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THESIS

MULTIVARIATE ANALYSIS OF THE EFFECT OF SOURCE OF SUPPLY AND CARRIER ON SHIPPING TIMES FOR ISSUE PRIORITY GROUP ONE (IPG-1) REQUISITIONS
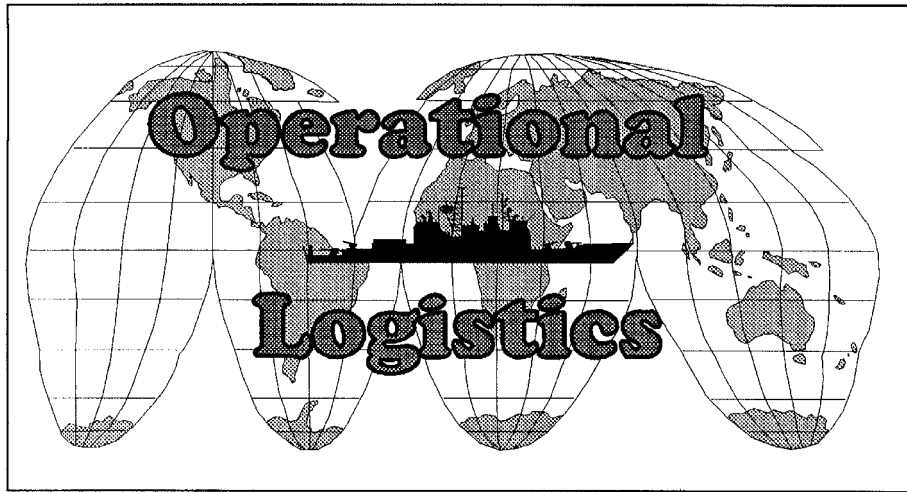
by

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September 2003

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Amateurs discuss strategy, Professionals study logistics

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13. ABSTRACT *(maximum 200 words)*

The objective of this thesis is to examine the effects of source of supply and carrier on shipping times of high-priority requisitions to primary destinations of Navy units in the Pacific Theater and Persian Gulf. Our focus was primarily on determining whether source of supply, carrier, and the interaction of these two factors, have an effect on shipping times of high-priority requisitions. "Source of supply" refers to Department of Defense supply depots and "carrier" refers to shippers, such as Federal Express® and DHL Worldwide Express®.

This study uses ordinary least square (OLS) linear models, generalized linear models (GLM's) and nonparametric methods to explore the structure of the historical requisition datasets. OLS linear models were found to be inadequate, but both the GLM's and nonparametric tests proved to be valid and yielded results from which inferences could be made. According to the GLM's and nonparametric tests, source of supply has a statistically significant effect on shipping times of high-priority requisitions, but carrier does not. The GLM's also indicated that there is no significant interaction between source of supply and carrier.

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MULTIVARIATE ANALYSIS OF THE EFFECT OF SOURCE OF SUPPLY AND CARRIER ON SHIPPING TIMES FOR ISSUE PRIORITY GROUP ONE (IPG-1) REQUISITIONS

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Submitted in partial fulfillment of the
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ABSTRACT

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EXECUTIVE SUMMARY

The Department of Defense (DoD) and the U.S. Navy are continuously seeking opportunities to improve the efficiency of logistic operations. Logistic response time (LRT) is the overall time it takes to satisfy a requisition and one of the main performance measures of the Navy's logistic system. A key component of LRT that the Navy would like to reduce is shipping time. Although reducing the shipping time for all categories and priorities of requisitions is desired, reducing the shipping time for the highest priority requisitions, often referred to as Issue Priority Group One (IPG-1) requisitions, is most important. The focus of this thesis is on IPG-1 requisitions submitted to the Priority Material Office (PMO), Bremerton WA, the point-of-entry for IPG-1 requisitions from Pacific Fleet units.

This study examines the impact of source of supply and carrier on shipping times of the highest priority requisitions to the primary overseas destinations of U.S. Navy units operating in the Pacific Theater and the Persian Gulf. Although there has been a similar study for Air Force requisitions, the author is not aware of any similar studies for Navy high-priority requisitions.

The data used in this study were taken from the Priority Material Office's requisition database for the period October 1999 to November 2002. The destinations included in the study were Guam, Bahrain, Singapore, Okinawa, Sasebo, and Yokosuka.

Our analysis was limited to primary sources of supply for IPG-1 requisitions. For our study, a primary source of supply was defined as a single DoD or Navy supply center, or a group of DoD and Navy supply activities within a single geographic location (e.g. Fleet and Industrial Supply Center, San Diego, and Defense Distribution Center, San Diego) that shipped at least 200 IPG-1 requisitions during the three-year period of the historical requisition data. Federal Express® (FedEx®) and DHL Worldwide Express® (DHL®) were the only carriers included in the analysis.

Ordinary least square (OLS) models were deemed inadequate to analyze the historical requisition data. However, Poisson generalized linear models (GLM's) provided valid models from which results could be gleaned. GLM's were utilized to explain and explore the effect of source of supply and carrier on shipping times. The results indicated that source of supply has a statistically significant effect on high-priority requisition shipping times, while carrier does not. Additionally, GLM's showed that there was no significant interaction between the two variables. Based solely on source of supply, the smallest observe mean shipping times ranged from approximately 3.25 days to 4.00 days, while the largest observed mean shipping times ranged from approximately 4.75 days to 6.75 days.

Nonparametric Kruskal-Wallis rank sum test results supported the GLM results. Specifically, this nonparametric test provided statistical evidence that source of supply had an effect on shipping times to all destinations with the exception of Okinawa. The nonparametric results also indicated that carrier does not

have a significant effect on shipping times; i.e., the two carriers included in the study were determined to have indistinguishable mean shipping times.

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I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DoD) and the U.S. Navy are continuously seeking opportunities to improve the efficiency of logistic operations. The 1996 edition of the *Department of Defense Logistics Strategic Plan* calls for significant reductions in the logistic response time (LRT), also referred to as customer wait time (CWT). As one of the main performance measures of the Navy's logistic system, LRT is the overall time it takes to satisfy a requisition from the date the requisition is initiated to the date the requisition is received by the ordering activity. LRT consists of the time necessary to submit, receive, and process a requisition; "pick" the items of supply; prepare for shipment; hold for transportation; transport to the requisitioning activity; and complete the receipt by the requisitioner. (Fortunato and Eanes, 1996, p. iii) During the last several years, the Navy has sought ways to reduce the overall LRT by attacking each LRT component. A key component of LRT that the Navy would like to reduce is shipping time, or transportation time, which is the time between carrier pick-up at a DoD source of supply and the time of delivery at the requisitioner's destination.

Although reducing the shipping time for all categories and priorities of requisitions is desired, reducing the shipping time for the highest priority requisitions, often referred to as Issue Priority Group

One (IPG-1) requisitions, is most important[1]. The Navy has two commands that serve as the point-of-entry for these high priority requisitions: the Priority Material Office (PMO), Bremerton WA and the Atlantic Fleet Logistic Support Center (AFLSC), Norfolk VA. The focus of this thesis is on IPG-1 requisitions handled by PMO.

PMO is the point-of-entry and expediter for Issue Priority Group One (IPG-1) requisitions from Pacific Fleet units, excluding aircraft carriers. When an IPG-1 requisition is received by PMO, the Department of Defense (DoD) supply system is screened to determine which DoD supply depot or center can satisfy the requirement. When the part is located, a PMO expeditor forwards the requisition to the supply depot carrying the part and directs the supply depot to ship the part. PMO provides the destination to where the part is to be shipped and the mode of transportation, which is primarily commercial air carrier.

PMO does not currently utilize statistical analysis of historical shipping data to determine the best combination of supply source and carrier, i.e. the combination that has historically resulted in the shortest mean shipping time. For example, if the part is available at more than one DoD supply depot, the individual at PMO who is expediting the requisition will make a decision based on personal experience and/or corporate knowledge to determine which supply depot to issue the part and what carrier to use.

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[1] IPG-1 requisitions are defined in Chapter II.

Here is an example of a possible IPG-1 requisition scenario:

> USS LAKE CHAMPLAIN (CG 57), currently steaming independently in the western Pacific, on its way to the Persian Gulf, has one of its water purifiers fail. The part required to repair the purifier is not available onboard. An IPG-1 requisition is submitted by the ship to PMO via satellite telephone. The ship will be making a brief stop for fuel in Singapore in three days and therefore requests PMO to have the part shipped to the Navy Regional Contracting Center in Singapore, which will then bring the part to the ship while it is pierside for refueling. Through the screening process, a PMO expediter determines that the required part is available at two different DoD supply depots, one in Pennsylvania and one in Virginia. The expediter chooses to have the item shipped via Federal Express® from the depot located in Pennsylvania. The required part arrives in Singapore in four days, a day after the ship left port.[2]

From the scenario presented above, it can be seen that it may benefit PMO to have an established procedure in determining the supply source and/or carrier that historically produces the shortest shipping times to the requisitioner's destination for IPG-1 requisitions. PMO's Commanding Officer is interested in establishing a formal protocol in selecting source of supply and carrier, rather than just using experience and corporate knowledge, for expediters to utilize when expediting IPG-1 requisitions

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[2] This scenario was created by the author based on his experiences while serving as Assistant Supply Officer on USS LAKE CHAMPLAIN (CG 57) form January 1995 to January 1997.

to overseas destinations in the Pacific Theater and Persian Gulf. (Conversation between Commander William Baker, Commanding Officer, Priority Material Office and the author, 19 November 2002)

B.   OBJECTIVES

The purpose of the thesis research is to analyze the effect of source of supply and carrier on shipping times for IPG-1 requisitions. In the course of the study, the following questions are answered:

- Is there statistical evidence to indicate that source of supply, carrier, and/or the interaction of these two variables, effect shipping times of IPG-1 requisitions to destinations within the Pacific Theater and Persian Gulf?
- What carrier, source of supply, and combinations of these two factors, for the various destinations, have the smallest mean shipping times?

To assist with the analysis, PMO has provided three years of IPG-1 requisition data, dating from October 1999 to November 2002, in spreadsheet format. The data provided includes requisition numbers, source of shipment, destination of shipment, shipping times from source to destination, and carrier.

C.   SCOPE, LIMITATIONS AND ASSUMPTIONS

The data analyzed was limited to IPG-1 requisitions that were submitted to PMO and filled from DoD supply system stocks. It does not include requisitions satisfied through open purchase from commercial sources or through

cannibalization from other naval operating units. Additionally, only IPG-1 requisitions shipped via primary air carriers from major DoD supply centers to major overseas destinations of Pacific Fleet units were included in this study. Primary air carriers, major DoD supply centers, and major overseas supply destinations are defined in Chapter III. The data analyzed covers the time period of October 1999 to November 2002.

Our study is not intended to analyze the complete order and shipping process used within the Navy for IPG-1 requisitions. It is also not intended to critique the operations of the various DoD supply depots or the receipt procedures of the individual destinations, or the impact these may have on shipping times. Finally, it is not meant to provide a detailed or in-depth review of the operations of the different carriers and how these operations may impact shipping times.

Our study, through the analysis of historical data, is interested first in determining what effect source of supply, carrier, and interaction of the two, have on shipping times for IPG-1 requisitions to overseas Navy locations. Second, our study aims to determine what source of supply and carrier, if applicable, result in the smallest mean shipping times to various overseas destinations. The results and conclusions of this study will assist PMO in revising current procedures and/or producing a new protocol for expediting IPG-1 requisitions.

It is assumed that the data, specifically supply source, destination, carrier, and shipping times, used for

this study are accurate. It is further assumed that the shipping time is the time between the date of pick-up at the supply source to the date of delivery at the destination. Shipping time includes order, processing, picking, packing, and receipt times. For example, if a carrier picks up an item at Defense Distribution Center, San Diego (DDDC) on June 1 and delivers the part to USS FRANK CABLE (AS 40) receipt department in Guam on June 4, the shipping time is 3 days.

D.   COURSE OF THE STUDY

This thesis is comprised of five chapters. Chapter II reviews pertinent literature and previous studies relevant to the shipment of high-priority requisitions within the Navy. Chapter III describes the datasets and variables used for the models. It also explains the statistical models and techniques used for the study. Chapter IV consists of preliminary, multivariate ordinary linear models, multivariate generalized linear models, and nonparametric analyses. Chapter V summarizes the conclusions of the analyses and presents recommendations for further study.

II. LITERATURE REVIEW

A. REQUISITIONING PROCEDURES WITHIN THE U.S. NAVY

Requisitioning channels are an essential element of the operational readiness of Navy activities and an essential part of the DoD integrated supply system. There are two basic methods by which a Navy unit may obtain the materials and services it requires. The first is by submission of a requisition to a supply activity or to another Navy unit, and the second is by direct purchase from a commercial source. A Navy unit normally will procure its requirements by submitting a requisition to a Navy or DoD supply activity as specified in current operational orders and instructions issued under the direction of Naval Supply System Command and Fleet Commanders. (NAVSUP P-485, 1997, p. 3-9)

The Military Standard Requisitioning and Issue Procedures (MILSTRIP) are used for ordering all material from the Navy Supply System, other military installations, the Defense Logistics Agency, and the General Services Administration. MILSTRIP is designed to permit transmission and receipt of requisitions by electronic communications. A MILTRIP requisition is an established sequence of letters and numbers that includes such things national stock number, unit identity code of requisitioning command, requisition serial number, quantity, required delivery date code, and priority code. The media used for submitting requisitions include: 1) Standard Automated Logistics Tool Set (SALTS) 2) Electronic Mail (E-mail), 3) Internet/World Wide Web (WWW)

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Interface, 4) Naval message, and 5) telephone, voice and facsimile (landline and satellite). (NAVSUP P-485, 1997, p. 3-34)

