INSTITUTO TECNOLÓGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

CAMPUS MONTERREY
DIVISIÓN DE INGENIERÍA Y ARQUITECTURA
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Study of current air cargo infrastructure in Mexico: Current strategic needs for air transportation activities, operational performance and national airport infrastructure

TESIS

PRESENTADA COMO REQUISITO PARCIAL PARA OBTENER EL GRADO ACADÉMICO DE:

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ESPECIALIDAD EN SISTEMAS DE CALIDAD Y PRODUCTIVIDAD

POR:
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Los miembros del comité de tesis recomendamos que el presente proyecto de tesis presentado por el Ing. Luis Armando Treviño Ortiz sea aceptado como requisito parcial para obtener el grado académico de:

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A Dios, que me ha guiado y brindado su luz en cada paso de mi camino

A mis padres, Roberto y Graciela, por darme la oportunidad de vivir... los amo con todo mi corazón

A mis hermanas Mónica, Graciela y mis sobrinos Paola y Marco… las mejores hermanas del mundo y que me apoyaron en todo momento

A ti mi amor… Karina, por haber cambiado mi vida y por brindarme tu amor sin límites

A mis amigos y maestros que me han apoyado con sus consejos y sus enseñanzas

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Study of current Air Cargo infrastructure in Mexico: Current strategic needs for transportation activities, operational performance and national airport infrastructure

ABSTRACT: *This study tries to remark the importance of air cargo operations for national competitiveness and to illustrate the current operational issues related to air cargo industry in Mexico. Infrastructure and operation activities of the Mexican Air Cargo Industry will be shown followed by a descriptive analysis of current air cargo operational performance developed by the national airports system. A set of conclusions about current operational features and future strategic needs for this industry are given at the end of this study, emphasizing the future challenges for air cargo industry in Mexico*

1. EXECUTIVE SUMMARY

This study attempts to determine characteristics, components and functioning relations that could affect the operative of the Mexican air cargo industry. The conceptual structure for this analysis is based on modeling techniques and geographical description of cargo activities in Mexico.

The content of this work includes an analysis of current situation of air cargo industry in Mexico, based initially on a brief description of actual perspective of cargo worldwide, an historical analysis of air cargo industry development in Mexico and identifying the existing infrastructure as well as main carriers that perform air cargo activities national and internationally. This analysis is based on governmental statistics related to the transported freight by different classes of airlines and services operating in Mexico as well as the amounts of cargo sent and received by the national airport system.

Some concise conclusions about the initial analysis mentioned above are related to the centralization of cargo operations in Mexico City Intl Airport and the lack of homogeneity in cargo movements between Mexican Airports based mainly on infrastructure and current airport allocation.

Therefore, using the descriptive analysis mentioned before and lead by the intention to find a quantitative tool that could lead to predict the behavior of cargo movement in Mexico, some mathematical models were generated based on multiple regression analysis and initially deployed with last year's origin-destination freight flows (national and international flights). The most important links and nodes that integrate the domestic and international air transportation network were identified and several variables were chosen in order to be added into the model.

With this scheme, two numerical representations were constructed in order to describe the generation and attraction of cargo existed among the national air cargo nodes using available information for the total generation and attraction of cargo registered during 2004. The variables chosen for being incorporated to the model were, as dependent variable, the generated and received freight by every node, and as independent variables, the mean traveled distance between nodes as well as manufacturing, transportation and warehousing industries established in each metropolitan area where each node is located. The results shown by this analysis provide a significant R square value based on the capability of the model to relate the independent and dependent variables selected. Final results of both models give a good fit of the data used to construct the models, indicating that they could be used for predicting the performance of cargo flows generated by the terminals and possible changes of the independent variables.

The main intention or objective of this numerical analysis is to provide useful information for any decision unit implicated on cargo activities in order to describe and understand cargo operations based on the activities and/or behavior of the independent variables chosen for this analysis. Hence, it could lead to support important managerial decisions for air cargo service providers, aiding to analyze possible investments as well as stimulate the development of cargo operations on diverse regions of Mexico by the national government that could lead to facilitate the mobility of cargo along and outside the country. An important issue to mention is that this study is well known as a cross-sectional study; this concept means that the data utilized for model development considered just a particular behavior of the system (in this case the 2004 domestic air cargo behavior). Hence, the results obtained by this model describe the performance of the air cargo system according to the input parameters used at this time.

