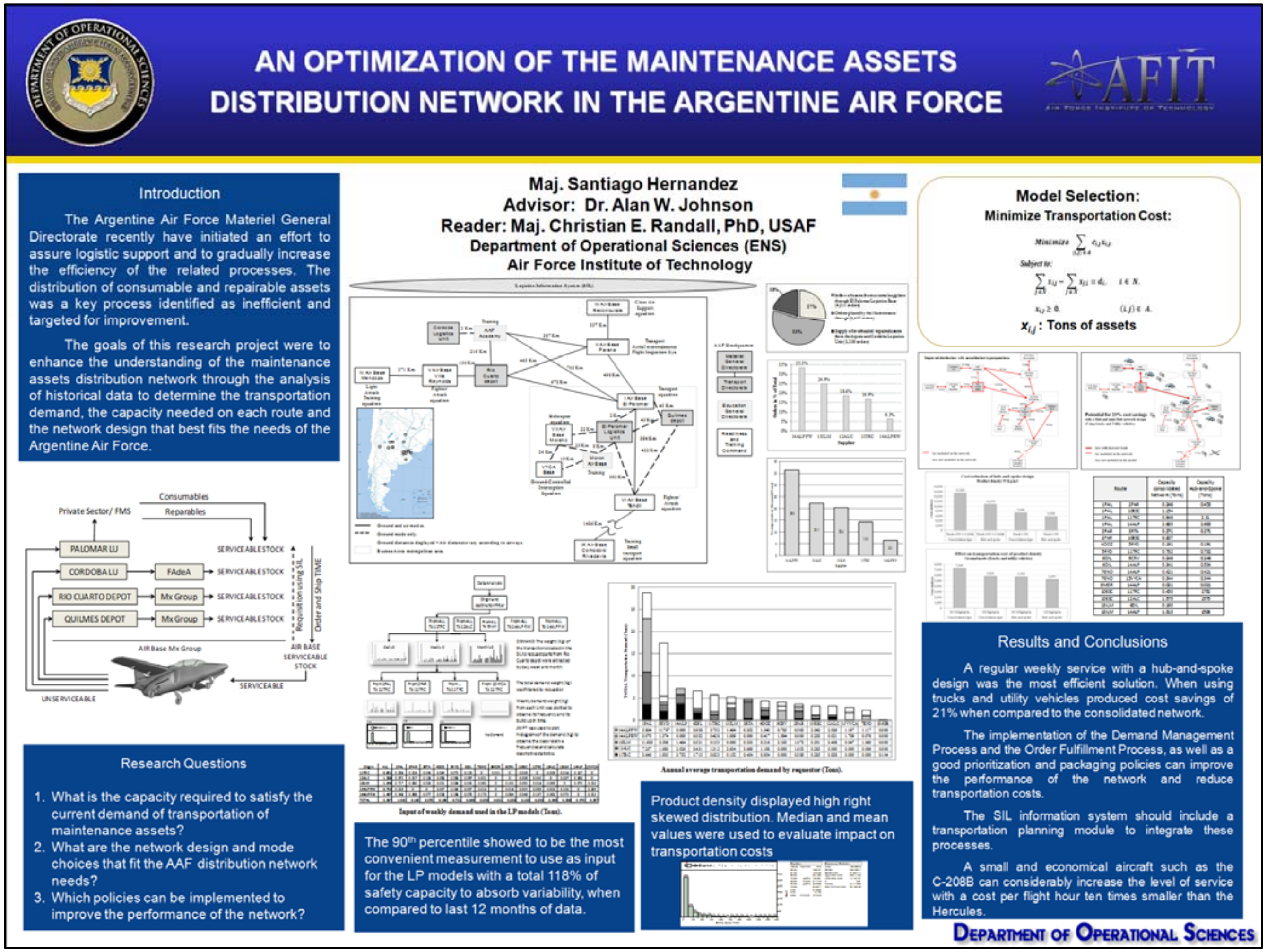


Figure IV.1. Thesis quad chart.