An integral and vital part of the MILSTRIP is the requirement to assign priorities in accordance with standards set forth in the Uniform Material Movement and Issue Priority System (UMMIPS). In the movement and issue of material, it is necessary to establish a common basis to determine the relative importance of competing demands for resources of the logistics systems such as transportation, warehousing, requisition processing, and material assets. The basis for expressing the military urgency of a requirement is the priority designator (PD), which ranges from 01 (highest) to 15 (lowest). The PD assigned to a requisition determines the time frame within which the requirement normally will be processed by the supply system. Requisitions with PD's 01 through 03 are referred to as Issue Priority Group One (IPG-1) requisitions, receiving Transportation Priority 1 (TP1) status, and are shipped via premium transportation, i.e., air carrier. IPG-1 requisitions have a total order-to-receipt time goal ranging from 6.5 to 11 days for overseas requisitions. (DLA Customer Handbook, 2002, pp. III-2:III-3) For Navy forces based or deployed overseas, IPG-1 requisitions are assigned for all critically needed material which includes Not Operationally Ready Supply (NORS) and Anticipated Not Operationally Ready Supply (ANORS) requirements, as defined in *Naval Supply Procedures*, *Volume I, Afloat Supply*. (NAVSUP P-485, 1997, p.3-31) Figure 2.1 provides a basic schematic of the IPG-1 requisitioning and shipping process.

```
                    ┌─────────────────────────┐
                    │  FISC/DDDC San Diego, CA │
                    └─────────────────────────┘
              ⟨3⟩

                    Carrier picks-up
                    part for
                    requisition at
                    DoD Supply Center
                    & transports to
                    receipt
                    hub/warehouse at                    Requisition
                    customer's                          Referral
                    location
                                                              ⟨2⟩

                                              ┌─────────────────────┐
                                              │  PMO Bremerton, WA   │
                                              └─────────────────────┘

              ⟨4⟩    Customer receives part            IPG-1 Requisition
                                                        Submitted

                                                              ⟨1⟩
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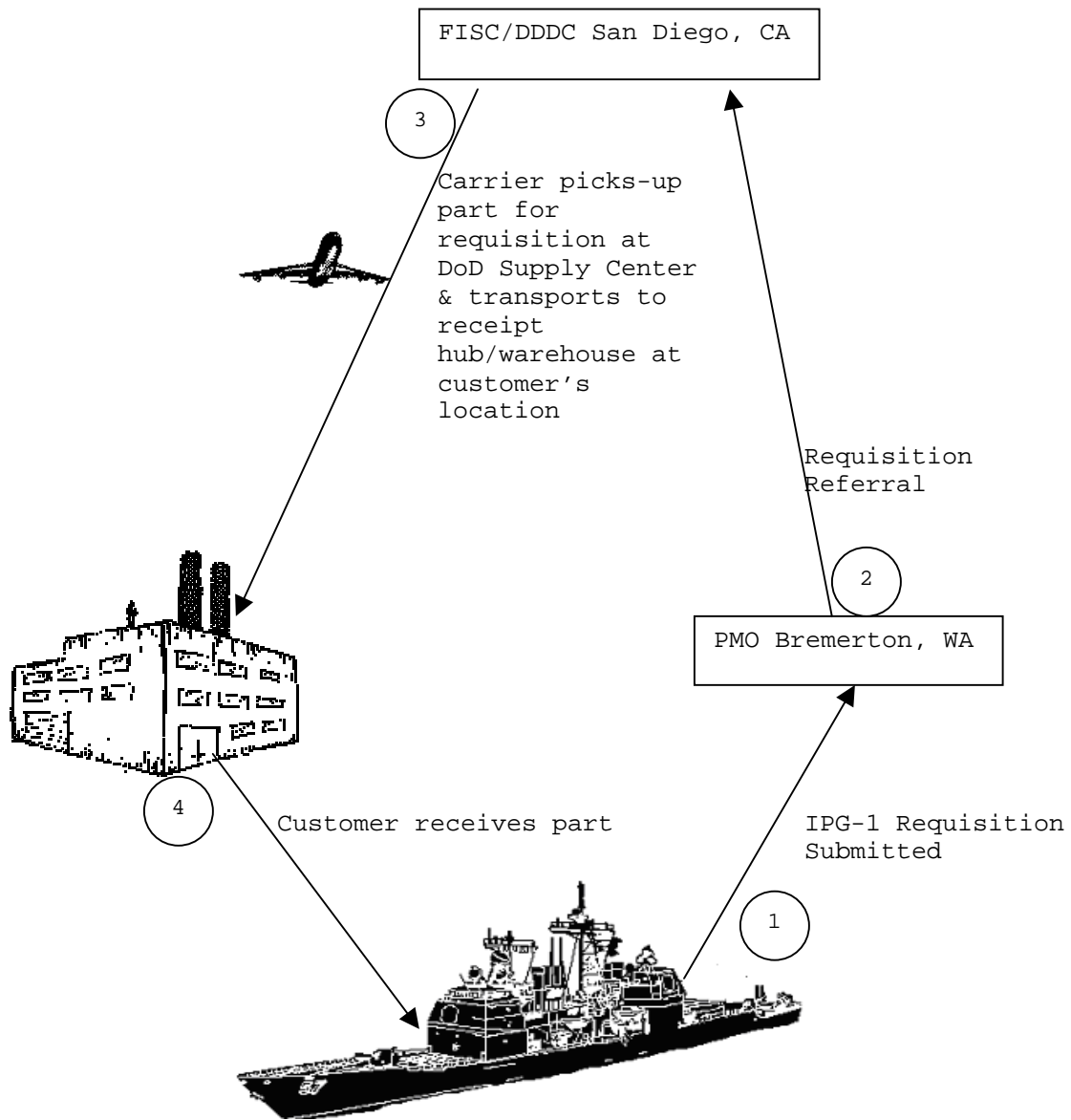
Figure 2.1.   IPG-1 Requisition/Shipping Process
Schematic

Further details on MILSTRIP and UMMIPS can be found
in the *Naval Supply Procedures*, *Volume I, Afloat Supply*,
and the *Defense Logistics Agency Customer's Handbook*.

In accordance with Commander, Pacific Fleet
(COMPACFLT), Commander, Naval Surface Force Pacific
(COMNAVSURFPAC), and Commander, Submarine Force Pacific

(COMSUBPAC) instructions, Priority Material Office (PMO), Bremerton WA, is the point-of-entry and expeditor for IPG-1 requisitions originating from Pacific Fleet activities, excluding aircraft carriers. (PMOINST, 2003, 4400.1C, p.1-1)

B.   PRIORITY MATERIAL OFFICE (PMO)

The Priority Material Office (PMO), Bremerton, WA, was initially commissioned Pacific Fleet Polaris Material Office in 1964. It has served since its inception under the operational control of Commander Submarine Force, U.S. Pacific Fleet. Originally established to provide logistic support to the Fleet Ballistic Missile submarines and their tenders, its role expanded in 1982 to provide support to the entire Pacific Fleet submarine force, afloat and ashore. In 1998, PMO's customer base expanded again to include all Pacific Fleet surface ships, excluding aircraft carriers, and shore-based Intermediate Maintenance Activities (IMA) in the Pacific Fleet area of operation. In 2000, the command was renamed Priority Material Office to better reflect its broader mission. (PMO, [http://www.pmohq.navy.mil/history.htm], 2003)

PMO receives and expedites approximately 25,000 to 30,000 requisitions annually for a customer base of about 200 Navy activities. PMO's customers include Pacific Fleet submarines, surface ships, submarine tenders, Military Sealift Command (MSC) ships, Intermediate Maintenance Facilities (Puget Sound WA and Pearl Harbor HI), and Ship Repair Facilities (Guam, Yokosuka and Sasebo).

PMO maintains and utilizes the Integrated Submarine Information System (ISIS)[3], a window-driven requisition tracking system. Requisition data is stored in an Oracle® relational database and can be extracted using real-time inquiries and reports. ISIS is the primary tool that allows PMO to provide its customers with plain language status and in-transit visibility of their requisitions. IPG-1 requisition status is updated in ISIS automatically via electronic interfaces with carrier tracking systems or manually by PMO expediters (i.e. when receipt confirmations are received from customers via Naval message, E-mail, or telephone).

(PMO, [http://www.pmohq.navy.mil/history.htm], 2003)

PMO has several divisions responsible for the various stages of the requisition process. The two primary divisions are Point-of-Entry (POE) and Shipping. Some of the main responsibilities of the POE division include:

- Receipt of all incoming IPG-1 requisitions[4];

- Conducting asset check of DoD supply system to locate required material through one of the primary electronic interfaces which include the Naval Supply Systems Command "One Touch" website, Defense Logistic Agency Network (DLANET) and the Combined Residual Asset Management Screening Improvement (CRAMSI) system;

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[3] The Integrated Submarine Information System (ISIS) is used for tracking requisitions from all Pacific Fleet customers, including surface ships, shore based activities, and submarines. The word "Submarine" in the system's description is a reflection of ISIS's origin as a tracking system for submarine requisitions.

[4] PMO receives requisitions by ISIS remote requisition input (via internet), Naval message, telephone, facsimile, e-mail, and SALTS. Requisitions not received via ISIS remote will be uploaded to ISIS by electronic file transfer (floppy disk) or manually (typing requisition directly into ISIS).

- Forwarding requisitions via facsimile, telephone, or electronically (e-mail/direct interface) to Navy or DoD supply depots which have required material in stock;

- Monitoring and expediting requisitions until material is shipped, and updating ISIS with status of requisitions;

- Sending updates to customers with requisitions status. (PMOINST 4400.1C, 2003, pp. 1-3:1-4)

Some of the main responsibilities of PMO's Shipping Division include:

- Monitoring and expediting requisitions during shipment.

- Reconciling requisition receipts and updating ISIS. (PMOINST 4400.1C, 2003, pp. 1-5)

In deciding the best source of supply for a requisition, PMO's current procedures recommend choosing the DoD supply depot that can completely satisfy the requirement (i.e., has full quantity requested) and that is physically closest to the customer's location. For example, if an IPG-1 requisition needed to be shipped to USS FRANK CABLE (AS 40), homeported in Guam, and the required material is available at supply depots in San Diego CA and Norfolk VA, the supply depot in San Diego would be chosen because it is closer to Guam than Norfolk. (PMOINST 4400.1C, 2003, p. 5-1) For carrier selection, PMO primarily requests supply depots to ship IPG-1 requisitions by fastest traceable means via Federal Express® (FedEx®) or DHL Worldwide Express® (DHL®)[5],

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[5] FedEx, DHL, and UPS, are currently contracted under the WorldWide Express (WWX) contract, a DoD awarded contract for international/overseas small package delivery service for IPG-1 requisitions. Use of the WWX contract is mandatory for all DoD activities. (Air Mobility Command, "WorldWide Express", [http://public.amc.af.mil/wwx/wwx.htm], 2003)

although Air Mobility Command (AMC) and other commercial carriers such as Emery® and United Parcel Service® (UPS®) are sometimes used. Although Emery and UPS are sometimes used for shipping IPG-1 requisitions[6], PMO prefers FedEx and DHL. (Simonson, 2003) Figure 2.2 provides a simple flowchart of how PMO processes IPG-1 requisitions.
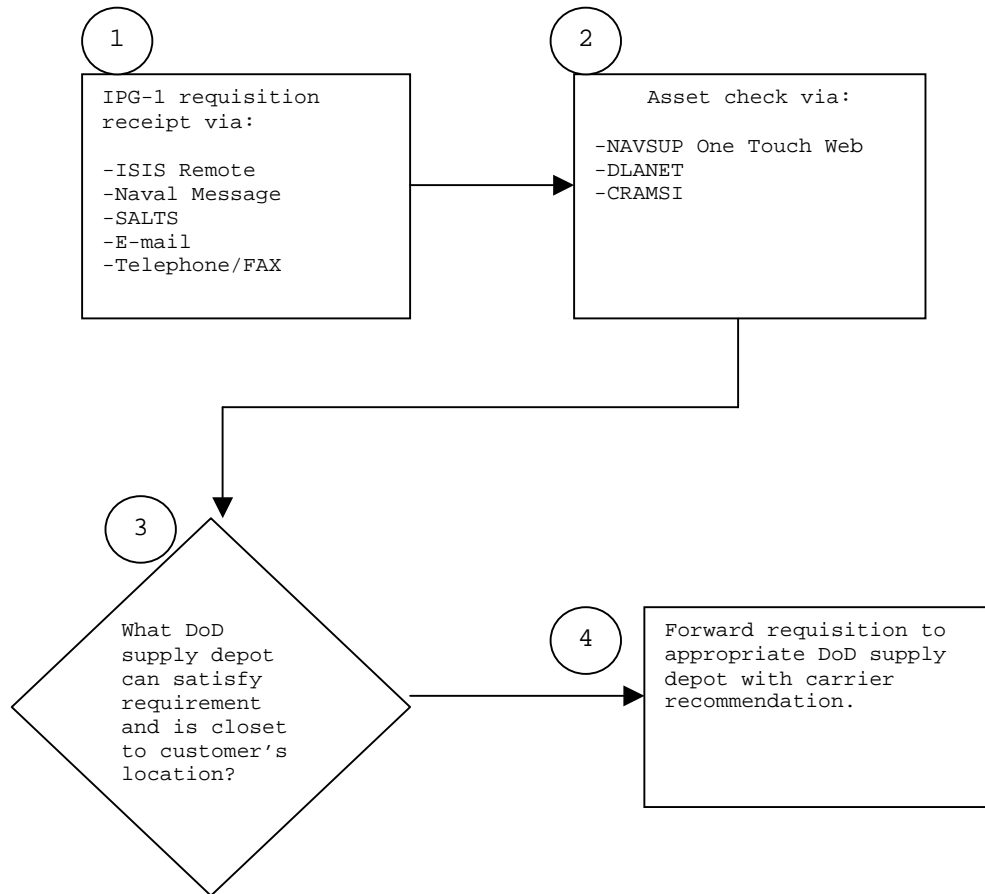
Figure 2.2.   PMO IPG-1 Requisition Process Flowchart

C.   PREVIOUS STUDIES

A literature review was conducted in order to find the results of relevant research that has been done on the effect of supply source and carrier on shipping times for IPG-1   requisitions   within   the   Navy.   Although   the

[6] The total number of IPG-1 requisitions shipped by Emery and UPS, combined, was less than 200 in calendar year 2002.

literature research found no previous studies with regards to Navy requisitions, one study by Vickers (1997) pertained to shipping times for requisitions within the Pacific Air Force.

Vickers analyzed and compared the shipment of reparable assets from the Air Force's Support Center Pacific (SCP), Kadena Air Base, Japan, and from continental United States (CONUS) Air Force repair activities to the various Western Pacific (WESTPAC) Air Force bases. The purpose of the research was to determine 1) whether mean shipping times between SCP and the Air Force bases in the Western Pacific were smaller than mean shipping times for shipments from CONUS to those bases; and 2) whether commercial express air carriers, specifically FedEx, produced significantly smaller mean delivery times than the Defense Transportation System (DTS) for shipments between SCP and WESTPAC Air Bases.

The data analyzed included two sets of sample shipping times for IPG-1 Air Force requisitions for WESTPAC Air Bases from July 1995 through January 1997; one dataset for requisitions shipped from SCP and the other dataset for requisitions shipped from CONUS repair facilities. The following assumptions were made: 1) the two samples were randomly selected in an independent manner and, 2) the sample sizes were large enough (greater than 30) so that the sample means had approximately a normal distribution. The combined sample sizes Vickers used in his analysis ranged from 191 to 3,223 observations. The Central Limit Theorem supported the second assumption.

Based on these assumptions, Vickers applied large-sample "z-test" procedures and corresponding hypothesis tests. The null hypothesis that "there is no difference between mean shipping times for shipments originating from CONUS and mean shipping times for shipments from SCP" was tested against the alternative hypothesis that "there is a difference in the mean shipping times."