2. INTRODUCTION

Actual situation of worldwide transportation services is derived from a natural mature process that has been provoked from globalization trends, economical integration, technological and industrial improvements and mainly for the continuously searching of competitive advantages that lead to assure to all users of different transportation modes to have world-class services that satisfy flexibility and permanent opportunities. The enormous volume of high-value, time-critical products traversing international boundaries by air annually has resulted in air cargo accounting for 40 percent of today's world trade value. With the substantial role that air cargo has played in these days, generating trade and manufacturing competitiveness, this industry is increasingly viewed as an important indicator for any national economy (Kasarda & Green, 2004).

Depending on the product that needs to be moved, air transportation could have more advantages and achieve better results comparing to other transportation modes, not only in decreasing transit time but also incurring in lesser direct cost for the users. In that context, air transportation companies started to implement diverse strategies looking to preserve and gain more clients, maintaining high-profit levels (Richkarday et al, 1992).

Also, in order to gain competitive advantage through speedy global supply chain connectivity that air cargo provides, high-tech manufacturers and other time-critical shippers are locating at sites around or accessible to major airports, driving substantial investment in airport regions and nations as a whole. Since jobs in time-critical industries tend to be higher paying than country averages therefore, raising the income levels of the population, as well.

Air freight transportation is progressively becoming an important source of revenue for the air transportation services industry (US Department of Transportation, 2003). Cargo revenue represents, on average, 15% of total traffic revenue with some airlines aiming to earn well over half of their revenue from this source (Boeing, 2004).

From Mexican perspective, since the North American Free Trade Agreement (NAFTA) entered into force on January 1st, 1994, the strategic influence of air cargo industry has been growth in a significant manner. Flexibility and speediness are strengths that have made cargo transportation an indispensable sector for business creation as well as domestic and international trade mode for high-economical value merchandises (Secretariat of Communications and Transportation, 2001). In overall terms, Mexico quadrupled its exports during the period of 1990 to 2000, from 41 billion dollars to 166 billion dollars, converting itself into the eight largest exporter in the world and the first among Latin American countries (Reforma, 2001).

Mexican Air Cargo industry has been developing lately; however in past years, main national carriers for domestic air cargo have been regular passenger airlines for which cargo services is an additional but not a main product. Referring to this condition, common practices for national cargo carriers were to handle cargo in baggage compartments of commercial airlines; consequently, the development of this sector was constrained mostly by the low amount of cargo transported by air comparing to other transportation means as well as the lack of aware from national airlines to provide, incentive and develop additional services. Nowadays, this situation begins to be reversed in where exclusive Mexican air cargo carriers began to perform this type of services. But in the other hand, it is important to remark that mostly of the cargo transported by air in Mexico goes abroad and the concentration of airlines that provide the service are foreign companies, which take substantial benefits from the evident competitive advantages that this mean of transportation offer for long deliveries and the opportunity to avoid transactional activities at transfer ports and boundaries.

In overall terms, the air cargo industry has aided to promote productive activities in Mexico in the past years as well as provoke the trade of high-value high-density commodities. The air cargo has the most potential competitive level comparing to the remaining transportation modes traditionally used for international commerce (Rico, 2001).

However, the described circumstances reflect that national air transportation players were unaware of the existence of this market, leaving the most important amounts of cargo to foreign-investment industries. This condition also shows deficient ability to understand and forecast future trends and lack of a proper set of based-cost strategies that could form a structure to attend this increasing demand. In overall terms, a proper characteristic that could be inferred from national air cargo transportation is that the movement of domestic and international freight is substantially lower in comparison with other means of transportation in Mexico (Castillo, 2000).