Bibliography

Anupindi R., Chopra S., Deshmukh, S., Van Mieghem J., Zemel E. (2012). *Managing Business Process Flows: Principles of Operations Management*. New Jersey: Pearson Education Inc.

Argentine Air Force (2010). *Manual de Conduccion Logistica*. Buenos Aires: HQ Argentine Air Force.

Argentine Air Force (2012). *El vuelo del condor: 1912-2012 Cien años defendiendo nuestro cielo*. Buenos Aires: HQ Argentine Air Force.

Business Chamber of Logistics Operators (2014). *Logistics specialists: Successful outsourcing*. CEDOL: Buenos Aires, Argentina.

Chan Y. and Poder R. (1979). *The small package air freight industry in the United States: A review of the Federal Express experience*. Transportation Research Part A. Volume 13, Issue 4: 221–229. Pergamon Press Ltd., Great Britain.

Condon T. and Patterson K. (1997). *A comparison of the military´s organic movement and commercial express carriers.* M. S. Theses, AFIT/GTM/LAL/97S-1, Air Force Institute of Technology.

Crainic T. G. (2000). *Service network design in freight transportation*. European Journal of Operational Research, 122: 272-288.

Crainic T.G. and Laporte G. (1997). *Planning models for freight transportation*. European Journal of Operational Research, 97: 409-438.

Department of Defense (2014). *DoD Supply Chain Materiel Management Procedures: Operational Requirements*. DoDM 4140.01, Volume 1. Washington: DoD, 10 February 10 2014.

Gladwell M. (2006) *Million-Dollar Murray*. New Yorker, 0028792X, Vol. 82, Issue 1.

Goulias K. G. (2003). *Transportation System Planning: Methods and Applications*. Boca Raton: CRC Press, 2003.

Hensher D. A. and Button K. J. (2000). *Handbook of Transport Modelling*. Oxford: Pergamon.

Khaler, H. M. (2004). *An analysis of Depot repair capacity as a criterion in transportation mode selection in the retrograde movement of reparable assets*. M. S. Thesis, AFIT/GLM/ENS/04-08, Air Force Institute of Technology.

Lambert D. M. (2014). *Supply Chain Management: Processes, Partnership, Performance Fourth Edition*. Ponte Vedra Beach: Supply Chain Management Institute

Leach S. E. (1997). *Transportation modeling of remote radar sites and support depots.* M. S. Thesis, AFIT/GOR/ENS/97M-13, Air Force Institute of Technology.

Magnanti T. L. and Wong R. T. (1986). *Network Design and Transportation Planning: Models and Algorithms*. Transportation Science 18/1: 1-55.

Masciulli J. L. (2001). *A cost comparison between modes in the shipment of mission capable parts within the continental United States.* M. S. Thesis, AFIT/GLM/ENS/01M-17, Air Force Institute of Technology.

Park M. (2005) *Capacity Modelling for Multimodal Freight Transportation Networks*. PhD Dissertation. University of California, Irvine CA, (3198651).

Ragsdale C. T. (2008). *Spreadsheet Modeling & Decision Analysis: A Practical Introduction to Management Science*. Mason: South-Western.

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14. ABSTRACT

The Argentine Air Force Materiel General Directorate is responsible for the supply and distribution of reparable and consumable assets to support the operations of more than thirty different weapons systems. The Materiel General Directorate recently initiated an effort to assure logistic support and to gradually increase the productivity and efficiency of the related processes. The distribution of consumable and reparable assets was a key process identified as inefficient and targeted for improvement, and a recommendation was made to consider organic or private transportation and reduce transportation time in order to improve responsiveness and drive down logistic pipeline costs.

This thesis uses network flow modeling methods to analyze the spare parts flows between Argentine Air Force units to determine overall transportation demand and capacity required for a defined level of service, and to evaluate the tradeoffs between costs and service levels. The goal is to assist in the development of an effective and efficient maintenance assets distribution network.

15. SUBJECT TERMS

Distribution, Network, Optimization, Transportation Capacity.

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