Similarly, z-test procedures were used to determine if there was a difference in the mean shipping time of requisitions shipped through the DTS and the mean shipping time of requisitions shipped via FedEx. The null hypothesis in this case was "there is no difference between the mean shipping times of DTS and FedEx shipments" and the alternative hypothesis was "there is a difference in the mean shipping times."

For both test cases the null hypothesis was rejected in favor of the alternative hypothesis at a significance level of 0.01 ($\alpha = 0.01$). Based on these results it was concluded that the shipping times for requisitions from SCP to WESTPAC Air Force bases was shorter than shipping times for requisitions from CONUS; therefore SCP was the preferred source of supply for WESTPAC air bases. It was also concluded that the shipping times for requisitions carried by FedEx was significantly smaller than the shipping times for requisitions carried by the DTS, and that FedEx (or other commercial express carrier) was the better choice for shipping IPG-1 requisitions. Vickers' study supports the notion that source of supply and carrier may impact shipping times for high-priority requisitions.

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III. DATA AND METHODOLOGY

A.   DATASETS

The data used in our study were provided by the Priority Material Office (PMO). PMO provided three years of shipping data for IPG-1 requisitions, dated from October 1999 to November 2002, in spreadsheet format. The data included 10 columns for requisition number, national stock number (NSN), supply source routing identifier code (RIC), supply source command name/location, destination RIC, destination command name/location, ship date, receipt date, shipping time (days), and carrier. For this study, the columns of interest included supply source command/location, destination command name/location, shipping time, and carrier.

The original dataset consisted of 61,958 requisitions. This original dataset was refined by removing data that were obviously erroneous and/or data that were not needed for this study. Of these, 4,049 requisitions (approximately 6.5%) were determined to be erroneous because of negative or zero shipping times and were deleted. The dataset was further reduced by eliminating 36,227 requisitions (approximately 58% of the original data) having destinations within the United States.[7]

Once erroneous data and requisitions with U.S. destinations were removed from the dataset, a further refinement was made by removing all requisitions with Air

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[7] Our study was only interested in major destinations outside the continental United States, Alaska, and Hawaii.

Mobility Command (AMC) as the carrier. This was done because AMC was the carrier for requisitions from only two sources, Defense Distribution Center, San Joaquin (DDJC), in Tracy CA and Defense Distribution Center, Norfolk (DDNC), in Norfolk VA. Additionally, AMC was the carrier for only a small percentage of the requisitions (approximately 7%) as compared to DHL and FedEx, which carried 22% and 71% of the requisitions, respectively.

The final step in refining the dataset was to determine primary supply sources and primary destinations. For this study, a primary supply source was defined to be an individual DoD supply depot (e.g. Defense Distribution Center Susquehanna (DDSP)) or a group of DoD supply activities within a single geographic locale (e.g. Fleet & Industrial Supply Center (FISC), San Diego, Defense Distribution Center, San Diego (DDDC), and Priority Material Office (PMO) Detachment, San Diego) that shipped at least 200 IPG-1 requisitions to overseas destinations within the time frame of the historical data. The names/locations of the primary supply sources are provided in Table 3.1. Similarly, a primary destination was defined to be an overseas geographic location that received at least 200 IPG-1 requisitions within the time frame of the historical data. Geographic locations rather than individual commands were used for destinations because individual command destinations are generally located within a single geographic locale (e.g. USS FRANK CABLE (AS 40) and Commander, Naval Forces Marianas (COMNAVMARIANAS) in Guam) and this study was not intended to analyze the effect of individual command destinations on shipping times. There were six primary destinations

Factor	Name (Level)	Description
SOURCE OF SUPPLY	DDBC	Defense Distribution Center, Barstow CA
	DDCO	Defense Distribution Center, Columbus OH
	DDJC	Defense Distribution Center, San Joaquin CA
	DDRV	Defense Distribution Center, Richmond VA
	DDSP	Defense Distribution Center, Susquehanna PA
	FISC CHEATHAM	Fleet & Industrial Supply Center, Cheatham Annex, Williamsburg VA
	FISC/DDDC	Fleet & Industrial Supply Center/Defense Distribution Center, San Diego CA
	FISC/DDJF	Fleet & Industrial Supply Center/Defense Distribution Center, Jacksonville FL
	FISC/DDNV	Fleet & Industrial Supply Center/Defense Distribution Center, Norfolk VA
	FISC/DDPH	Fleet & Industrial Supply Center/Defense Distribution Center, Pearl Harbor HA
	FISC/DDPW	Fleet & Industrial Supply Center/Defense Distribution Center, Puget Sound WA
	FISC/DDYJ	Fleet & Industrial Supply Center/Defense Distribution Center, Yokosuka Japan
	NSY PORTSMOUTH	Naval Shipyard, Portsmouth NH
CARRIER	FEDEX	Federal Express (FedEx)
	DHL	DHL Worldwide Express (DHL)

Table 3.1.   Explanatory Factors: Names (Levels) and Descriptions

analyzed in this study. They were Guam, Bahrain, Singapore, Okinawa, Sasebo, and Yokosuka. Using these criteria for primary source of supply and primary destination, another 740 requisitions were deleted. After this refining process, the final dataset used in this study consisted of 15,824 requisitions.

These 15,824 requisitions were divided into six subsets, one subset per primary destination. These six datasets were analyzed individually and a unique model was created for each of them; therefore geographic destination is an implicit explanatory variable within each model.

B. VARIABLE INTRODUCTION

1. Dependent Variable

Models we will use for our study will have a dependent variable, SHIPPING TIME (calendar days), and two independent variables, SOURCE OF SUPPLY and CARRIER. The dependent variable, SHIPPING TIME, is an integer with a value greater than zero. Although some of the data points had non-integer shipping times (e.g. 3.5, 6.33, 2.66, etc.), the vast majority of the data points (approximately 98%) had integer shipping times. Based on the high percentage of data with discrete values, all continuous shipping times were rounded to the nearest integer.

2. Independent Variables

Independent variables are the explanatory factors that have the potential of effecting shipping times. For our study, the independent variables are factors with multiple levels and include SOURCE OF SUPPLY and CARRIER. Table 3.1 provides a listing of the explanatory factors.

C. METHODOLOGY

1. Ordinary Least Square (OLS) Linear Regression

a. *Multivariate Linear Regression*

The goal of an analysis using this method is the same as that of any model-building technique used in statistics: to find the best-fitting and most parsimonious and reasonable model to describe the relationship between a dependent (outcome or response) variable and a set of independent (predictor or explanatory) variables.

In any regression model the key quantity is the mean value of the outcome variable, given the value of the independent variables. Multivariate regression models view the expected value of Y_i as a linear function of the elements of X_i, $E[Y_i] = \beta_0 + \beta_1 X_{i1} + \ldots + \beta_j X_{ij}$, and the actual Y_i is equal to the expected Y_i plus a random error, $Y_i = E[Y_i] + \varepsilon_i$. The specific form of the multiple regression model we used, which included interaction effects, is as follows:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i1} X_{i2} + \varepsilon_i \ .$$

In our study, Y_i represents the shipping time variable, X_{i1} represents the CARRIER factor variable, X_{i2} represents the SOURCE OF SUPPLY factor variable, and $X_{i1} X_{i2}$ represents the interaction between these two variables (X_{i1} and X_{i2} represent the *i*th values of variables X_1 and X_2). (Hamilton, 1992, pp.17-18)

In order to reduce the effects of the positive skewness and outliers, a natural logarithm transformation, denoted by "log", was applied to the dependent variable Y, producing the following model:

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$$\log(Y_i) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i1} X_{i2} + \varepsilon_i \ .$$

This model was applied using the six individual datasets, one for each primary destination.

b. F-Tests

The *F*-test was utilized to test hypotheses regarding sets of parameters by comparing nested models. We tested whether a model with *K* parameters, including interaction effect, improves upon a simpler model with *H* fewer parameters:

$$F_{n-K}^{H} = \frac{(RSS\{K-H\} - RSS\{K\})/H}{(RSS\{K\})/(n-K)} \ ,$$

where *n* is the sample size, RSS{*K*} is the residual sum of squares for the full model and RSS{*K-H*} is the residual sum of squares for a model with *K-H* parameters. The *F*-statistic calculated from this equation is compared to a theoretical *F*-distribution with numerator degrees of freedom (df_1) equal to *H* and denominator degrees of freedom (df_2) equal to *n-K*. (Hamilton, 1992, pp.80-81)

For our analysis, we compared the full model (*K* parameters) that included the CARRIER, SOURCE OF SUPPLY, and the interaction of these variables, to simpler models (*H* fewer parameters). The simpler models included a model with both factor variables and no interaction effects and models with only one of the factor variables.

The *F*-tests were applied to the null hypothesis that coefficients on all independent *X* variables in the full model equal zero; the alternate hypothesis was that coefficients are not equal zero. The level of significance for the *F*-tests was 0.01 (α=0.01), i.e., if

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the p-value for the F-tests was less than 0.01, the null hypothesis was rejected. See Chapter IV, Section B, for results.

c. Linear Model Validation

There are several assumptions that must be checked to determine if the OLS models are valid. These assumptions include:

- Errors have mean zero.

- Errors have constant variance.

- There is no autocorrelation between errors.

- Errors are normally distributed. (Hamilton, pp. 110-111)

As our analysis was primarily interested in using analysis of variance (ANOVA) F-tests to determine the effects of the factor variables, including interaction, the assumption that errors are normally distributed was the first to be tested. Non-normal error distributions reduce the efficiency of OLS and invalidate F-tests. This assumption was checked by examining the Quantile-Normal plot of the model's residuals. If this plot clearly indicated that the errors were not normally distributed, the model was rejected in favor of a generalized linear model (GLM) that is discussed in the following paragraphs. However, if a model's residuals did follow a normal distribution, the other assumptions were checked for validity. If the linear model was deemed adequate, it was used to make inferences regarding the effect of the explanatory variables on the outcome variable. See Chapter IV, Section B, for the results.