The general objective of this study is to remark the importance of air cargo operations for national competitiveness, illustrating the current operational issues related to air cargo industry worldwide and the current situation in Mexico based on its infrastructure and operation activities of the Mexican Air Cargo Industry. Moreover, a decision tool based on quantitative analysis that could lead to describe current air cargo operational performance developed by the national airports system is attempted to be perform in order to define specific patterns that influence the mobility of commodities in Mexico, providing useful information for any decision unit implicated on cargo activities in order to predict the amount of cargo operations in the national cargo environment based on specific variables that could incite the changes in cargo movement demand. Hence, the development of this type of analysis gives an important approach to understand general and particular characteristics of the event studied (cargo movement in national terminals). The expected result from this analysis is to provide valuable information for possible infrastructure investments by the any decision entity (air cargo provider, private investments or government) and stimulate the development of cargo operations on diverse regions of Mexico.

Based on the background expressed before, this analysis is centered in perform the following activities:

1) To cover different aspects related on air cargo industry. A current status of the air cargo in the world will be deployed from the market environment point of view and remark some of the most important issues in the air cargo environment.

2) Initially a complete summary of air cargo forecast and trends will be presented in the report. Then, a brief description about the evolution of the Mexican Air Cargo Industry during recent years will be realized, followed by the actual situation of this industry. The study of actual situation for Mexican Air Cargo industry will be realized mainly based on intensive literature research.

3) Following the overview of air cargo operations in Mexico, it would be deployed an analysis of the actual environment of air transportation performance in Mexico, as well as briefly talk about some interesting topics that could affect air cargo performance, like NAFTA implications in transportation activities, existing structure and participation on cargo movements per mean of transportation in the country, the need to implement multimodal transportation for competitiveness, main characteristics for allocating air cargo facilities based on the research given in the literature as well as deploy some principals for allocation of air cargo infrastructure will be covered.

4) In order to find possible variables that could lead to define a descriptive analysis of current air cargo behavior as well as the possibility to predict the performance of cargo movement in Mexico, a mathematical model based on regression analysis will be generated. This analysis based on multiple regression techniques is primarily develop looking to foresee the activities of air cargo movement, initially in the domestic movement of cargo sense and based on selected factors that could affect the movement of air cargo, and defining if current cargo transportation has been influenced by the industry allocated in the region in where the cargo terminal is located as well as the amount of population that lives in the area.

5) Specific findings and conclusions will be posted, based on the literature research, the analysis of the current status of the Mexican air cargo industry and the results obtained by the multiple regression analysis.

3. LITERATURE RESEARCH

3.1 CHARACTERISTICS OF AIR CARGO INDUSTRY

3.1.1 IMPORTANCE OF AIR CARGO OPERATIONS

Led by a convergence of aviation, globalization, digitization, and time-based competition, the worlds of commerce and supply chain management are rapidly changing. New economy products (typically small, light, compact, high value-to-weight parts, components and assembled products) are increasingly shipped internationally by air in a fast and flexible manner. In the new speed-driven, globally-networked economy, individual companies are no longer the effective competing units. Rather, competitive advantage resides in networks of globally dispersed firms whose integrated supply chains move via air.

Air cargo industry, like most industrial groups, gains in the economy, and growth in international trade perspective. The volume of freight shipped by air will also be sensitive to the shipping tariffs of other modes of transportation. In addition to the primary influence of economic activity, many other factors can influence the levels of world air cargo, particularly the express and small package carriers. These factors include changing inventory management techniques, deregulation and liberalization of trade, national development programs, and the possible commodities that could be transported by air (Keiser Phillips Associates, 2002). Users from around the world choose air cargo transportation for the following reasons (Martner, et al, 2003):

- High ratio Economic Value/ Weight for each item transported.
- Give an appropriate handle of fragile cargo.
- Allows quick respond to variable demand or in cases where the product needs to be allocated based on emergency or the specific product has too short product cycle.
- Excellent option to transport perishable products, which could be defined as physically perishable like flowers, food and those perishables that have seasonal trends like apparel.

3.1.2 AIR CARGO INDUSTRY STRUCTURE

Air cargo is an increasingly significant portion of the overall activity that takes place at most airports. Nowadays, this industry is a significant contributor to the economy. In its simplest form, the air cargo market consists of freight and mail. Air mail is contracted out by Postal Service and travels in compartments of commercial passenger aircraft and on freighters operated by contractors. Air freight refers to all cargo other than mail and passenger baggage.