2. Generalized Linear Models (GLM)

a. Poisson GLM

Generalized linear models are an extension of ordinary linear models that allow for modeling data with errors that are not normally distributed. As with ordinary linear models, the goal with GLM regression is to find the best-fitting and most parsimonious and reasonable model by which to describe the relationship between a dependent (outcome or response) variable and a set of independent (predictor or explanatory) variables.

A GLM can be defined in terms of a set of independent random variables $Y_1, ..., Y_N$, each with a distribution from the exponential family (e.g. Binomial, Poisson, or Gamma) with the following property:

- Each Y_i comes from the same family of distributions indexed by its own canonical parameter θ_i. (Dobson, p. 30)

A GLM provides a way of estimating a function of the mean response as a linear combination of some set of predictors and can be written as:

$$g(\mu_i) = \beta_0 + \sum_{i=1}^{p} \beta_j x_{ij} = \eta(x_{ij}) ,$$

where $\mu_i = E(Y_i)$, x_{ij} is the ith observation of the jth explanatory variable, β_0 is the intercept, β_j is the coefficient parameter for the jth explanatory variable, and p is less than the number of observations. The function of mean responses, $g(\mu_i)$, is called the link function, and the linear function of parameters, $\eta(x_{ij})$, is called the linear predictor. The variance of the outcome

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variable, Y, may be written as a function of the mean response: $\text{var}(Y) = \phi V(\mu)$, where ϕ is the dispersion parameter and $V(\mu)$ is the variance function. (Insightful Corporation, 2001, p.381)

For our analysis, a Poisson GLM appeared to be a sensible choice, as the response variable, SHIPPING TIME, was discrete with non-negative integer values. The Poisson probability distribution is given by:

$$P(Y = y) = \frac{e^{-\mu}\mu^{y}}{y!}; \quad y = 0, 1, 2, \ldots,$$

where parameter μ is equal to the mean and variance of Y. The canonical link for a Poisson distribution is $g(\mu) = \log\mu$, the dispersion parameter ϕ is 1, and the variance function is $V(\mu) = \mu$. The resulting GLM is:

$$g(\mu_i) = \log\mu_i = \beta_0 + \sum_{i=1}^{p}\beta_j x_{ij} \ .$$

The maximum likelihood method is commonly used to estimate the parameters in a GLM. For a given probability distribution specified by $f(y;\mu)$ and observations $y = (y_1, \ldots, y_n)$, the log-likelihood function for μ, expressed as a function of mean values of the responses $\{Y_1, \ldots, Y_n\}$ has the form:

$$l(\mu_1, \ldots, \mu_n; y_1, \ldots, y_n) = \sum_{i=1}^{n}\log f(y_i; \mu_i) \ .$$

The Poisson log-likelihood function is:

$$l(\mu_i, \ldots, \mu_n; y_1, \ldots, y_n) = \sum_{i=1}^{n}(y_i \log\mu_i - \mu_i) \ .$$

The maximum likelihood estimates of the parameters μ can be obtained by the iterative re-weighted least squares (IRLS) process. (Chambers and Hastie, 1991, pp. 242-243) Detailed information about the iterative algorithm and asymptotic properties of the parameter estimates can be found in McCullagh and Nelder (1989).

b.   Analysis of Deviance

Analogous to the residual sum of squares in linear regression, the goodness-of-fit of a GLM can be measured by the residual deviance:

$$D(y_1,...,y_n;\hat{\mu}_1,...,\hat{\mu}_n) = 2[l(\mu^*;y) - l(\hat{\mu};y)] \ ,$$

where $l(\mu^*;y)$ is the maximum likelihood achievable for an exact fit in which the fitted values are equal to the observed values, and $l(\hat{\mu};y)$ is the log-likelihood function calculated at the estimated parameters μ.   The Poisson deviance function is given by:

$$D(y_1,...,y_n;\hat{\mu}_1,...,\hat{\mu}_n) = 2\sum_{i=1}^{n} y_i \log(y_i/\hat{u}_i) \ ,$$

where $\hat{\mu}_i$ is an estimate of $E(Y_i) = \mu_i$. (McCullagh and Nelder, 1989, p. 197)

The deviance function is useful for comparing two models when one model's parameters are a subset of the second model's. The deviance is additive for such nested models if maximum likelihood estimates are used. (McCullagh and Nelder, 1989, pp. 33-34) Consider two nested models with the second having some explanatory factors omitted and denote the maximum likelihood estimates in the two models by $\hat{\mu}_1$ and $\hat{\mu}_2$, respectively.

Then the deviance difference $\{D(y;\hat{\mu}_2) - D(y;\hat{\mu}_1)\}$ is identical to the likelihood-ratio statistic and has an approximate χ^2 distribution with degrees of freedom equal to the difference between the numbers of parameters in the two models. For probability distributions in the exponential family the χ^2 approximation is usually quite accurate for differences of deviance even though it may be inaccurate for the deviances themselves. (Chambers and Hastie, 1991, p. 244)

Given a sequence of nested models, the deviance can be used as the generalized measure of discrepancy and an analysis of deviance table can be created by determining the differences of the models' deviances. Similar to an analysis of variance table in ordinary linear regression, the analysis of deviance table is used to determine what explanatory factors affect the outcome variable. Specifically, the significance (*p*-value) of the χ^2–test statistic is used in deciding what factors have a significant effect on the outcome variable. (McCullagh and Nelder, 1989, p. 36) See Chapter IV, Section C, for the results.

c. GLM Validation

The statistics and methods used for validating GLM's are similar to those used in ordinary linear model checking. The statistics include fitted values, $\hat{y}$,

$$\text{where } \hat{y} = \begin{pmatrix} \hat{y}_1 \\ \vdots \\ \hat{y}_n \end{pmatrix} = \begin{pmatrix} g^{-1}(\hat{\eta}_1) \\ \vdots \\ g^{-1}(\hat{\eta}_n) \end{pmatrix} = \begin{pmatrix} g^{-1}(x_1\hat{\beta}) \\ \vdots \\ g^{-1}(x_n\hat{\beta}) \end{pmatrix},$$

the variance estimate, $V_i = V(\hat{\mu}_i)$, and standardized deviance residuals, $r'_{D,i}$,

$$\text{where } r'_{D,i} = \frac{r_{D,i}}{\sqrt{\hat{\phi}(1 - h_{ii})}} .$$

For a Poisson distribution,

$$r_{D,i} = sign(y_i - \hat{\mu}_i)\sqrt{2(y_i)\log(y_i/\hat{\mu}_i) - y_i + \hat{\mu}_i} ,$$

where $\hat{\phi}$ is 1, and h_{ii} is the ith diagonal element of the projection ('hat') matrix. For the purpose of our analysis, the following residual plots were created and analyzed to determine the adequacy of the GLM for each dataset:

- Standardized deviance residuals, $r'_{D,i}$, plotted against the fitted values transformed to the constant-information scale, $2\sqrt{\hat{y}}$, for Poisson errors.

- Absolute Standardized deviance residuals, $|r'_{D,i}|$, plotted against fitted values.

If these residual plots indicated no obvious curvature or systematic change of range with fitted values, the Poisson GLM was deemed to be an acceptable model for the data. (McCullagh and Nelder, 1989, pp. 396-401)

To reiterate, if a satisfactory ordinary linear model could not be created for the datasets, Poisson GLM's were used to determine if any of explanatory variables, SOURCE OF SUPPLY and CARRIER, or interaction of the two, had an effect on the outcome variable, SHIPPING TIME.

3. Nonparametric Statistical Analysis

a. *Kruskal-Wallis Test*

In an effort to support the OLS and GLM analyses, the Kruskal-Wallis test, a nonparametric statistical test, was applied to the data. The Kruskal-Wallis test is a nonparametric rank test analogous to ANOVA, which is robust to the presence of outliers and does not require the distribution of the sample data to be normal or the variances to be equal. This rank sum test makes the following assumptions:

- All samples are random samples from their respective populations.

- In addition of independence within each sample, there is mutual independence among the various samples.

- The measurement scale is at least ordinal.

(Conover, 1999, p. 289)

Each of six datasets in our study consisted of a possible k random samples[8] of various sizes. The ith random sample of size n_i was denoted by $X_{i1}, X_{i2}, ..., X_{in_i}$. The data was arranged into columns as follows:

Sample 1	Sample 2	...	Sample k
$X_{1,1}$	$X_{2,1}$		$X_{k,1}$
$X_{1,2}$	$X_{2,2}$		$X_{k,2}$
$\vdots$	$\vdots$		$\vdots$
X_{1,n_1}	X_{2,n_2}		X_{k,n_k}

---

[8] k is equal to 2 for CARRIER factor variable and may range from 2 to 13 for the SOURCE OF SUPPLY factor variable.

The total number of observations was denoted by N, where $N = \sum_{i=1}^{k} n_i$. A rank 1 was assigned to the smallest of the total of N observations, rank 2 to the second, and continued to the largest of the N observations, which received rank N. The expression "$R(X_{ij})$" represented the rank assigned to X_{ij}, and R_i was the sum of the ranks assigned to the ith sample, i.e., $R_i = \sum_{j=1}^{n_i} R(X_{ij})$ where $i = 1, 2, ..., k$. When observations were equal to each other the average rank was assigned to each of the tied observations.

The Kruskal-Wallis test statistic K is defined as:

$$K = \frac{1}{S^2} \left(\sum_{i=1}^{k} \frac{R_i^2}{n_i} - \frac{N(N+1)^2}{4} \right),$$

$$\text{where } S^2 = \frac{1}{N-1} \left(\sum_{\substack{all \\ ranks}} R(X_{ij})^2 - \frac{N(N+1)^2}{4} \right).$$

The χ^2 distribution with $k-1$ degrees of freedom is used as an approximation of the null distribution of K. (Conover, 1999, pp. 288-289)

Hypothesis testing was used to determine if there was a difference in the mean in at least one of the k samples. The null hypothesis was H$_0$: "All the k sample means are identical," and the alternate hypothesis was H$_A$: "The k samples do not all have identical means." The null hypothesis was rejected at a significance level α = 0.01,

i.e., a *p*-value greater than 0.01, if the test statistic K was greater than $1-\alpha$ quantile from the χ^2 distribution. (Conover, 1999, p. 290)

If for any of the datasets, the null hypothesis was rejected, the following procedure was used to determine which pairs of population samples had different mean shipping times. Population samples *i* and *j* were deemed to be different if the following inequality was satisfied:

$$\left| \frac{R_i}{n_i} - \frac{R_j}{n_j} \right| > t_{1-\frac{\alpha}{2}} \left(S^2 \frac{N-1-K}{N-k} \right)^{\frac{1}{2}} \left(\frac{1}{n_i} + \frac{1}{n_j} \right)^{\frac{1}{2}},$$

where R_i and R_j are rank sums of the two samples, and $t_{1-\frac{\alpha}{2}}$ is the $1-\alpha/2$ quantile of the *t* distribution with $N-k$ degrees of freedom. (Conover, 1999, p. 290)

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IV. ANALYSIS

A.   PRELIMINARY DATA ANALYSIS

A preliminary review of the data indicated that mean shipping times for each destination dataset were different. Figures 4.1 through 4.6 on the next six pages provide bar graphs of the mean shipping times to the six primary destinations broken down by CARRIER (top graph), SOURCE OF SUPPLY (middle graph), and combination of CARRIER and SOURCE OF SUPPLY (bottom graph). Additionally, Appendix A provides summary statistics for the shipping times in all datasets.

Although the two variables appeared to have an impact on SHIPPING TIME, the SOURCE OF SUPPLY variable seemed to have the greater impact. The differences between the mean shipping times based on the CARRIER variable alone was less than one-half calendar day for each dataset, while the differences between mean shipping times based on the SOURCE OF SUPPLY variable alone ranged from approximately one calendar day to over three calendar days for each dataset. When both variables were taken into account, the mean shipping time differences ranged from approximately one-half calendar day to over three calendar days, indicating the potential of interaction between the two variables.   The following sections will discuss the statistical evidence for the two explanatory variables having an effect on shipping times through the analysis of multivariate OLS models, generalized linear models, and nonparametric tests.

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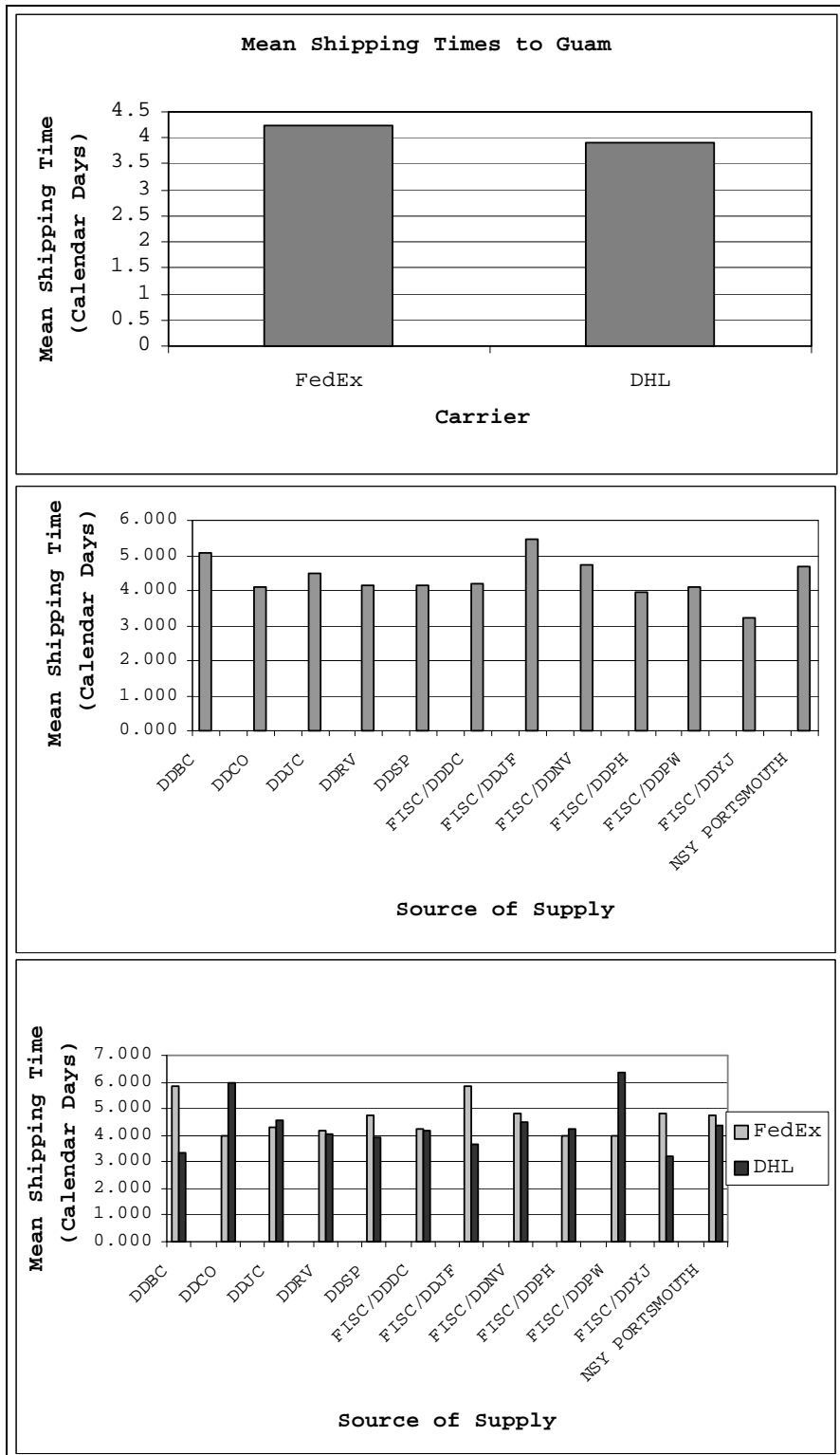
Figure 4.1.   Mean Shipping Times to Guam
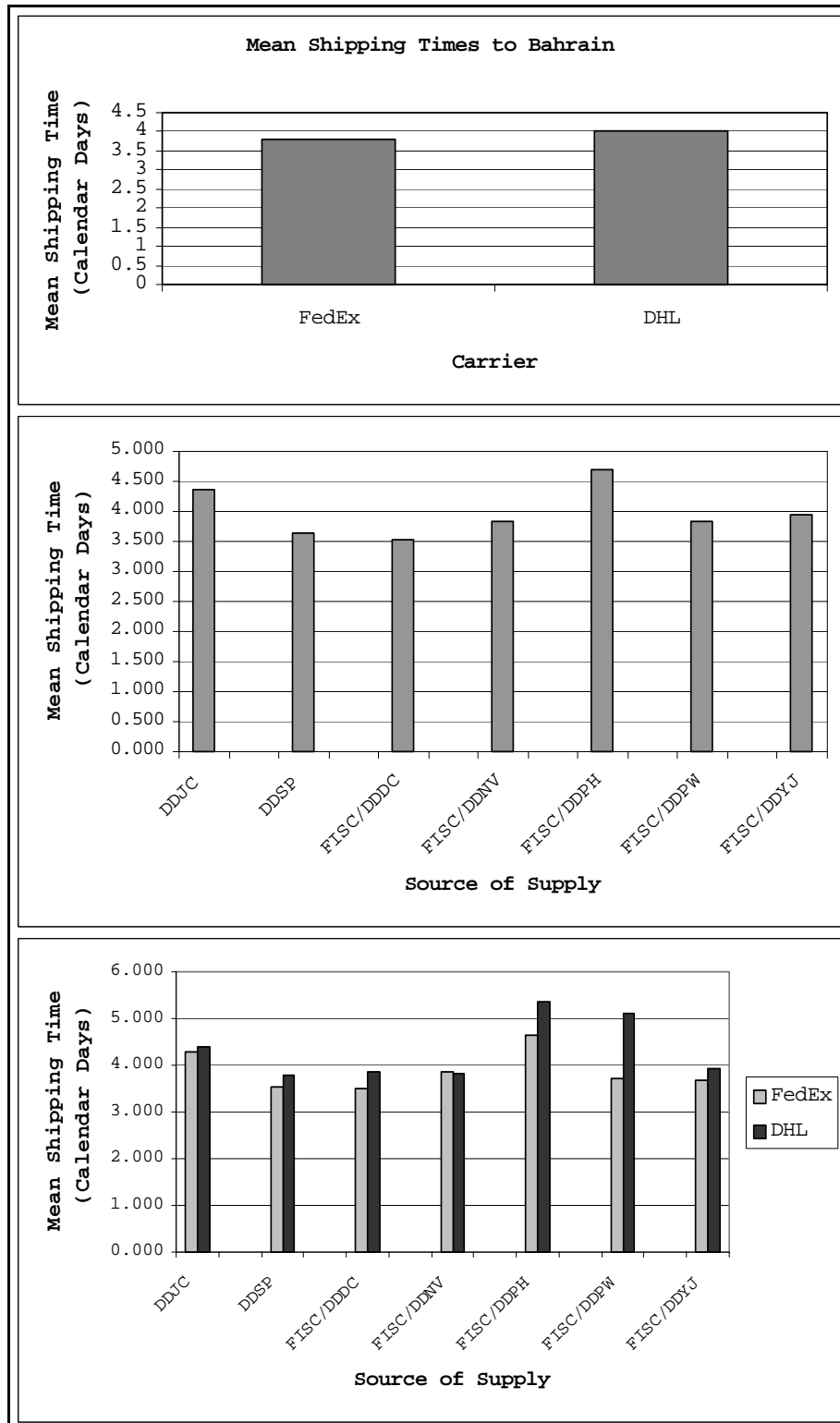
Figure 4.2.   Mean Shipping Times to Bahrain
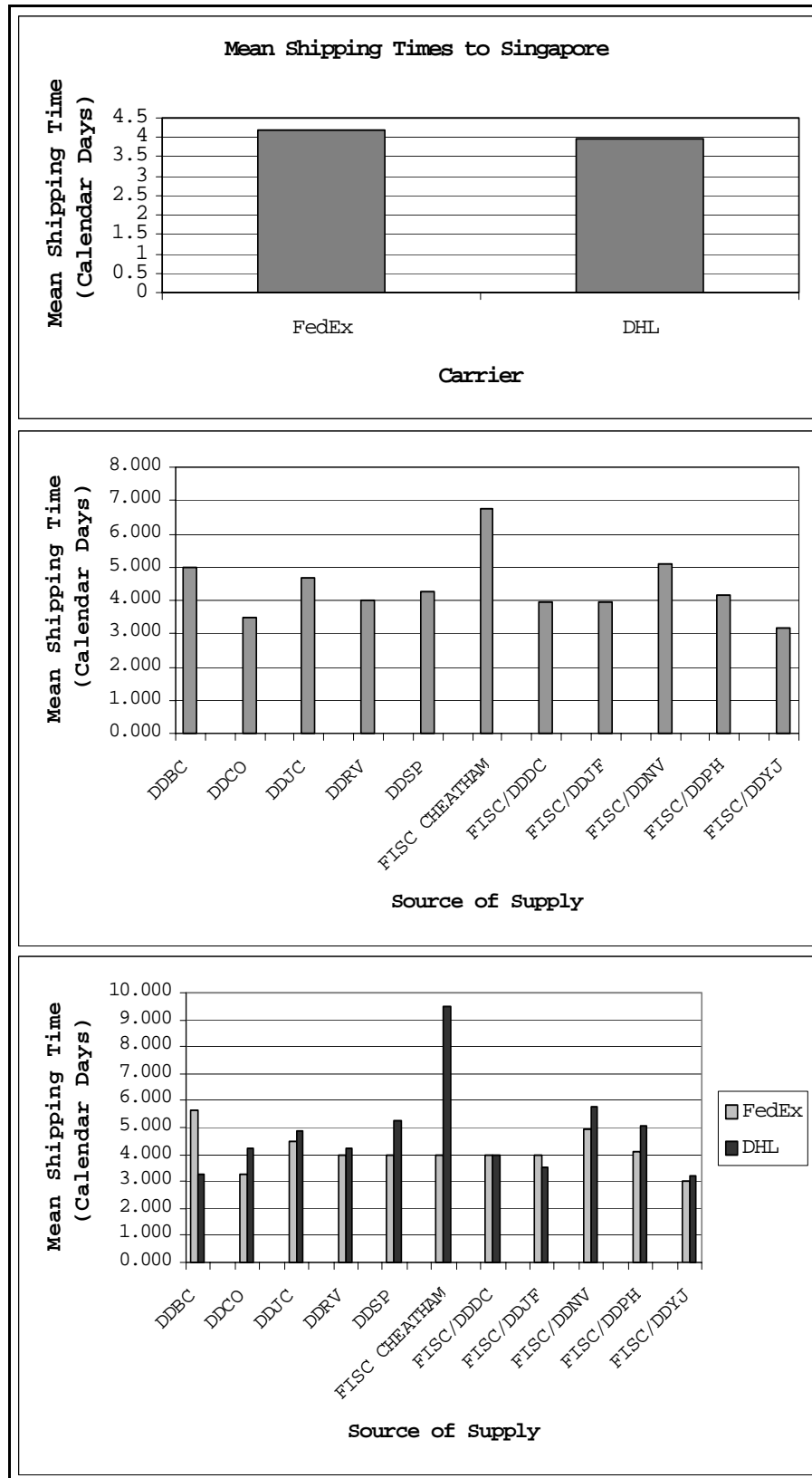
Figure 4.3.   Mean Shipping Times to Singapore
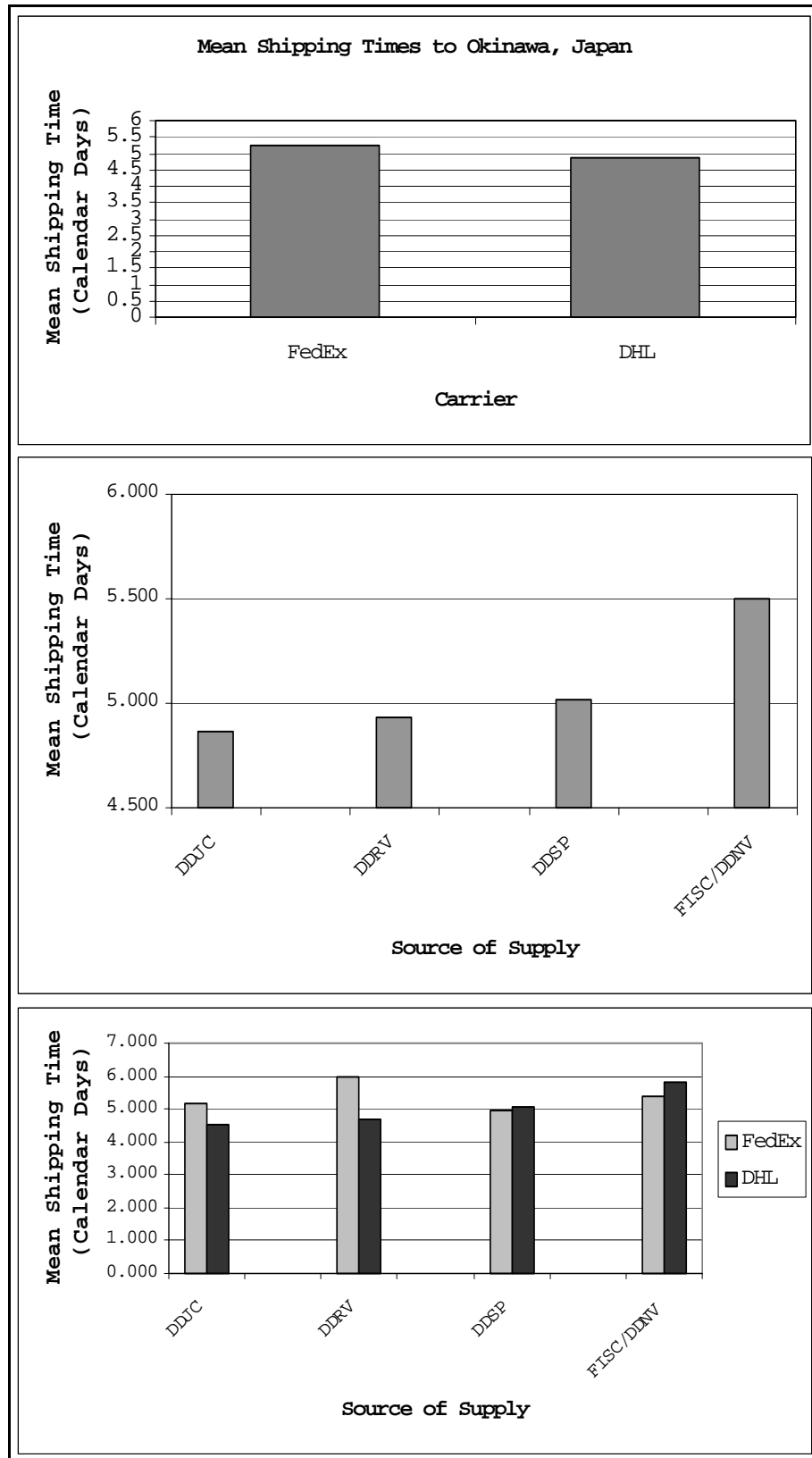
Figure 4.4.   Mean Shipping Times to Okinawa
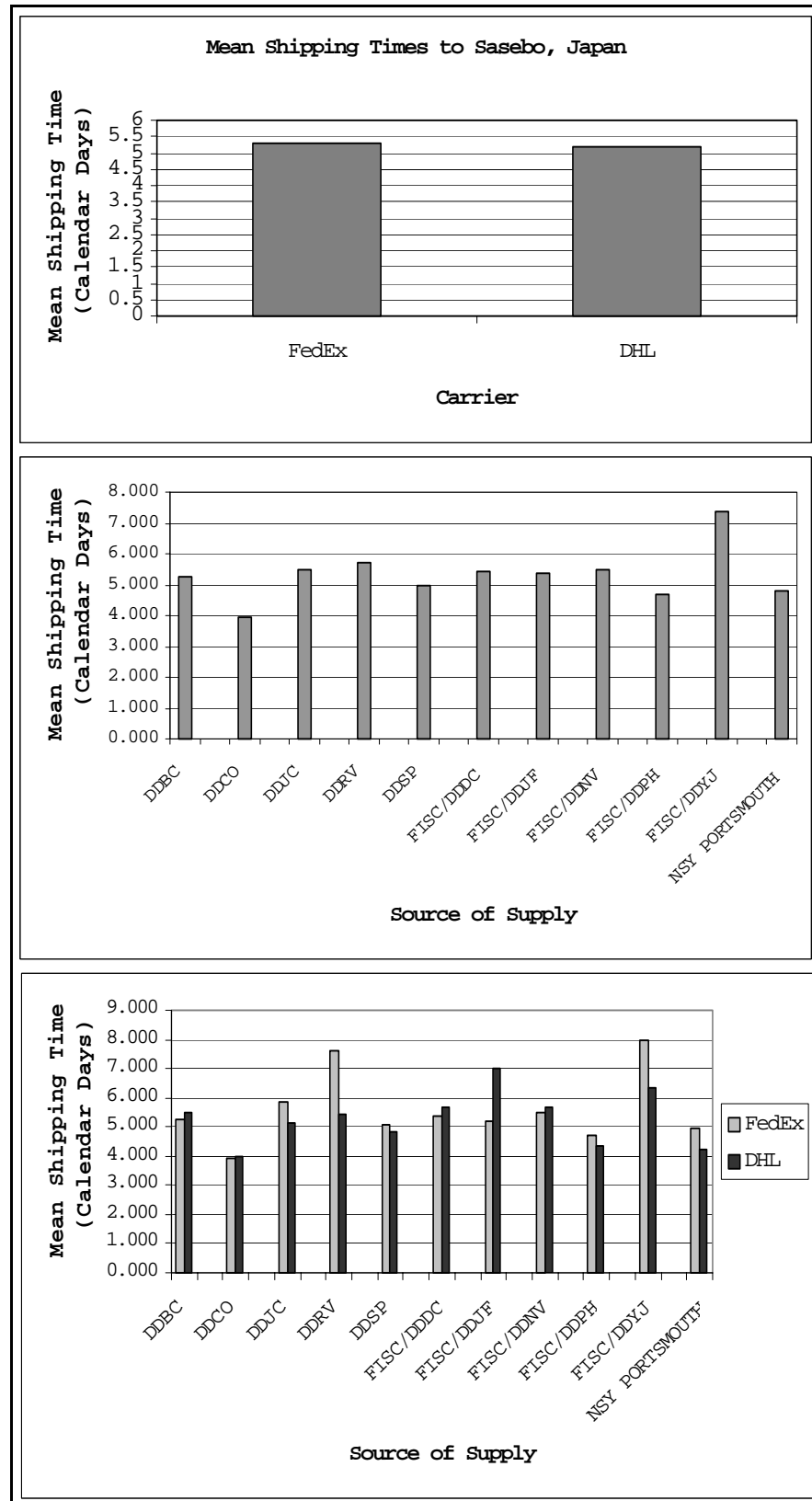
Figure 4.5.   Mean Shipping Times to Sasebo
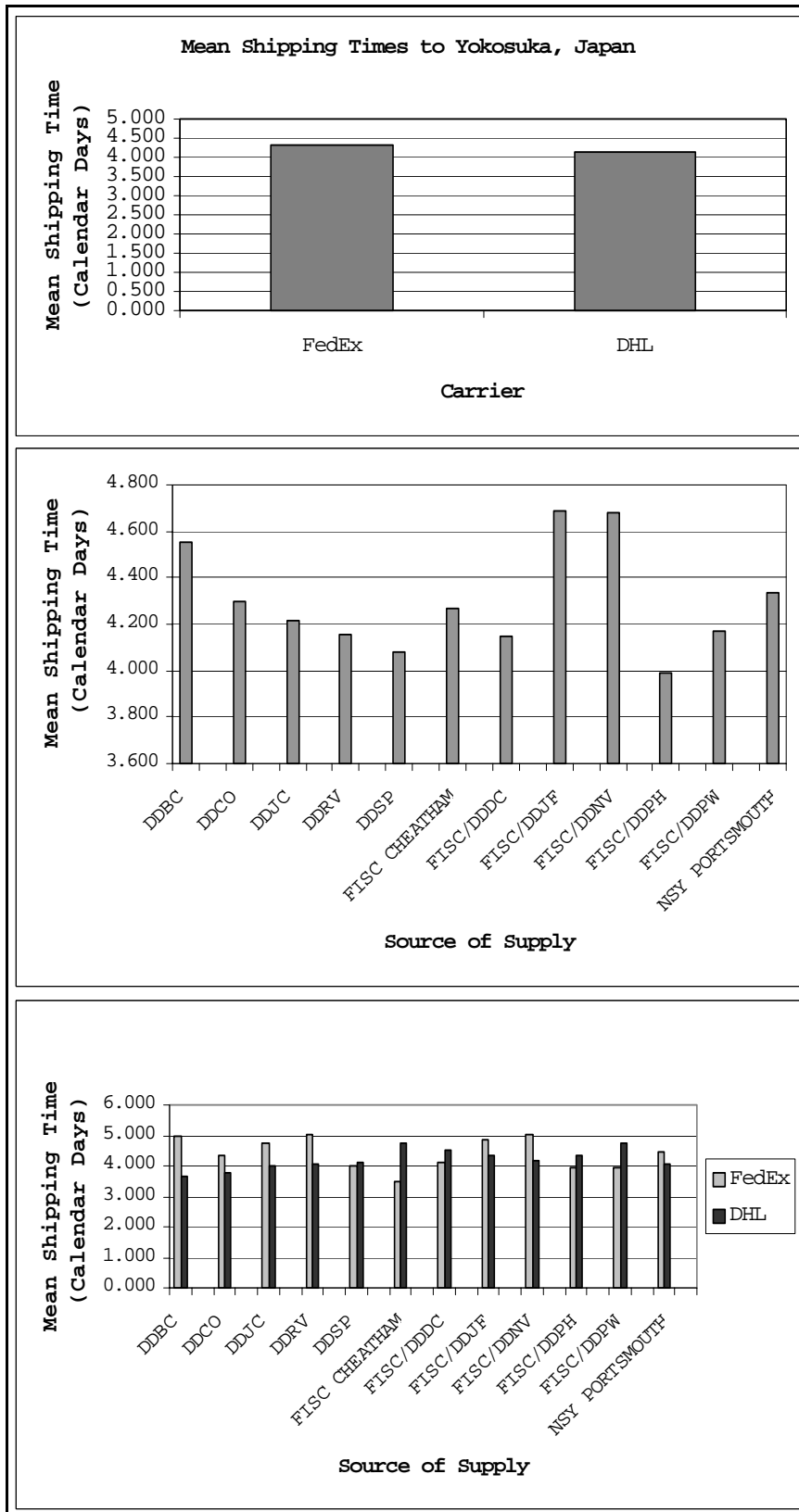
Figure 4.6.   Mean Shipping Times to Yokosuka

B.   OLS LINEAR MULTIVARIATE ANALYSIS

Multivariate modeling analyzes the effects of individual independent variables on the response variable by holding the effects of other variables constant. Ordinary linear models that included both factor variables and interaction terms were fitted to the six datasets. To reduce the effect of outliers, the response variable (SHIPPING TIME) was transformed using the natural log function. A stepwise model selection procedure was used to determine whether the two-way interaction was significant.

The software package S-Plus® 2000 (MathSoft, 2000) was used to estimate OLS regression models. After performing stepwise additions and deletions of terms, a two-way analysis of variance test (Hamilton, 1992) was used to determine whether the main factors or interactions were statistically significant.

Having developed the models, diagnostics were checked to determine if the ANOVA F-tests were reliable. Specifically, Quantile-Normal plots of each model's residuals were used to determine if the errors were normally distributed. If the Quantile-Normal plots did not indicate that the errors were normally distributed, the ordinary linear model was rejected. Appendix B provides the Quantile-Normal plots for each model's residuals. The plots for each dataset clearly illustrated heavy tails and high outliers, indicating non-normal distributions. The obvious non-normality of each of the six datasets argued strongly against assuming normal populations. Therefore the OLS linear models were

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rejected in favor of GLM's. Because the linear models
were determined not to be valid, the *F*-test results are
not presented in this analysis.

C.   GLM MULTIVARIATE ANALYSIS

As with the OLS linear models, S-Plus was used to
estimate GLM's for each of the datasets. This study used
Poisson GLM's with a log link function because the
response variable, SHIPPING TIME, was discrete.   A
stepwise model selection procedure was used to determine
if the two-way interaction was significant. The two-way
interaction between CARRIER and SOURCE OF SUPPLY was
determined to be negligible and was removed from all
models, producing simpler models with the main effects of
CARRIER and SOURCE OF SUPPLY.

Having developed the models, diagnostics were checked
to determine if the models were reasonable. Specifically,
standardized deviance residual plots were analyzed to
determine if the Poisson GLM's were valid models for the
six destination datasets.   Standardized deviance
residuals, $r'_{D,i}$, were plotted against the fitted values, $\hat{y}$,
transformed to the constant-information scale, $2\sqrt{\hat{y}}$, for
Poisson errors. Absolute standardized deviance residuals,
$|r'_{D,i}|$, were also plotted against fitted values, $\hat{y}$,
transformed to the constant-information scale, $2\sqrt{\hat{y}}$, for
Poisson errors. These residual plots indicated no obvious
curvature or systematic change of range with fitted values
for all six destinations. So, the Poisson GLM's were
deemed to be acceptable models for the shipping time data.

(McCullagh and Nelder, 1989) Appendix C provides the standardized residual plots for the six Poisson GLM's.

An analysis of deviance (McCullagh and Nelder, 1989) test was used to determine whether the main factors, SOURCE OF SUPPLY and CARRIER, were statistically significant. Table 4.1 provides the p-values for the analysis of deviance chi-square test for each destination. The SOURCE OF SUPPLY factor was found to have a significant effect on shipping time at a 0.01 significance level (p-values $\approx$ 0.000), for all destinations with the exception of Okinawa, while the CARRIER factor seemed to have little effect on shipping times at the same significance level (p-values > 0.01) for all destinations.

Destination	Explanatory Factor	p-value
Guam	SOURCE OF SUPPLY	0.000
	CARRIER	0.106
Bahrain	SOURCE OF SUPPLY	0.000
	CARRIER	0.085
Singapore	SOURCE OF SUPPLY	0.000
	CARRIER	0.093
Okinawa	SOURCE OF SUPPLY	0.596
	CARRIER	0.217
Sasebo	SOURCE OF SUPPLY	0.000
	CARRIER	0.157
Yokosuka	SOURCE OF SUPPLY	0.000
	CARRIER	0.143

Table 4.1. p-values for GLM Analysis of Deviance for SOURCE OF SUPPLY and CARRIER Explanatory Factors for Each Destination

It is reasonable to conclude that the CARRIER factor has no significant effect on SHIPPING TIME. Although the operating procedures of each of the carriers analyzed in

this study is not known in detail, it is assumed that FedEx and DHL have similar processes in handling express shipments to overseas destinations. Furthermore, though these carriers may have different shipping routes and trans-shipment hubs, they do use similar aircraft and land vehicles (i.e., similar transit speed) for shipping material. Additionally, one would expect carriers operating in the same markets to be competitive, i.e., have similar performance (shipping time) standards.

It is also reasonable to conclude that the SOURCE OF SUPPLY factor had a statistically significant effect on SHIPPING TIMES. The distance between the destinations and sources of supply obviously varies depending on the location of the source of supply. So it makes sense that if a source of supply is located further from a destination, the shipping times can be expected to be longer than for shipping times from sources that are closer to the destination. Although distances between destinations and sources of supply were not explicitly stated in the models, they are included implicitly based on the locations of the sources of supply. For example, the sources FISC/DDYJ (Yokosuka, Japan) and FISC/DDPH (Pearl Harbor HI) are obviously closer to Guam than are the sources FISC/DDJF (Jacksonville FL) and FISC/DDNV (Norfolk VA). So, shipping times to Guam from FISC/DDYJ and FISC/DDPH can be expected to be shorter than shipping times from FISC/DDNV and FISC/DDJF.

The Okinawa dataset was an exception to the above trend as the SOURCE OF SUPPLY factor did not appear to have a statistically significant effect on SHIPPING TIMES

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to this destination. This may be explained by the relatively small number of observations (213 IPG-1 requisitions) used in creating the GLM for Okinawa. The other five destinations had over 1,000 observations that were used in creating their GLM's. 213 observations may not have been enough to model and discern the effects of source of supply on shipping times to Okinawa. Possibly, with a larger sample size, SOURCE OF SUPPLY may have been shown to have a statistically significant impact on SHIPPING TIME to this destination. Another possible explanation may be that the small number of IPG-1 requisitions to Okinawa is an indication that this destination does not receive daily express shipments from any source of supply; therefore, the SOURCE OF SUPPLY factor does not appear to affect shipping times.

Having determined that there was statistical evidence indicating that the SOURCE OF SUPPLY factor has an effect on SHIPPING TIME to five of the six destinations and that the CARRIER factor does not, the next question that needed to be examined was what effect does source of supply have on shipping times to each of the individual destinations. This question was answered by analyzing the model coefficients for the SOURCE OF SUPPLY factor levels for each GLM with the exception of Okinawa. Tables 4.2 through 4.6 provide a listing of the SOURCE OF SUPPLY coefficients, percentage change from baseline SOURCE OF SUPPLY, and mean shipping times, in ascending order for each destination.

Source of Supply	Coefficient	Percentage Change from Baseline	Mean Shipping Time (Calendar Days)
FISC/DDYJ	−0.426	−35%	3.23
FISC/DDPH	−0.253	−22%	3.97
FISC/DDPW	−0.223	−20%	4.10
DDCO	−0.222	−20%	4.10
DDRV	−0.208	−19%	4.15
FISC/DDDC	−0.198	−18%	4.17
DDSP	−0.181	−17%	4.21
DDJC	−0.114	−11%	4.47
NSY PORTSMOUTH	−0.085	−8%	4.69
FISC/DDNV	−0.070	−8%	4.75
DDBC (Baseline)	0.000	0%	5.07
FISC/DDJF	0.071	+7%	5.47

Table 4.2.   SOURCE OF SUPPLY Coefficients for Guam GLM, Percentage Change from Baseline and Mean Shipping Times

Source of Supply	Coefficient	Percentage Change from Baseline	Mean Shipping Time (Calendar Days)
FISC/DDDC	−0.176	−16%	3.54
DDSP	−0.163	−15%	3.65
FISC/DDYJ	−0.116	−11%	3.93
FISC/DDNV	−0.109	−10%	3.84
FISC/DDPW	−0.094	−9%	3.84
DDJC (Baseline)	0.000	0%	4.37
FISC/DDPH	0.108	+11%	4.69

Table 4.3.   SOURCE OF SUPPLY Coefficients for Bahrain GLM, Percentage Change from Baseline and Mean Shipping Times

Source of Supply	Coefficient	Percentage Change from Baseline	Mean Shipping Time (Calendar Days)
FISC/DDYJ	−0.814	−56%	3.19
DDCO	−0.622	−46%	3.50
FISC/DDJF	−0.474	−38%	3.96
DDRV	−0.464	−37%	3.96
FISC/DDDC	−0.462	−37%	3.96
FISC/DDPH	−0.426	−35%	4.15
DDSP	−0.422	−34%	4.28
DDJC	−0.362	−30%	4.68
DDBC	−0.267	−24%	5.00
FISC/DDNV	−0.237	−21%	5.11
FISC CHEATHAM (Baseline)	0.000	0%	6.75

Table 4.4.   SOURCE OF SUPPLY Coefficients for Singapore GLM, Percentage Change from Baseline and Mean Shipping Times

Source of Supply	Coefficient	Percentage Change from Baseline	Mean Shipping Time (Calendar Days)
FISC/DDPH	−0.298	−26%	4.03
DDCO	−0.123	−12%	4.58
NSY PORTSMOUTH	−0.087	−8%	4.78
DDSP	−0.028	−3%	4.97
DDBC (Baseline)	0.000	0%	5.27