Air cargo activity can be divided into a number of components:

- That conducted by the passenger airlines, primarily in the lower holds of wide body aircraft.
- The traditional all-cargo carriers that provide airport-to-airport freighter service.
- The service oriented an integrated/express carrier that provides door-to-door service.

The passenger airlines and traditional all-cargo carriers typically rely on a network of freight forwarders and customs brokers to generate shipments and provide ground transportation to and from the customer. The integrator airlines rely on an extensive hub and spoke network utilizing a variety of aircraft and truck combinations.

Air cargo could be classified into two distinct groups: **time-sensitive group and value-sensitive group.** Time-sensitive group items could be perishables, like flowers, fruits and vegetables, live animals, bakery products, various food products, obsolescent items such as apparel, footwear, as well as emergency items like drugs, machinery parts, and so on. Value-sensitive group items could be pharmaceutical products, electronic components, photographic equipment, chemicals, machine parts, fragile goods, etc (Radnoti, 2002).

3.1.3 ORIGIN OF AIR CARGO OPERATIONS

Air cargo industry operations began in the United States on 1940, when United Airlines made its first scheduled flight carrying only all-cargo. Following the industry deregulation and restructure for US Air Transportation in the second half of the 1970´s, air cargo operations began to growth as a main option for cargo transportation.

Deregulation allows emerging dedicated integrators for air cargo services. Federal Express ("FedEx") began operations in 1973, followed by other express carriers like Airborne, Burlington, DHL, Emery and United Parcel Services ("UPS"), which jointly with FedEx are considering the biggest integrated/express carrier companies in the world[1].

3.1.4 AIR CARGO MARKET ENVIRONMENT [2]

Although economic activity is the primary influence affecting world air cargo development, it is still necessary to recognize the effects of other factors, some of which are influenced by airline activities. Examples of airline activities that influence air cargo development include the acquisition of aircraft and expansion of services, which have had particularly favorable impacts on the express and small-package market.

Factors beyond the control of airlines include inventory management techniques, globalization, market liberalization, national development programs, and continuing introduction of new air-eligible commodities, all of which play significant roles in air cargo growth.

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1 Air Transport Association of America, *Annual Report 1997*, Washington, DC.

2 Report presented by Boeing: World Air Cargo Forecast 2004/2005

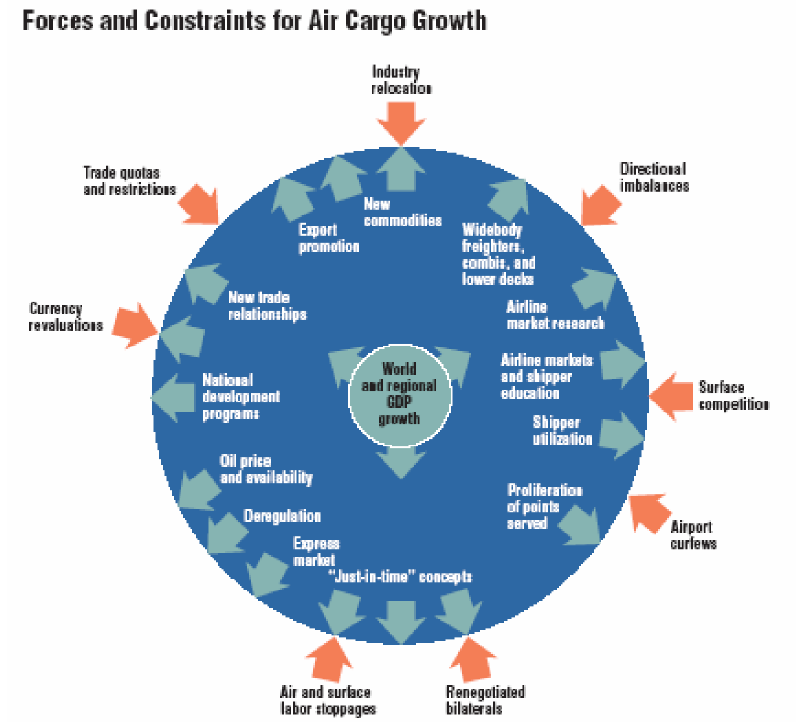

Fig.1: Forces and Constraints for Air Cargo Growth (Boeing, 2004)

Constraints to growth, primarily originating outside the airline industry, can hinder industry growth just as dramatically. A variety of air transport industry constituencies and policymakers continue to address these issues, both positive forces and constraints, in an effort to facilitate air cargo growth.