FISC/DDDC	0.019	+2%	5.41
DDJC	0.025	+3%	5.49
FISC/DDNV	0.050	+5%	5.50
FISC/DDJF	0.075	+8%	5.58
DDRV	0.148	+16%	5.75

Table 4.5.   SOURCE OF SUPPLY Coefficients for Sasebo GLM, Percentage Change from Baseline and Mean Shipping Times

Source of Supply	Coefficient	Percentage Change from Baseline	Mean Shipping Time (Calendar Days)
FISC/DDPH	-0.067	-7%	3.99
DDSP	-0.046	-4%	4.08
FISC/DDDC	-0.029	-3%	4.15
DDRV	-0.026	-3%	4.15
FISC/DDPW	-0.023	-2%	4.17
DDJC	-0.013	-1%	4.21
FISC CHEATHAM (Baseline)	0.000	0%	4.27
DDCO	0.007	+1%	4.30
NSY PORTSMOUTH	0.015	+2%	4.33
DDBC	0.064	+7%	4.55
FISC/DDNV	0.091	+10%	4.68
FISC/DDJF	0.094	+10%	4.69

Table 4.6.   SOURCE OF SUPPLY Coefficients for Yokosuka GLM, Percentage Change from Baseline and Mean Shipping Times

Because the log link was used in the Poisson GLM's the coefficients for the explanatory levels are in log scale. Therefore, the more negative the coefficient, the larger the effect of the corresponding SOURCE OF SUPPLY had on reducing the shipping time to the destination. For example, in the Guam GLM the FISC/DDYJ and FISC/DDPH SOURCES OF SUPPLY had coefficients of -0.426 and -0.253, respectively, indicating that these sources had the smallest mean shipping times to Guam, while the FISC/DDJF SOURCE OF SUPPLY had a coefficient of 0.071, indicating that this source had the largest mean shipping time to Guam. The mean shipping time to Guam from FISC/DDYJ was approximately 35% smaller than the mean shipping time from DDBC, the baseline for this model. Similar differences were observed in the other destination models.

Although there was statistical evidence at a 0.01 significance level that SOURCE OF SUPPLY has an effect on SHIPPING TIME, the magnitude of the differences in mean

shipping times between sources of supply was relatively small, i.e., less than one calendar day (with a few exceptions). As a result of these small differences in mean shipping times, a recommendation cannot be made on an absolute order for selecting a source of supply, from best source (smallest mean shipping times) to worst source (largest mean shipping times), for each destination. However, for most destinations, the models do suggest that certain sources of supply are better choices and should be used for IPG-1 requisitions whenever possible (i.e. when the required part is in stock) while other sources of supply are bad choices and should be avoided whenever possible (i.e. when the required part is available from another source). Table 4.7 provides recommendations of best and worst choices for source of supply for each destination based on the results of the GLM analyses.

| Destination | Source of Supply | |
	Best Choices (Mean Shipping Time)	Worst Choices (Mean Shipping Time)
Guam	FISC/DDYJ (3.23 days)	FISC/DDJF (5.47 days)
	FISC/DDPH (3.97 days)	DDBC (5.07 days)
Bahrain	FISC/DDDC (3.54 days)	FISC/DDPH (4.69 days)
	DDSP (3.65 days)	DDJC (4.37 days)
Singapore	FISC/DDYJ (3.19 days)	DDBC (5.00 days)
		FISC/DDNV (5.11 days)
		FISC CHEATHAM (6.75 days)
Sasebo	FISC/DDPH (4.03 days)	FISC/DDJF (5.58 days)
		DDRV (5.75 days)
Yokosuka	FISC/DDPH (3.99 days)	DDBC (4.55 days)
		FISC/DDJF (4.69 days)
		FISC/DDNV (4.68 days)

Table 4.7.   Best and Worst Choices for Source of Supply

D. NONPARAMETRIC STATISTICAL ANALYSIS

As a verification of the results produced with the Poisson GLM's, the Kruskal-Wallis test was performed on each destination dataset. S-Plus was used to implement this nonparametric rank sum test to check the null hypothesis that all sample mean shipping times were equal within each dataset. Two tests were performed on each dataset, one test for SOURCE OF SUPPLY and another for CARRIER.

The null hypothesis was rejected at a significance level α = 0.01 if the test statistic K was greater than $1-\alpha$ quantile from the χ^2 distribution. The p-values were computed using an asymptotic chi-squared approximation. Table 4.8 provides the p-values of the Kruskal-Wallis tests for each destination.

Destination	Explanatory Factor	p-value
Guam	SOURCE OF SUPPLY	0.0000
	CARRIER	0.1260
Bahrain	SOURCE OF SUPPLY	0.0000
	CARRIER	0.1100
Singapore	SOURCE OF SUPPLY	0.0000
	CARRIER	0.0821
Okinawa	SOURCE OF SUPPLY	0.4052
	CARRIER	0.3436
Sasebo	SOURCE OF SUPPLY	0.0003
	CARRIER	0.1774
Yokosuka	SOURCE OF SUPPLY	0.0003
	CARRIER	0.1360

Table 4.8. p-values for Kruskal-Wallis Test on SOURCE OF SUPPLY and CARRIER Explanatory Factors for Each Destination

With the exception of Okinawa, the SOURCE OF SUPPLY
p-value for each destination is less than 0.01, indicating
that the null hypothesis can be rejected for this
explanatory factor. However, the CARRIER *p*-value for all
destinations is greater than 0.01, indicating that the
null hypothesis cannot be rejected for this explanatory
factor.

If the null hypothesis was rejected, as was the case
with five of the six destinations for SOURCE OF SUPPLY,
additional comparisons were performed within each of the
five destinations' datasets to determine which pairs of
sources within a dataset tended to have different mean
shipping times at a 0.01 significance level. As stated in
Chapter III, Section C.3, SOURCE OF SUPPLY samples *i* and *j*
were deemed to be different if the following inequality
was satisfied:

$$\left| \frac{R_i}{n_i} - \frac{R_j}{n_j} \right| > t_{1-\frac{\alpha}{2}} \left(S^2 \frac{N-1-K}{N-k} \right)^{\frac{1}{2}} \left(\frac{1}{n_i} + \frac{1}{n_j} \right)^{\frac{1}{2}},$$

where R_i and R_j are rank sums of the two samples, and $t_{1-\frac{\alpha}{2}}$
is the $1-\alpha/2$ quantile of the t distribution with
$N-k$ degrees of freedom. The value of $t_{1-\frac{\alpha}{2}}$ was determined
to be 2.576 at a 0.01 significance level. (Conover, 1999,
p.559)

The software package Excel® (Microsoft, 2000) was
used for the multiple comparison testing by calculating
and comparing the values of the inequality. Tables 4.9
through 4.13 list which SOURCE OF SUPPLY samples were
found to have different mean shipping times at a 0.01
level of significance. A "Yes" indicates that the two

sources of supply had statistically different mean shipping times while a "No" indicates otherwise. As the tables show, most destinations did have statistically different mean shipping times between the various sources of supply.

SOURCE OF SUPPLY *i*/SOURCE OF SUPPLY *j*	DDBC	DDCO	DDJC	DDRV	DDSP	FISC/DDDC	FISC/DDJF	FISC/DDNV	FISC/DDPH	FISC/DDPW	FISC/DDYJ	NSY PORTSMOUTH
DDBC	–	No	No	No	No	No	No	No	No	No	Yes	Yes
DDCO	–	–	Yes	No	No	No	Yes	Yes	No	No	Yes	Yes
DDJC	–	–	–	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
DDRV	–	–	–	–	No	No	Yes	Yes	No	No	Yes	Yes
DDSP	–	–	–	–	–	No	No	Yes	No	No	Yes	No
FISC/DDDC	–	–	–	–	–	–	No	Yes	No	No	Yes	Yes
FISC/DDJF	–	–	–	–	–	–	–	Yes	Yes	Yes	Yes	Yes
FISC/DDNV	–	–	–	–	–	–	–	–	Yes	Yes	Yes	No
FISC/DDPH	–	–	–	–	–	–	–	–	–	No	Yes	Yes
FISC/DDPW	–	–	–	–	–	–	–	–	–	–	Yes	Yes
FISC/DDYJ	–	–	–	–	–	–	–	–	–	–	–	Yes
NSY PORTSMOUTH	–	–	–	–	–	–	–	–	–	–	–	–

Table 4.9.   Multiple Comparisons of Mean Shipping Times Between Sources of Supply for Guam

SOURCE OF SUPPLY *i*/SOURCE OF SUPPLY *j*	DDJC	DDSP	FISC/DDDC	FISC/DDNV	FISC/DDPH	FISC/DDPW	FISC/DDYJ
DDJC	–	Yes	Yes	Yes	Yes	Yes	No
DDSP	–	–	No	Yes	Yes	Yes	Yes
FISC/DDDC	–	–	–	Yes	Yes	Yes	Yes
FISC/DDNV	–	–	–	–	Yes	No	No
FISC/DDPH	–	–	–	–	–	Yes	Yes
FISC/DDPW	–	–	–	–	–	–	No
FISC/DDYJ	–	–	–	–	–	–	–

Table 4.10.   Multiple Comparisons of Mean Shipping Times Between Sources of Supply for Bahrain

SOURCE OF SUPPLY *i*/SOURCE OF SUPPLY *j*	DDBC	DDCO	DDJC	DDRV	DDSP	FISC CHEATHAM	FISC/DDDC	FISC/DDJF	FISC/DDNV	FISC/DDPH	FISC/DDYJ
DDBC	–	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
DDCO	–	–	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
DDJC	–	–	–	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DDRV	–	–	–	–	No	No	No	No	Yes	No	Yes
DDSP	–	–	–	–	–	No	No	No	Yes	No	Yes
FISC CHEATHAM	–	–	–	–	–	–	Yes	No	No	No	Yes
FISC/DDDC	–	–	–	–	–	–	–	No	Yes	No	Yes
FISC/DDJF	–	–	–	–	–	–	–	–	No	Yes	Yes
FISC/DDNV	–	–	–	–	–	–	–	–	–	Yes	Yes
FISC/DDPH	–	–	–	–	–	–	–	–	–	–	Yes
FISC/DDYJ	–	–	–	–	–	–	–	–	–	–	–

Table 4.11.   Multiple Comparisons of Mean Shipping Times Between Sources of Supply for Singapore

SOURCE OF SUPPLY *i*/SOURCE OF SUPPLY *j*	DDBC	DDCO	DDJC	DDRV	DDSP	FISC/DDDC	FISC/DDJF	FISC/DDNV	FISC/DDPH	NSY PORTSMOUTH
DDBC	–	No	No	No	No	No	No	No	Yes	No
DDCO	–	–	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
DDJC	–	–	–	No	No	No	No	No	Yes	No
DDRV	–	–	–	–	No	No	No	No	Yes	No
DDSP	–	–	–	–	–	No	No	No	Yes	No
FISC/DDDC	–	–	–	–	–	–	No	No	Yes	No
FISC/DDJF	–	–	–	–	–	–	–	No	Yes	No
FISC/DDNV	–	–	–	–	–	–	–	–	Yes	No
FISC/DDPH	–	–	–	–	–	–	–	–	–	Yes
NSY PORTSMOUTH	–	–	–	–	–	–	–	–	–	–

Table 4.12.   Multiple Comparisons of Mean Shipping Times Between Sources of Supply for Sasebo

SOURCE OF SUPPLY *i*/SOURCE OF SUPPLY *j*	DDBC	DDCO	DDJC	DDRV	DDSP	FISC CHEATHAM	FISC/ DDDC	FISC/ DDJF	FISC/ DDNV	FISC/ DDPH	FISC/ DDPW	NSY PORTSMOUTH
DDBC	–	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	Yes
DDCO	–	–	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
DDJC	–	–	–	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No
DDRV	–	–	–	–	Yes	No	Yes	Yes	Yes	Yes	Yes	No
DDSP	–	–	–	–	–	Yes	No	Yes	Yes	Yes	Yes	No
FISC CHEATHAM	–	–	–	–	–	–	Yes	No	No	Yes	Yes	No
FISC/DDDC	–	–	–	–	–	–	–	Yes	Yes	No	No	Yes
FISC/DDJF	–	–	–	–	–	–	–	–	No	Yes	Yes	Yes
FISC/DDNV	–	–	–	–	–	–	–	–	–	Yes	Yes	Yes
FISC/DDPH	–	–	–	–	–	–	–	–	–	–	No	Yes
FISC/DDPW	–	–	–	–	–	–	–	–	–	–	–	Yes
NSY PORTSMOUTH	–	–	–	–	–	–	–	–	–	–	–	–

Table 4.13.   Multiple Comparisons of Mean Shipping Times Between Sources of Supply for Yokosuka

The Kruskal-Wallis test results provide statistical evidence that the SOURCE OF SUPPLY factor had a significant effect on SHIPPING TIME for all destinations with the exception of Okinawa. Additionally, the results indicate that the CARRIER factor does not have a significant effect on SHIPPING TIME to all primary destinations. The nonparametric results buttressed the GLM's results that SOURCE OF SUPPLY has an effect on SHIPPING TIME while CARRIER does not.

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V.   SUMMARY, LIMITATIONS AND RECOMMENDATIONS

The purpose of this study was to examine whether or not source of supply and carrier had an effect on shipping times for IPG-1 requisitions to primary Navy destinations in the Pacific Theater and the Persian Gulf. Specifically, the following questions were explored:

- Is there statistical evidence to indicate that source of supply, carrier, and/or the interaction of these two variables, effect shipping times of IPG-1 requisitions to destinations within the Pacific Theater and Persian Gulf?

- What carrier, source of supply, and/or combinations of these two factors, for the various destinations, result in smallest mean shipping times?

The IPG-1 requisition data used in our study was provided by the Priority Material Office and covered the period October 1999 to November 2002. The destinations included in the study were Guam, Bahrain, Singapore, Okinawa, Sasebo, and Yokosuka. Each destination in our study was analyzed separately, i.e., the data was divided into six datasets.

Our analysis was limited to primary sources of supply for IPG-1 requisitions. For our study, a primary source of supply was defined as a single DoD or Navy supply center, or a group of DoD and Navy supply activities within a single geographic locale (e.g. Fleet and Industrial Supply Center, San Diego, and Defense

Distribution Center, San Diego) that shipped at least 200 IPG-1 requisitions during the three-year period of the historical requisition data. FedEx® and DHL® were the only carriers included in the analysis. These two carriers shipped over 90% of the IPG-1 requisitions in the historical dataset and shipped from all the supply sources and to all destinations included in our study.

Although the data could not be analyzed using ordinary least square (OLS) linear models, Poisson generalized linear models (GLM's) proved to be adequate for analyzing the six datasets. In light of the p-values produced by the GLM's analysis of deviance chi-square test, the short answer to the main question of the thesis is, "Yes, source of supply has an effect on IPG-1 requisitions shipping times, but carrier does not."   In answering the secondary question of the thesis, the GLM's provided relative rankings of mean shipping times from each source in relation to a baseline source.   In quantitative terms, the percentage change from the baseline mean shipping time ranged from -35% to +7% for Guam, -16% to +11% for Bahrain, -21% to -56% for Singapore, -26% to +16% for Sasebo, and -7% to +10% for Yokosuka. Additionally, the best (i.e. smallest) mean shipping times ranged from approximately 3.25 days to 4.00 days, while the worst, i.e. largest, mean shipping times ranged from approximately 4.75 days to 6.75 days. Because carrier was found not to impact shipping times to any of the destinations in the study, FedEx and DHL were determined to be equally good choices for shipping IPG-1 requisitions.   Lastly, the GLM's indicated that there was

no statistical evidence of interaction between source of supply and carrier.

The nonparametric Kruskal-Wallis rank sum test results supported those found with the GLM analysis. Specifically, this nonparametric test provided statistical evidence that source of supply had an effect on mean shipping times. The nonparametric results also indicated that carrier does not have a significant effect on mean shipping time to all primary destinations.

Although statistically significant, the differences between the mean shipping times to each destination for the majority of sources of supply were relatively small (less than one calendar day). Therefore, a definite recommendation could not be made on an absolute ordering for selecting a source of supply, from best source (smallest mean shipping times) to worst source (largest mean shipping times), for each destination. So rather than provide a specific and definitive protocol for selecting a source of supply for each destination, the results of our analysis provided "rules of thumb" for PMO to use in selecting a source of supply for IPG-1 requisitions. Table 4.7 in Chapter IV provides the best and worst choices for source of supply.

Although the approach and methods used in this study may be applicable to similar situations, the results are not generalizable beyond the specific destinations, sources of supply, and carriers included in the analysis. Since the historical data did not include requisitions from all the primary sources of supply for each destination dataset, inferences and recommendations cannot

be made on shipping times for these missing combinations of source of supply and destination. For example, Bahrain dataset did not include any IPG-1 requisitions from DDRV, so, although this source was found to be bad choice for shipping to Sasebo, no inference can be made on the shipping times from DDRV to Bahrain.

Further studies can be done to determine what effect other variables, such as distances between sources of supply and destinations, weight and volume of material, and shipping cost have on IPG-1 requisition shipping times. Additionally, similar analyses could be used for IPG-1 requisitions to other major U.S. Navy destinations, such as locations in the Atlantic Theater, specifically the Mediterranean and Caribbean regions. Finally, other analytical techniques, such as network models or linear optimization, may be applied to the IPG-1 requisition shipping process, and results found here can be compared with results from analysis of historical requisitions.

APPENDIX A. SUMMARY STATISTICS

The summary statistics for shipping times to each of the six primary destinations broken down by carrier and source of supply:

Shipping Times to Guam by Carrier

Carrier	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
FedEx	3342	1.000	3.000	4.000	4.251	5.000	19.000	2.210
DHL	2125	1.000	3.000	4.000	3.902	5.000	18.000	1.858

Table A.1.a   Summary Statistics for Shipping Times to Guam by Carrier (Calendar Days)

Shipping Times to Guam by Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	44	1.000	3.000	4.000	5.068	5.000	16.000	3.757
DDCO	101	1.000	3.000	4.000	4.099	5.000	18.000	2.837
DDJC	1053	1.000	3.000	4.000	4.466	5.000	18.000	2.196
DDRV	213	1.000	3.000	3.000	4.150	5.000	18.000	2.454
DDSP	673	1.000	3.000	4.000	4.165	5.000	19.000	2.100
FISC/DDDC	687	1.000	3.000	4.000	4.207	5.000	19.000	2.070
FISC/DDJF	19	3.000	3.000	5.000	5.474	6.000	13.000	2.836
FISC/DDNV	374	1.000	3.000	4.000	4.749	6.000	18.000	2.746
FISC/DDPH	845	1.000	3.000	4.000	3.972	5.000	17.000	1.591
FISC/DDPW	578	1.000	3.000	4.000	4.104	4.000	14.000	1.544
FISC/DDYJ	788	1.000	2.000	3.000	3.228	4.000	13.000	1.535
NSY PORTSMOUTH	92	1.000	3.000	4.000	4.685	6.000	14.000	2.927

Table A.1.b Summary Statistics for Shipping Times to Guam by Source of Supply (Calendar Days)

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Shipping Times to Guam by FedEx and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	30	1.000	3.000	4.000	5.867	6.000	16.000	4.297
DDCO	96	1.000	3.000	3.500	4.000	5.000	18.000	2.787
DDJC	384	1.000	3.000	4.000	4.297	5.000	18.000	2.787
DDRV	194	1.000	3.000	3.000	4.160	5.000	18.000	2.787
DDSP	186	1.000	3.000	4.000	4.763	5.000	19.000	3.131
FISC/DDDC	681	1.000	3.000	4.000	4.207	5.000	19.000	2.076
FISC/DDJF	16	3.000	3.750	5.000	5.813	6.250	13.000	2.949
FISC/DDNV	299	1.000	3.000	4.000	4.819	6.000	18.000	2.918
FISC/DDPH	792	1.000	3.000	4.000	3.953	5.000	17.000	1.582
FISC/DDPW	572	1.000	4.000	4.000	4.012	4.000	14.000	1.181
FISC/DDYJ	14	1.000	4.000	4.000	4.786	5.000	10.000	2.547
NSY PORTSMOUTH	78	1.000	3.000	4.000	4.744	6.000	14.000	2.987

Table A.1.c   Summary Statistics for Shipping Times to Guam by FedEx and Source of Supply (Calendar Days)

Shipping Times to Guam by DHL and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	14	2.000	3.000	3.000	3.357	3.750	6.000	0.929
DDCO	5	3.000	5.000	5.000	6.000	5.000	12.000	3.464
DDJC	669	1.000	3.000	4.000	4.564	5.000	18.000	2.163
DDRV	19	1.000	3.000	4.000	4.053	5.000	9.000	1.747
DDSP	487	1.000	3.000	4.000	3.936	5.000	12.000	1.476
FISC/DDDC	6	3.000	3.000	4.000	4.167	5.000	6.000	1.329
FISC/DDJF	3	3.000	3.000	3.000	3.667	4.000	5.000	1.155
FISC/DDNV	75	1.000	3.000	4.000	4.467	5.000	13.000	1.898
FISC/DDPH	53	2.000	3.000	4.000	4.245	5.000	9.000	1.709
FISC/DDPW	6	3.000	5.500	8.000	6.333	8.000	8.000	2.887
FISC/DDYJ	774	1.000	2.000	3.000	3.200	4.000	13.000	1.499
NSY PORTSMOUTH	14	1.000	3.000	4.000	4.357	6.500	10.000	2.649

Table A.1.d   Summary Statistics for Shipping Times to Guam by DHL and Source of Supply (Calendar Days)

Shipping Times to Bahrain by Carrier

Carrier	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
FedEx	1550	1.000	3.000	3.000	3.79	4.000	19.000	1.820
DHL	1363	1.000	3.000	4.000	40.012	5.000	19.000	2.051

Table A.2.a   Summary Statistics for Shipping Times to Bahrain by Carrier (Calendar Days)

Shipping Times to Bahrain by Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDJC	369	1.000	3.000	4.000	4.369	5.000	19.000	2.570
DDSP	406	1.000	3.000	3.000	3.648	4.000	18.000	1.862
FISC/DDDC	694	1.000	3.000	3.000	3.539	4.000	19.000	1.618
FISC/DDNV	533	1.000	3.000	3.000	3.842	4.000	18.000	1.779
FISC/DDPH	231	1.000	4.000	4.000	4.688	5.000	18.000	1.911
FISC/DDPW	106	1.000	3.000	3.000	3.840	4.000	16.000	2.256
FISC/DDYJ	574	1.000	3.000	4.000	3.932	5.000	16.000	1.794

Table A.2.b   Summary Statistics for Shipping Times to Bahrain by Source of Supply (Calendar Days)

Shipping Times to Bahrain by FedEx and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDJC	79	1.000	3.000	4.000	4.278	4.000	19.000	2.722
DDSP	223	1.000	3.000	3.000	3.538	4.000	13.000	1.488
FISC/DDDC	615	1.000	3.000	3.000	3.498	4.000	19.000	1.573
FISC/DDNV	317	1.000	3.000	3.000	3.855	4.000	18.000	1.887
FISC/DDPH	217	1.000	4.000	4.000	4.645	5.000	18.000	1.917
FISC/DDPW	96	1.000	3.000	3.000	3.708	4.000	12.000	1.952
FISC/DDYJ	3	1.000	2.500	4.000	3.667	5.000	6.000	2.517

Table A.2.c   Summary Statistics for Shipping Times to Bahrain by FedEx and Source of Supply (Calendar Days)

Shipping Times to Bahrain by DHL and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDJC	290	1.000	3.000	4.000	4.393	5.000	19.000	2.531
DDSP	183	1.000	3.000	3.000	3.781	5.000	18.000	2.233
FISC/DDDC	79	1.000	3.000	3.000	3.861	4.000	12.000	1.913
FISC/DDNV	216	1.000	3.000	3.000	3.824	5.000	13.000	1.610
FISC/DDPH	14	4.000	4.000	4.500	5.357	6.750	9.000	1.737
FISC/DDPW	10	2.000	3.000	3.000	5.100	5.750	16.000	4.149
FISC/DDYJ	571	1.000	3.000	4.000	3.933	5.000	16.000	1.793

Table A.2.d   Summary Statistics for Shipping Times to Bahrain by DHL and Source of Supply (Calendar Days)

Shipping Times to Singapore by Carrier

Carrier	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
FedEx	1054	1.000	3.000	3.000	4.199	5.000	18.000	2.365
DHL	592	1.000	2.000	3.000	3.976	5.000	19.000	2.707

Table A.3.a   Summary Statistics for Shipping Times to Singapore by Carrier (Calendar Days)

Shipping Times to Singapore by Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	15	3.000	3.000	4.000	5.000	5.500	13.000	2.903
DDCO	16	1.000	3.000	4.000	3.500	4.000	6.000	1.366
DDJC	293	1.000	3.000	4.000	4.676	5.000	18.000	2.742
DDRV	83	1.000	3.000	3.000	3.961	5.000	12.000	1.858
DDSP	180	1.000	3.000	3.000	4.267	5.000	18.000	2.599
FISC CHEATHAM	4	3.000	3.750	4.500	6.750	7.500	15.000	5.560
FISC/DDDC	334	1.000	3.000	3.000	3.964	4.000	18.000	1.890
FISC/DDJF	25	1.000	3.000	3.000	3.960	5.000	8.000	1.947
FISC/DDNV	182	1.000	3.000	4.000	5.110	5.000	17.000	2.958
FISC/DDPH	166	1.000	3.000	4.000	4.151	5.000	15.000	1.883
FISC/DDYJ	348	1.000	1.000	3.000	3.193	4.000	19.000	2.536

Table A.3.b   Summary Statistics for Shipping Times to Singapore by Source of Supply (Calendar Days)

Shipping Times to Singapore by FedEx and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	11	3.000	3.500	5.000	5.636	6.000	13.000	3.171
DDCO	12	1.000	2.750	3.000	3.250	4.000	6.000	1.485
DDJC	157	1.000	3.000	4.000	4.510	5.000	17.000	2.908
DDRV	78	1.000	3.000	3.000	3.974	5.000	12.000	1.851
DDSP	137	1.000	3.000	3.000	3.956	4.000	18.000	2.520
FISC CHEATHAM	2	3.000	3.500	4.000	4.000	4.500	5.000	1.414
FISC/DDDC	332	1.000	3.000	3.000	3.964	4.000	18.000	1.896
FISC/DDJF	23	1.000	3.000	3.000	4.000	5.500	8.000	2.023
FISC/DDNV	144	1.000	3.000	4.000	4.938	5.000	17.000	3.041
FISC/DDPH	153	1.000	3.000	3.000	4.072	5.000	15.000	1.882
FISC/DDYJ	5	1.000	3.000	3.000	3.000	4.000	4.000	1.225

Table A.3.c   Summary Statistics for Shipping Times to Singapore by FedEx and Source of Supply (Calendar Days)

Shipping Times to Singapore by DHL and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	4	3.000	3.000	3.000	3.250	3.250	4.000	0.500
DDCO	4	4.000	4.000	4.000	4.250	4.250	5.000	0.500
DDJC	136	1.000	3.000	4.500	4.868	6.000	18.000	2.535
DDRV	5	3.000	3.000	3.000	4.200	4.000	8.000	2.168
DDSP	43	2.000	3.000	5.000	5.256	6.000	16.000	2.629
FISC CHEATHAM	2	4.000	6.750	9.500	9.500	12.250	15.000	7.778
FISC/DDDC	2	4.000	4.000	4.000	4.000	4.000	4.000	0.000
FISC/DDJF	2	3.000	3.250	3.500	3.500	3.750	4.000	0.707
FISC/DDNV	38	3.000	4.000	5.000	5.763	7.750	13.000	2.551
FISC/DDPH	13	4.000	4.000	5.000	5.077	5.000	10.000	1.706
FISC/DDYJ	343	1.000	1.000	3.000	3.195	4.000	19.000	2.551

Table A.3.d   Summary Statistics for Shipping Times to Singapore by DHL and Source of Supply (Calendar Days)

Shipping Times to Okinawa by Carrier

Carrier	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
FedEx	118	1.000	3.000	5.000	5.246	7.000	17.000	3.105
DHL	95	1.000	3.000	4.000	4.863	6.000	16.000	2.616

Table A.4.a   Summary Statistics for Shipping Times to Okinawa by Carrier (Calendar Days)

Shipping Times to Okinawa by Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDJC	72	1.000	3.000	4.000	4.861	6.000	16.000	2.718
DDRV	30	1.000	3.000	4.000	4.933	6.000	16.000	3.383
DDSP	57	1.000	3.000	5.000	5.018	7.000	17.000	2.850
FISC/DDNV	54	1.000	4.000	5.000	5.500	7.000	15.000	2.925

Table A.4.b   Summary Statistics for Shipping Times to Okinawa by Source of Supply (Calendar Days)

Shipping Times to Okinawa by FedEx and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDJC	37	1.000	3.000	5.000	5.189	6.000	15.000	2.623
DDRV	6	1.000	1.500	4.000	6.000	8.750	16.000	5.933
DDSP	33	1.000	3.000	5.000	4.970	6.000	17.000	3.235
FISC/DDNV	42	1.000	4.000	5.000	5.405	7.000	15.000	2.972

Table A.4.c   Summary Statistics for Shipping Times to Okinawa by FedEx and Source of Supply (Calendar Days)

Shipping Times to Okinawa by DHL and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDJC	35	1.000	3.000	3.000	4.514	5.500	16.000	2.811
DDRV	24	1.000	3.000	4.000	4.667	6.000	12.000	2.531
DDSP	24	1.000	3.000	5.000	5.083	7.000	9.000	2.283
FISC/DDNV	12	2.000	4.000	5.000	5.833	6.500	11.000	2.855

Table A.4.d   Summary Statistics for Shipping Times to Okinawa by DHL and Source of Supply (Calendar Days)

Shipping Times to Sasebo by Carrier

Carrier	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
FedEx	779	1.000	3.000	5.000	5.293	6.000	19.000	2.753
DHL	334	1.000	4.000	5.000	5.177	6.000	19.000	2.260

Table A.5.a   Summary Statistics for Shipping Times to Sasebo by Carrier (Calendar Days)

Shipping Times to Sasebo by Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	22	2.000	4.000	5.000	5.273	6.000	11.000	2.334
DDCO	30	1.000	3.000	4.000	4.582	5.000	7.000	1.285
DDJC	250	1.000	4.000	5.000	5.488	6.000	19.000	2.688
DDRV	93	1.000	4.000	5.000	5.751	6.000	19.000	3.121
DDSP	190	1.000	3.000	5.000	4.979	6.000	17.000	2.443
FISC/DDDC	200	2.000	4.000	5.000	5.410	6.000	18.000	2.679
FISC/DDJF	10	1.000	3.000	4.000	5.580	6.250	13.000	4.033
FISC/DDNV	151	1.000	4.000	5.000	5.503	6.500	16.000	2.492
FISC/DDPH	138	1.000	3.000	4.000	4.043	5.000	17.000	2.337
NSY PORTSMOUTH	18	2.000	4.000	4.500	4.778	5.750	10.000	1.734

Table A.5.b   Summary Statistics for Shipping Times to Sasebo by Source of Supply (Calendar Days)

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Shipping Times to Sasebo by FedEx and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	20	2.000	3.750	5.000	5.250	6.000	11.000	2.447
DDCO	29	1.000	3.000	4.000	3.931	5.000	7.000	1.307
DDJC	127	1.000	4.000	5.000	5.843	7.000	19.000	3.279
DDRV	10	1.000	5.500	7.500	7.600	9.000	14.000	4.326
DDSP	110	1.000	4.000	5.000	5.073	5.750	17.000	2.601
FISC/DDDC	197	2.000	4.000	5.000	5.406	6.000	18.000	2.695
FISC/DDJF	9	1.000	3.000	4.000	5.222	4.000	13.000	4.236
FISC/DDNV	124	1.000	4.000	5.000	5.468	7.000	16.000	2.545
FISC/DDPH	132	1.000	3.000	4.000	4.697	5.000	17.000	2.370
NSY PORTSMOUTH	14	2.000	4.000	5.000	4.929	5.750	10.000	1.859

Table A.5.c   Summary Statistics for Shipping Times to Sasebo by FedEx and Source of Supply (Calendar Days)

Shipping Times to Sasebo by DHL and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	2	5.000	5.250	5.500	5.500	5.750	6.000	0.707
DDCO	1	4.000	4.000	4.000	4.000	4.000	4.000	0.000
DDJC	123	1.000	4.000	5.000	5.122	6.000	14.000	1.836
DDRV	83	1.000	4.000	5.000	5.458	6.000	19.000	2.894
DDSP	80	1.000	3.000	5.000	4.850	6.000	13.000	2.217
FISC/DDDC	3	4.000	5.000	6.000	5.667	6.500	7.000	1.528
FISC/DDJF	1	7.000	7.000	7.000	7.000	7.000	7.000	0.000
FISC/DDNV	27	3.000	4.500	5.000	5.667	6.000	15.000	2.270
FISC/DDPH	6	3.000	3.250	4.000	4.333	4.750	7.000	1.506
NSY PORTSMOUTH	4	3.000	3.750	4.000	4.250	4.500	6.000	1.258

Table A.5.d   Summary Statistics for Shipping Times to Sasebo by DHL and Source of Supply (Calendar Days)

Shipping Times to Yokosuka by Carrier

Carrier	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
FedEx	2652	1.000	3.000	4.000	4.302	5.000	19.000	2.085
DHL	1811	1.000	3.000	4.000	4.118	5.000	19.000	1.949

Table A.6.a   Summary Statistics for Shipping Times to Yokosuka by Carrier (Calendar Days)

Shipping Times to Yokosuka by Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	29	3.000	3.000	4.000	4.552	6.000	9.000	1.617
DDCO	93	1.000	3.000	4.000	4.301	5.000	12.000	1.731
DDJC	1123	1.000	3.000	4.000	4.214	5.000	19.000	2.022
DDRV	184	1.000	3.000	3.500	4.158	5.000	15.000	2.366
DDSP	580	1.000	3.000	4.000	4.079	5.000	19.000	1.898
FISC CHEATHAM	26	1.000	3.000	4.000	4.269	6.000	6.000	1.733
FISC/DDDC	771	1.000	3.000	4.000	4.149	5.000	18.000	1.648
FISC/DDJF	55	1.000	3.000	4.000	4.691	5.000	16.000	2.638
FISC/DDNV	577	1.000	3.000	4.000	4.678	6.000	18.000	2.543
FISC/DDPH	566	1.000	3.000	4.000	3.993	5.000	15.000	1.601
FISC/DDPW	271	1.000	3.000	4.000	4.173	5.000	16.000	2.181
NSY PORTSMOUTH	66	1.000	3.000	4.000	4.333	5.000	13.000	2.633

Table A.6.b   Summary Statistics for Shipping Times to Yokosuka by Source of Supply (Calendar Days)

Shipping Times to Yokosuka by FedEx and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	10	3.000	3.000	5.000	4.950	6.000	9.000	1.731
DDCO	20	1.000	3.000	4.000	4.357	6.000	12.000	1.774
DDJC	84	1.000	3.000	5.000	4.736	6.000	19.000	2.157
DDRV	333	1.000	3.000	4.000	5.056	6.000	13.000	3.226
DDSP	18	1.000	3.000	4.000	4.000	5.000	19.000	2.054
FISC CHEATHAM	237	1.000	3.000	3.500	3.500	4.000	6.000	1.434
FISC/DDDC	717	1.000	3.000	4.000	4.123	5.000	18.000	1.558
FISC/DDJF	38	1.000	3.000	4.000	4.842	5.750	16.000	3.000
FISC/DDNV	352	1.000	3.000	5.000	5.014	6.000	18.000	2.822
FISC/DDPH	473	1.000	3.000	4.000	3.928	5.000	15.000	1.618
FISC/DDPW	210	1.000	3.000	4.000	3.966	5.000	11.000	1.881
NSY PORTSMOUTH	47	1.000	3.000	4.000	4.447	5.000	13.000	2.273

Table A.6.c   Summary Statistics for Shipping Times to Yokosuka by FedEx and Source of Supply (Calendar Days)

Shipping Times to Yokosuka by DHL and Source of Supply

Source of Supply	Observations	Min	1st Qu.	Median	Mean	3rd Qu.	Max	Std Deviation
DDBC	16	3.000	3.000	3.000	3.667	4.000	5.000	0.866
DDCO	9	2.000	3.000	4.000	3.778	4.000	6.000	1.202
DDJC	9	1.000	3.000	4.000	3.994	5.000	19.000	1.922
DDRV	790	1.000	3.000	3.000	4.060	5.000	15.000	2.245
DDSP	166	1.000	3.000	4.000	4.134	5.000	15.000	1.783
FISC CHEATHAM	343	1.000	3.000	6.000	4.750	6.000	6.000	1.770
FISC/DDDC	54	1.000	3.000	4.000	4.500	5.000	16.000	2.561
FISC/DDJF	17	2.000	3.000	4.000	4.353	5.000	8.000	1.579
FISC/DDNV	225	1.000	3.000	4.000	4.151	5.000	17.000	1.921
FISC/DDPH	93	1.000	3.000	4.000	4.323	5.000	11.000	1.476
FISC/DDPW	61	2.000	3.000	4.000	4.746	7.000	7.000	1.748
NSY PORTSMOUTH	19	1.000	3.000	3.000	4.053	4.000	13.000	3.423

Table A.6.d   Summary Statistics for Shipping Times to Yokosuka by DHL and Source of Supply (Calendar Days)

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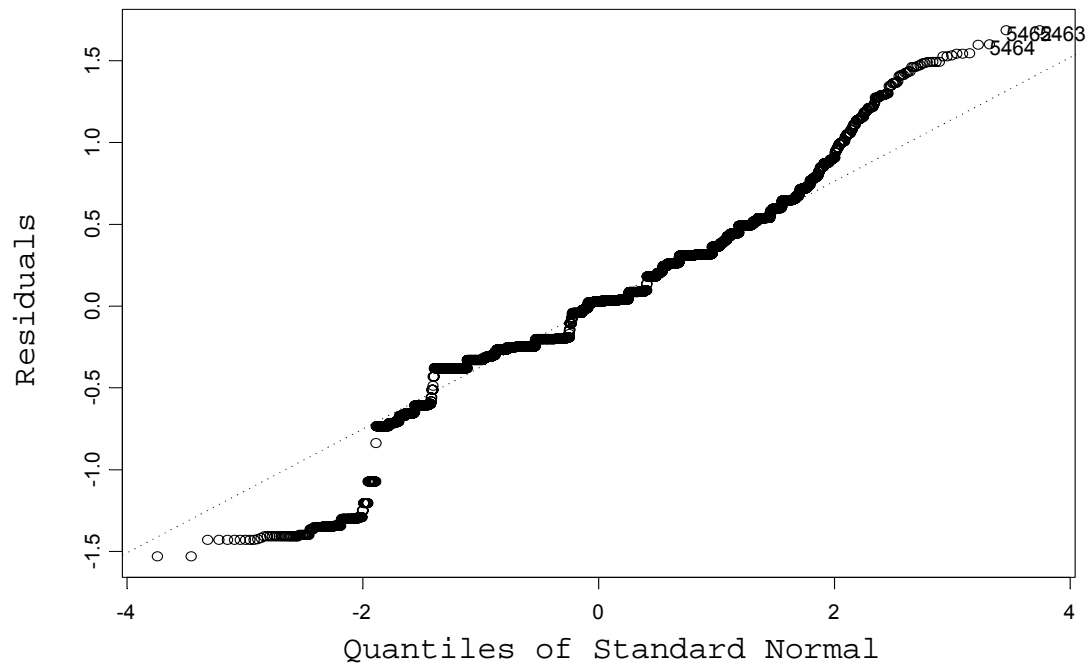
Figure B.1.   Quantile-Normal Plot of Residuals for Full Linear Model of Guam Shipping Times
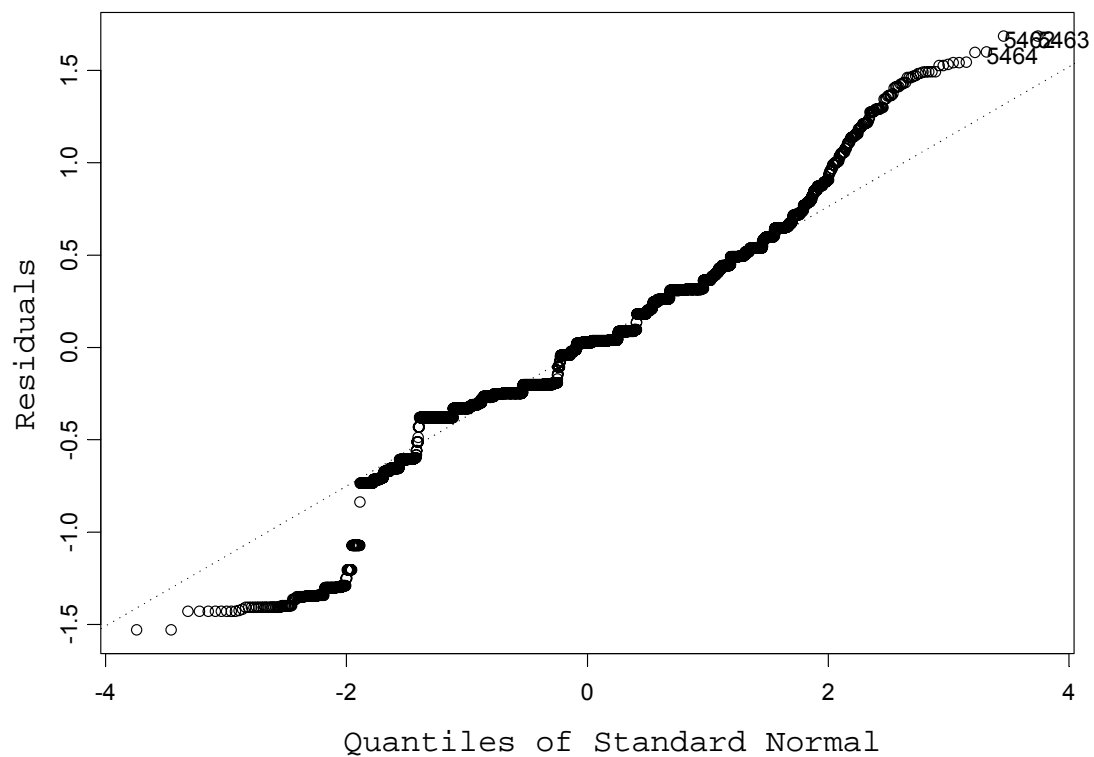
Figure B.2.   Quantile-Normal Plot of Residuals for Full
Linear Model of Bahrain Shipping Times
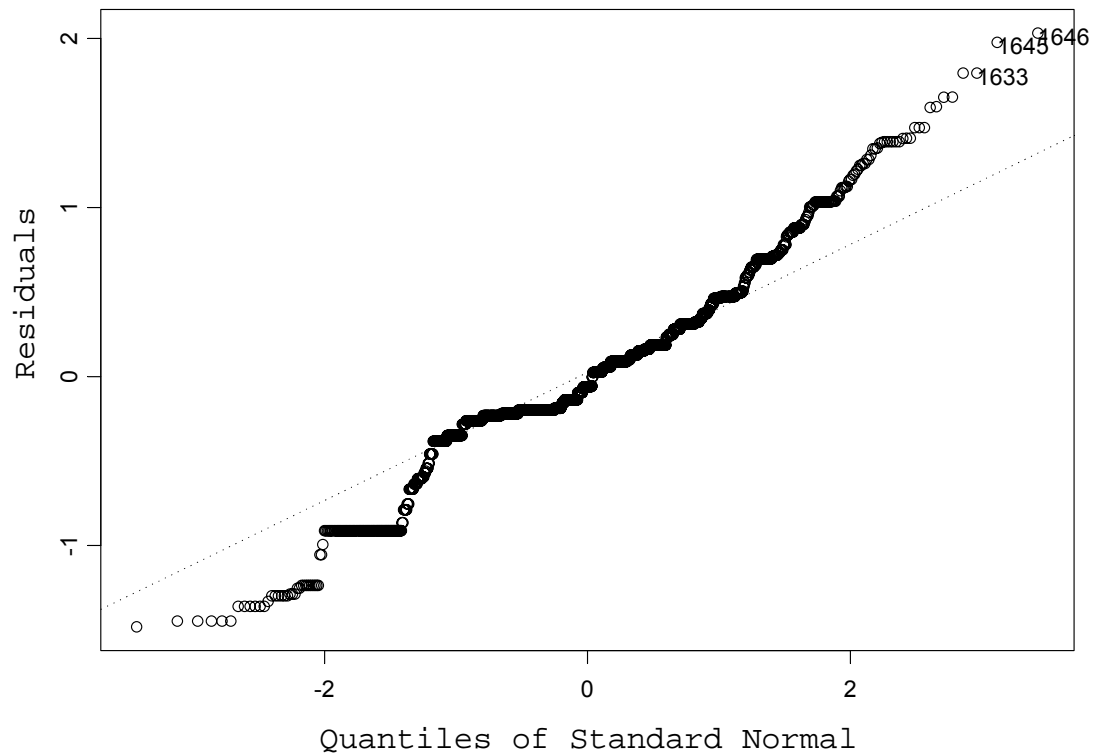
Figure B.3.   Quantile-Normal Plot of Residuals for Full
        Linear Model of Singapore Shipping Times
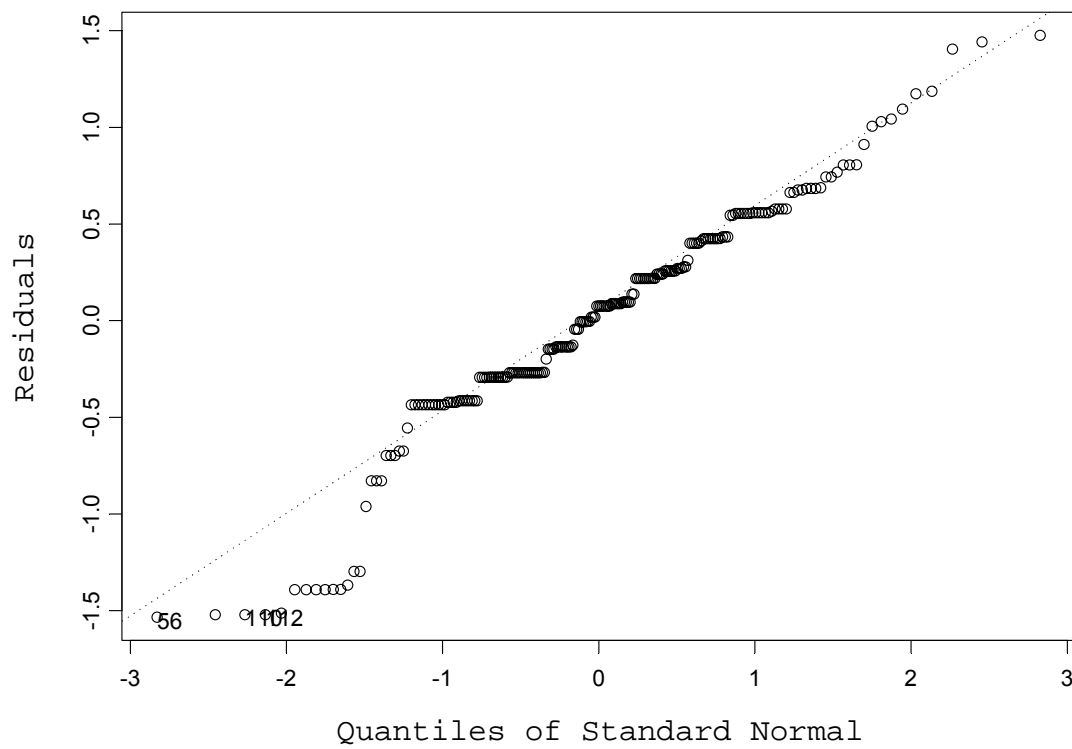
Figure B.4.   Quantile-Normal Plot of Residuals for Full
              Linear Model of Okinawa Shipping Times
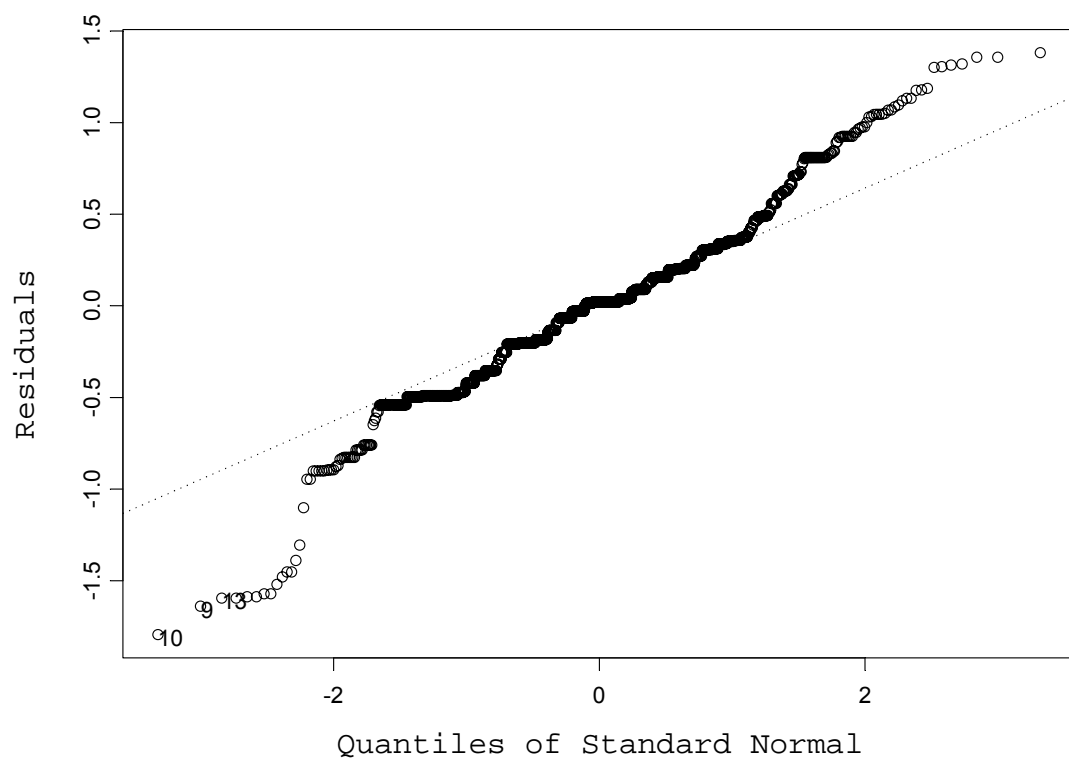
Figure B.5.   Quantile-Normal Plot of Residuals for Full
Linear Model of Sasebo Shipping Times
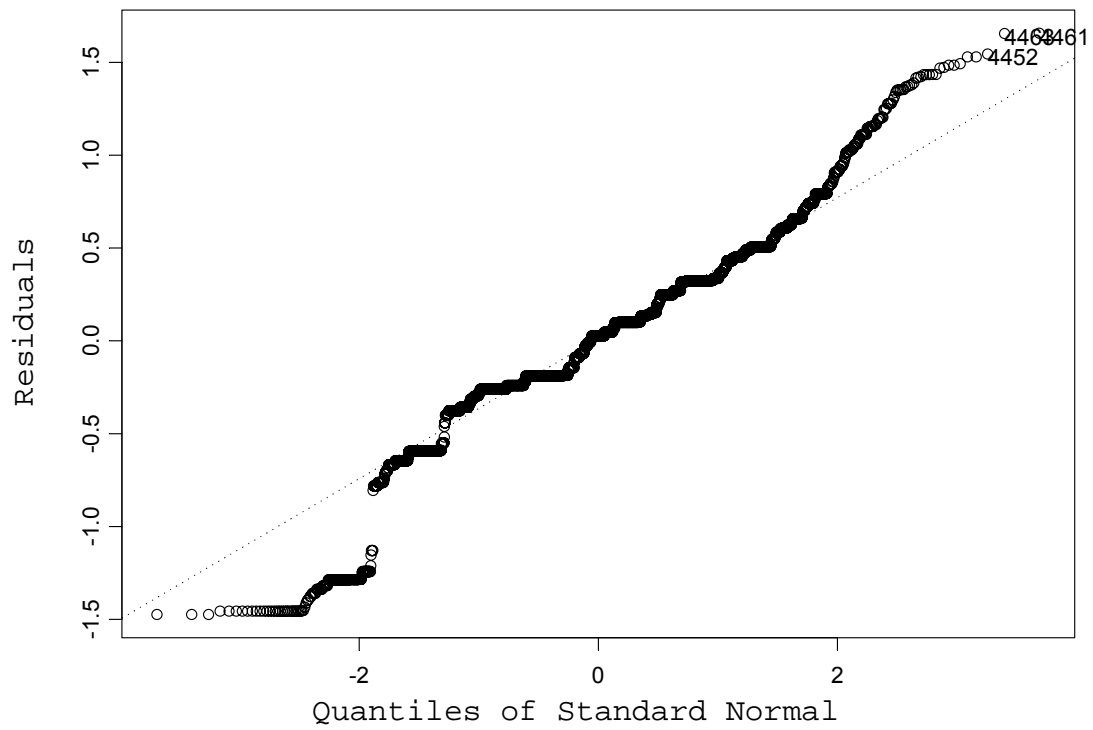
Figure B.6.   Quantile-Normal Plot of Residuals for Full
Linear Model of Yokosuka Shipping Times

APPENDIX C.   GLM DEVIANCE RESIDUAL PLOTS
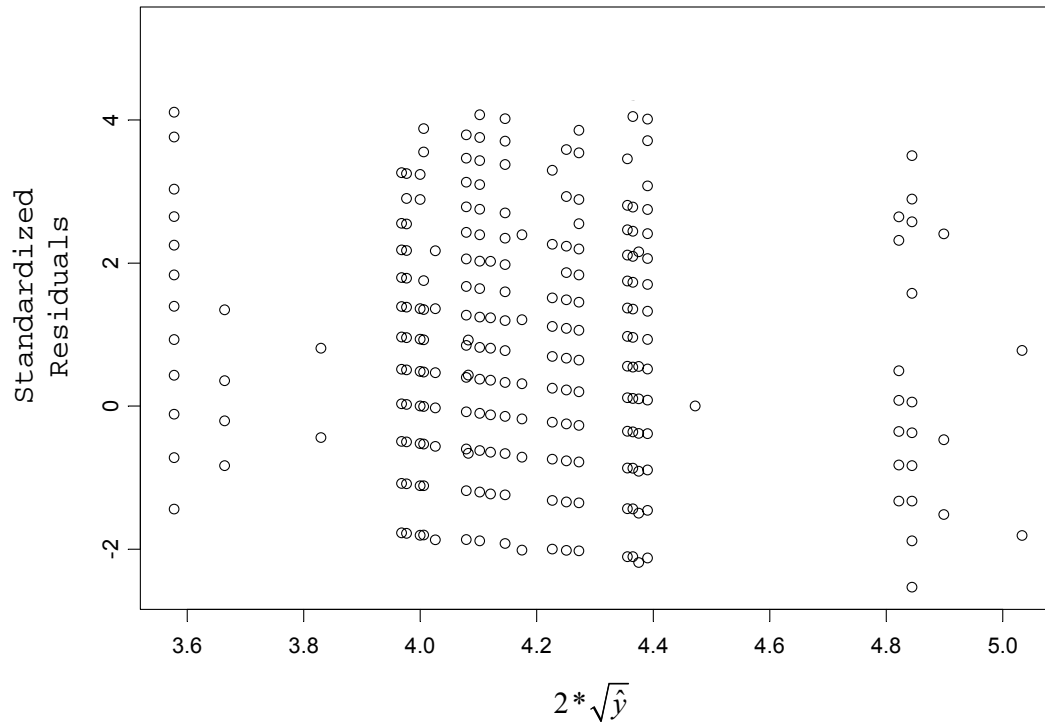
Figure C.1.a   Standardized Deviance Residuals Versus
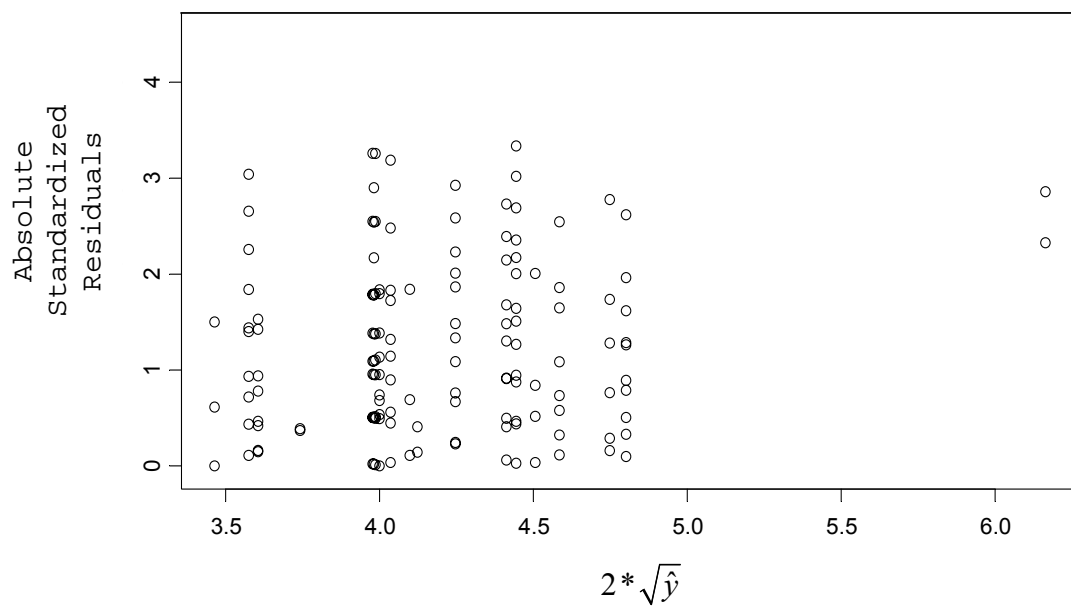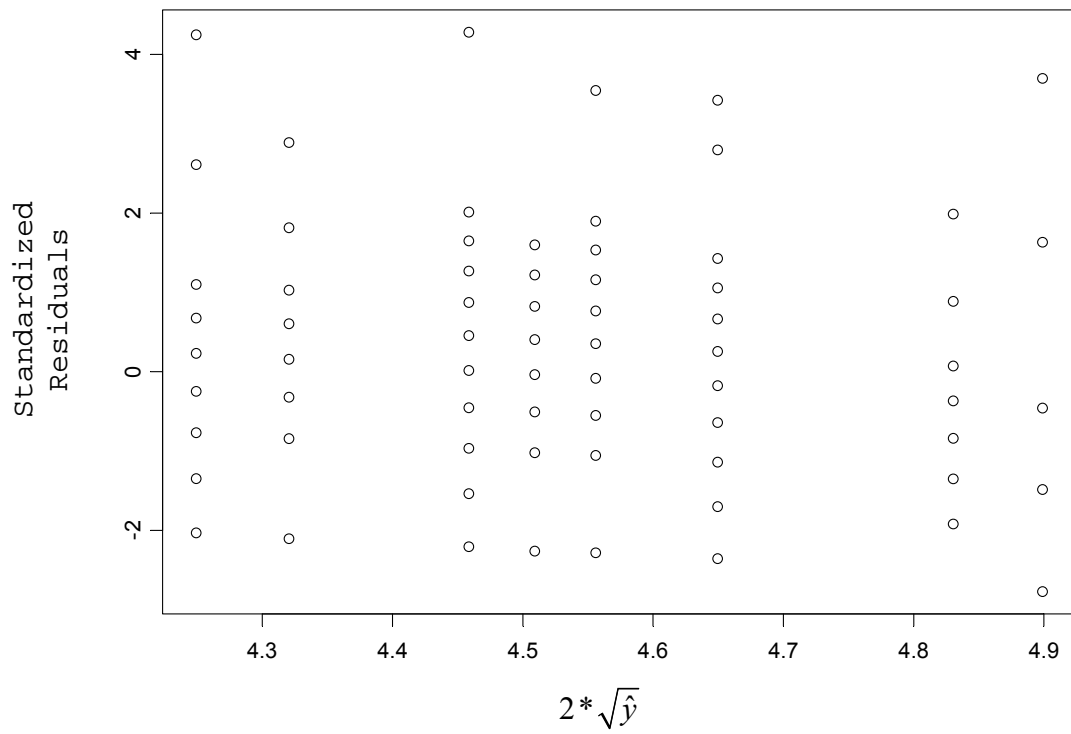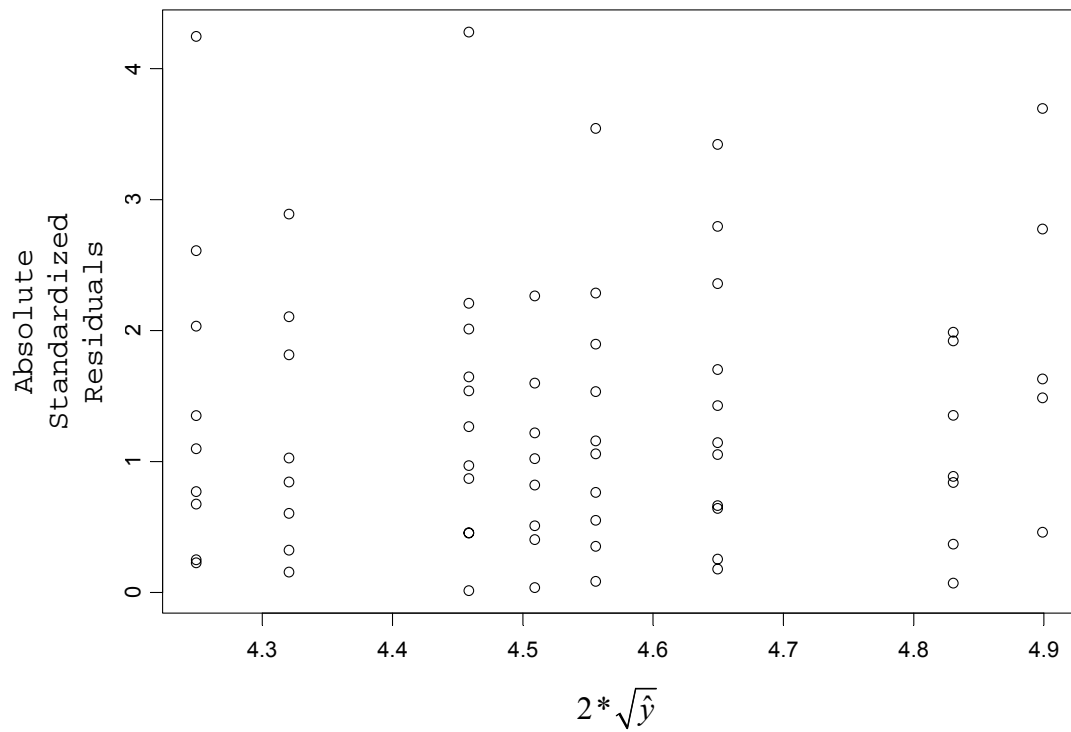Fitted Values (constant-information scale) for Guam
Poisson GLM
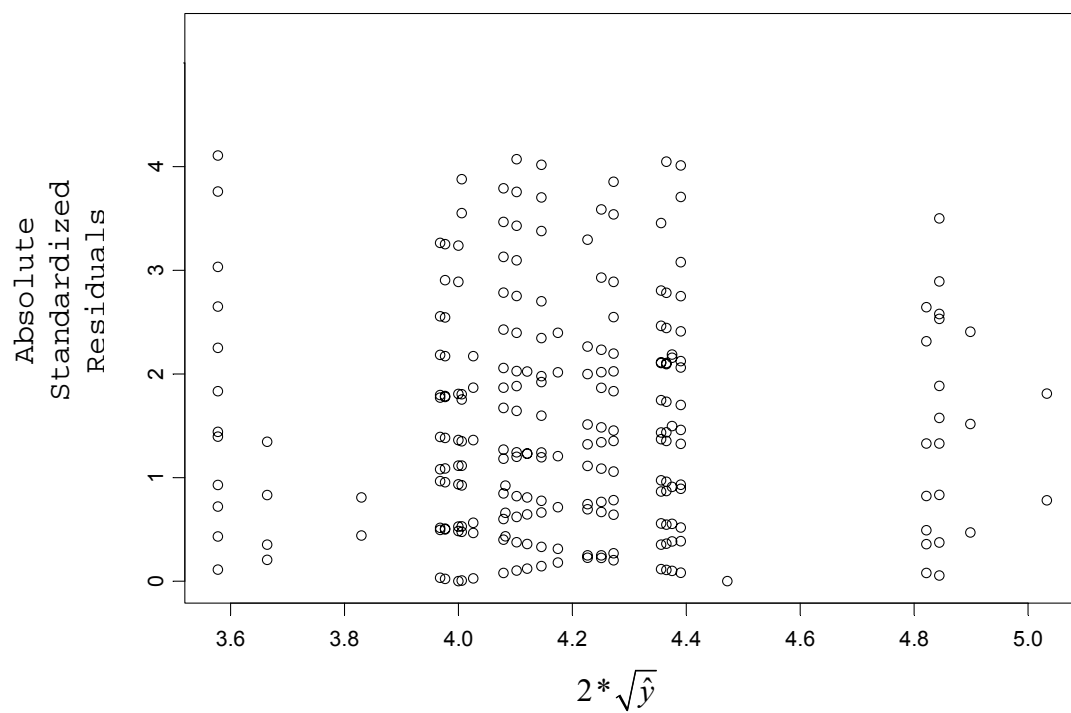
Figure C.1.b   Absolute Standardized Deviance Residuals
Versus Fitted Values (constant-information scale) for Guam
Poisson GLM
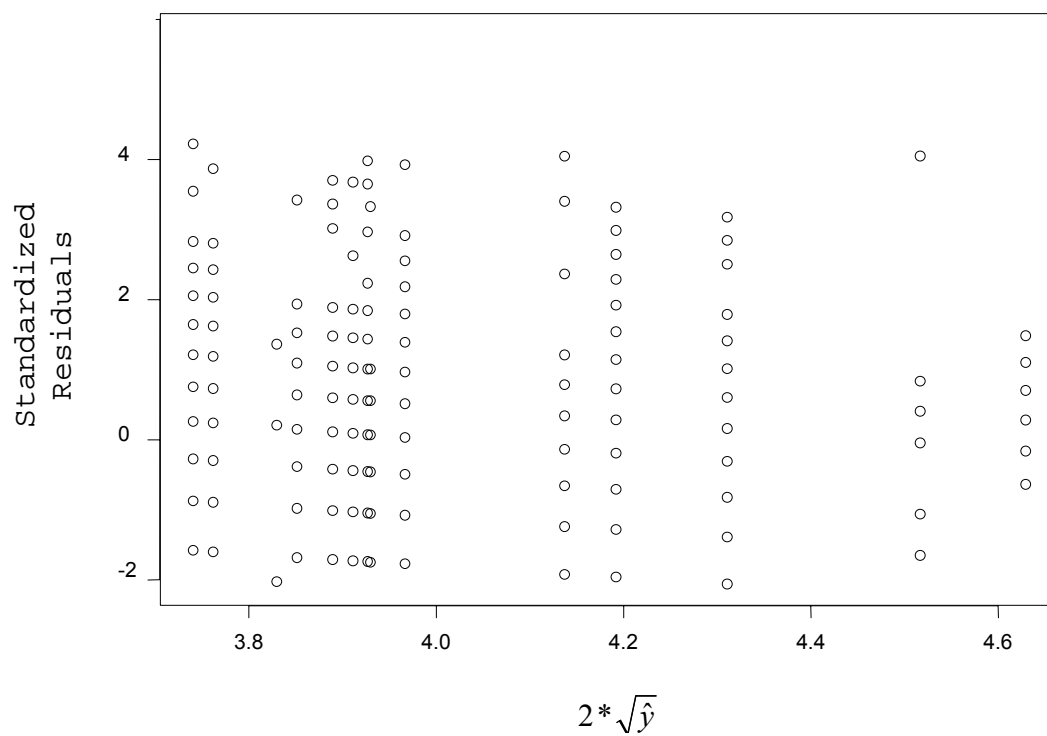
Figure C.2.a   Standardized Deviance Residuals Versus
Fitted Values (constant-information scale) for Bahrain
Poisson GLM
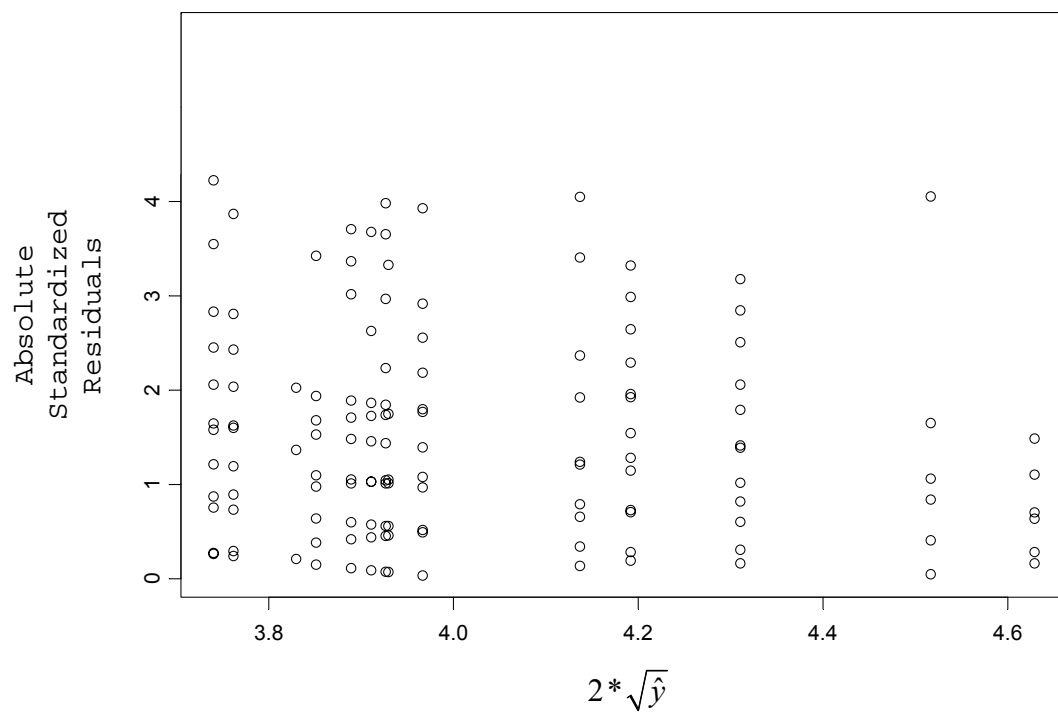
Figure C.2.b Absolute Standardized Deviance Residuals
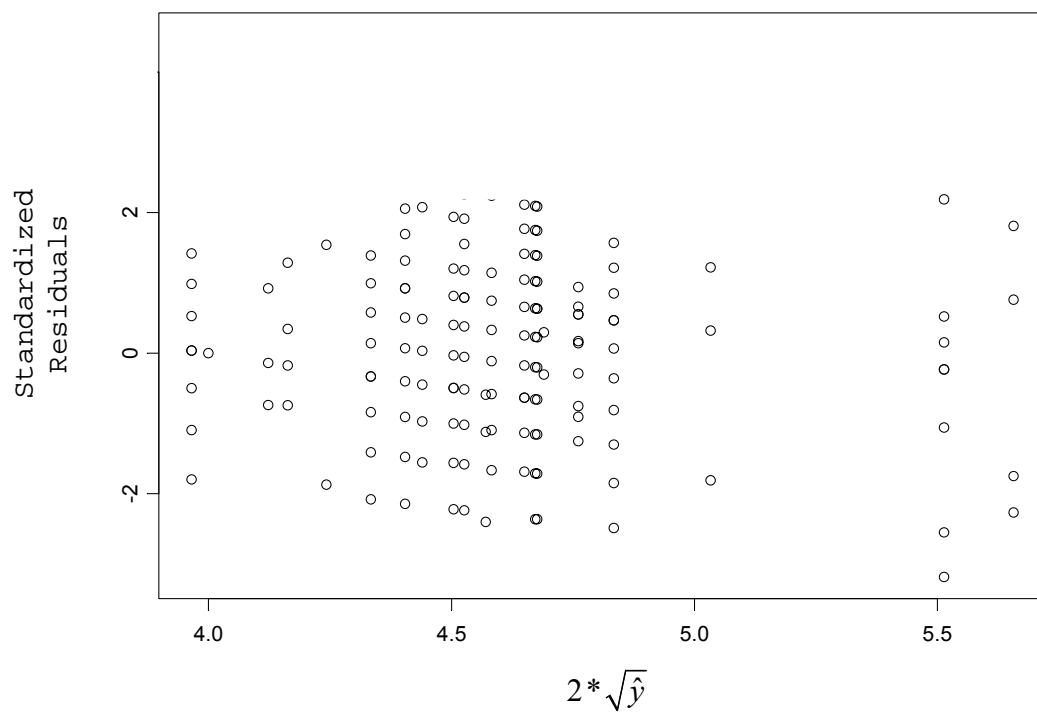Versus Fitted Values (constant-information scale) for
Bahrain Poisson GLM
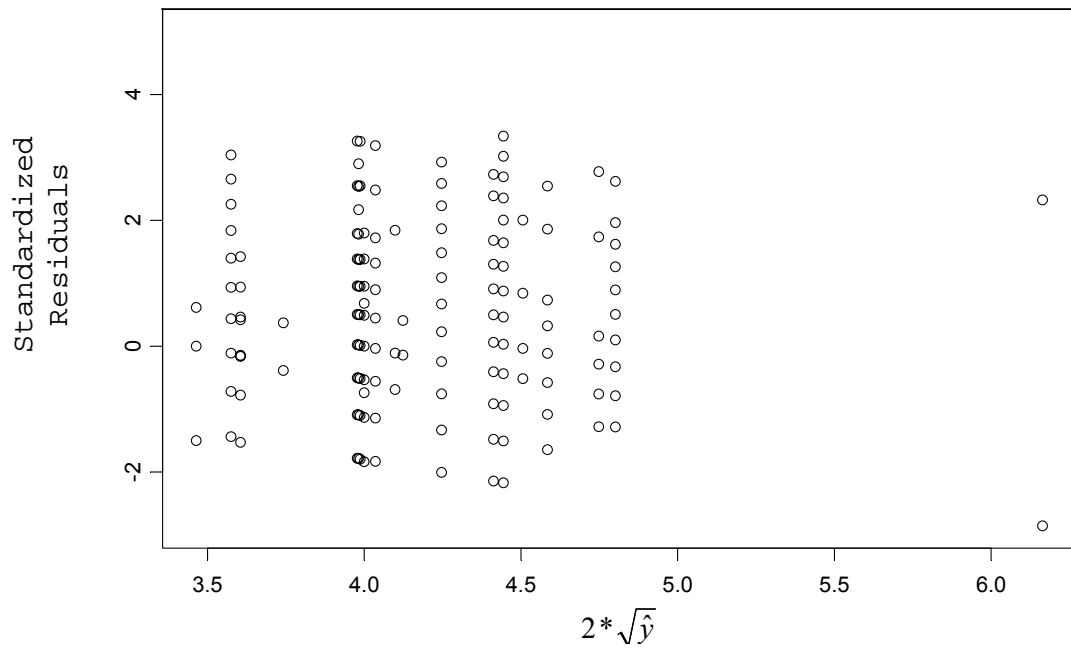
Figure C.3.a   Standardized Deviance Residuals Versus
Fitted Values (constant-information scale) for Singapore
Poisson GLM

Figure C.3.b   Absolute Standardized Deviance Residuals
Versus Fitted Values (constant-information scale) for
Singapore Poisson GLM

Figure C.4.a   Standardized Deviance Residuals Versus
Fitted Values (constant-information scale) for Okinawa
Poisson GLM

Figure C.4.b   Absolute Standardized Deviance Residuals
Versus Fitted Values (constant-information scale) for
Okinawa Poisson GLM

Figure C.5.a   Standardized Deviance Residuals Versus
Fitted Values (constant-information scale) for Sasebo
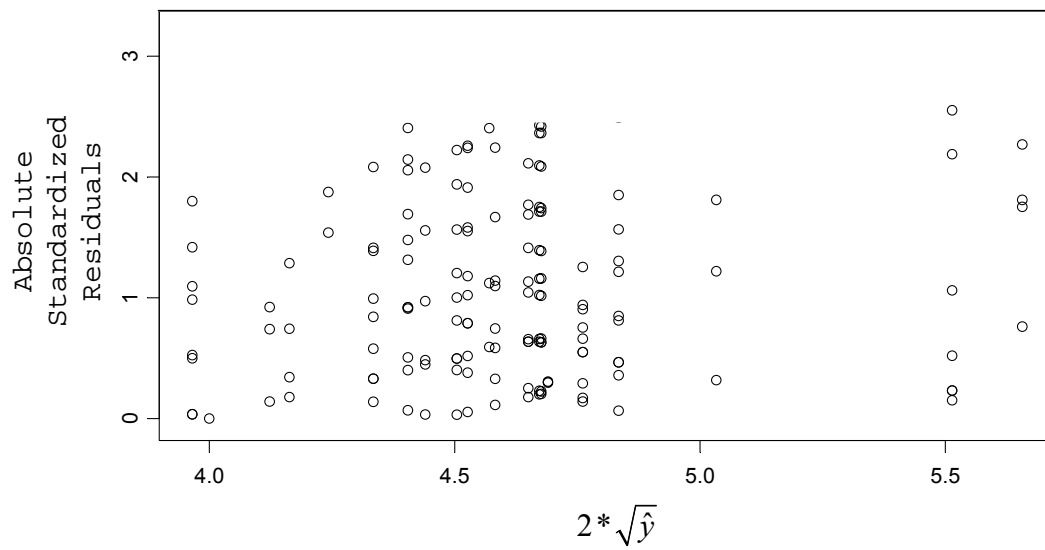Poisson GLM

Figure C.5.b   Absolute Standardized Deviance Residuals
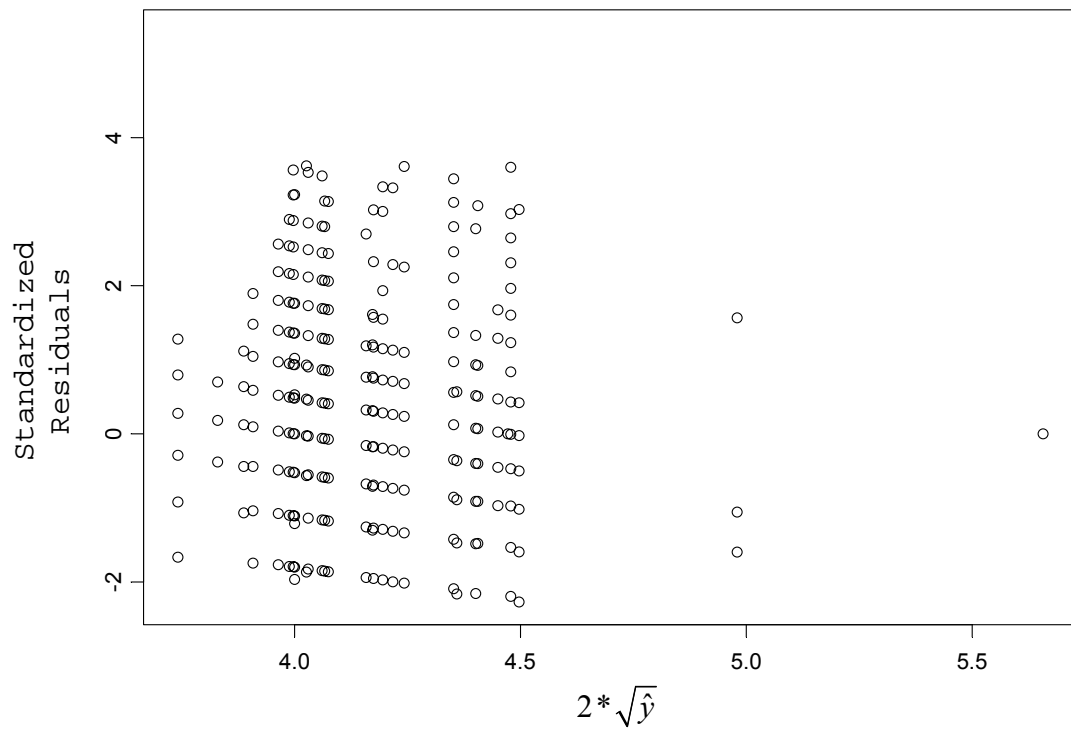Versus Fitted Values (constant-information scale) for
Sasebo Poisson GLM

Figure C.6.a   Standardized Deviance Residuals Versus
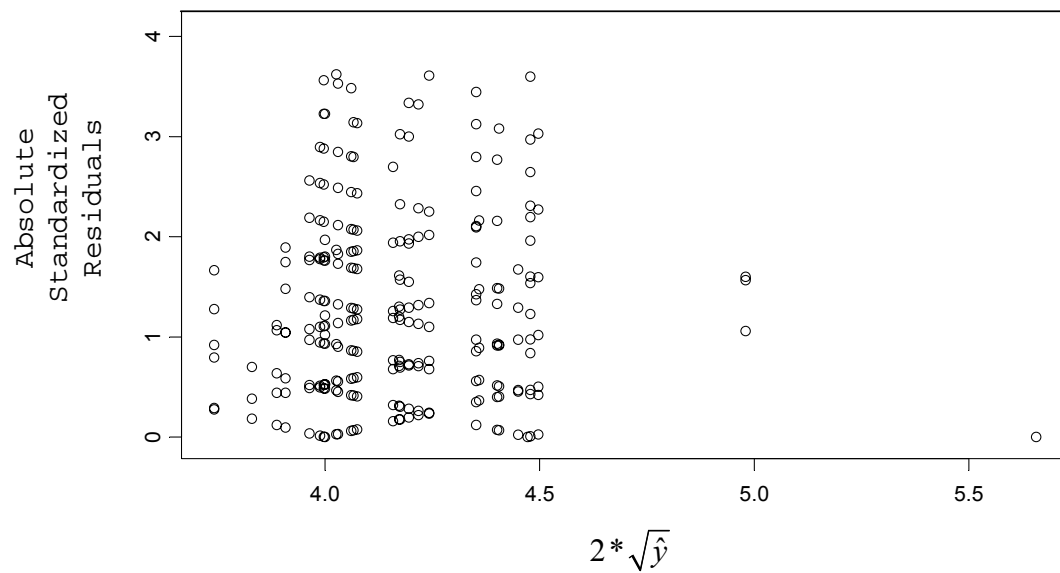Fitted Values (constant-information scale) for Yokosuka
Poisson GLM

Figure C.6.b   Absolute Standardized Deviance Residuals
Versus Fitted Values (constant-information scale) for
Yokosuka Poisson GLM

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