3.1.5 SIGNIFICANT ISSUES TO IMPACT AIR CARGO INDUSTRY

Regardless of the actual air cargo situation where this industry is an increasingly significant portion of the overall activity that takes place at most airports and a significant contributor to economy, it is still necessary to recognize the effects of other issues that have the potential to create significant impact on the air cargo industry. These issues related to air transportation behavior could influence the volume of freight shipped by air, which in most of the cases will be sensitive to the shipping tariffs of other modes of transportation. Thus, in addition to the primary influence that national economy has in air transportation activities, many other factors can influence the levels of world air cargo, particularly the express and small package carriers.

These factors consist of **(1) Security requirements,** where from the government-mandated security regulations, this presents the highest potential for adverse impact upon the air cargo industry. They may have debilitating effects on shipment transit time. After the terrorist attacks of 9/11, the industry must work with authorities to realize security enhancements that are balanced with a time-sensitive industry's realities; **(2) Deployment of productivity indexes and low-cost practices for cargo carriers,** based on the proliferation of low-cost practices in many passenger carriers. Also, adding the respective demands of passenger flights and the current environment mainly focus on operational efficiency measures (e.g., quick airplane turnarounds) are giving to air cargo industry the pressure to implement the same practices for its carriers. However, some low-cost passenger carriers taking advantages of the current drawbacks in air cargo industry emphasizing their lower-hold space in the body of their aircraft (where baggage is also allocated) and realize express shipments which represent additional revenues; and finally **(3) Service fragmentation,** where the issue of air cargo service "hub" versus "point-to-point" often comes up in the context of passenger transport. Compared with the passenger business, air cargo is more concerned with time and efficiency than routing. Hubbing then becomes a more acceptable alternative to cargo customers when significant handling, volume, and rate efficiencies can be realized (Boeing, 2004).

From the security requirements point of view, the terrorist attacks of September 11th, 2001 displayed the shortcomings of aviation security around the world. Efforts to ensure worldwide security of air cargo since September 11th, 2001 have been performed, being containerized shipping the most regulated to date, mainly because almost 90% of all cargo worldwide is moved by container (Hannon, 2004).

The United States Government began to consider some initiatives like (identified by their acronyms) C-TPAT, CSI, and FAST to reduce the threat generated by a possible terrorist attack and mark the future trend in commerce trade and distributions among US and partner countries. But even though this initiatives are actually affecting not only US but worldwide commerce, lack of legislation pertaining to air cargo security, has left a large gap in a major sector of transportation security. According to the FBI, cargo terminals, cargo transfer facilities, and consolidation facilities are common places for cargo theft (Rountree, et al., 2004). Hence, not only knowledge of initiatives´ procedures are enough for companies that are mainly users of cargo services, but a standardized system or set procedures for screening cargo within airport facilities is needed in order to effectively monitor as much cargo as the limited time element allows and at a reasonable cost to the industry that is giving the service and cargo transportation service users as well.

From the operational performance perspective, numerous studies provided by the literature are focus on measuring specific air carriers, but have not been evaluated airports as major service providers to air cargo companies from the managerial point of view. Much of the literature on airports focuses on technical subjects such as planning, design, legal and environmental issues. The analysis and evaluation of airport operational efficiency have implications for a large number of airport users, including air cargo companies, mainly based on the idea that those companies schedule and allocate their services at those airports that are more efficient and provide reliable infrastructure to attend customers properly (Sarkis, 2000). Also, in terms of efficiency for better operational performance, companies started to implement strategies based on the combination of transportation services.

Shippers demand that cargo must arrive at their destination on time, undamaged and at reasonable price. Such expectation leads to create integrate transport systems through multimodalism. This involves the use of at least two different modes in a trip from origin to destination through an multimodal transport chain. Multimodal transportation strategies surge given the intensive competition in global markets, and the need to design or redesign large-scale distribution networks. To efficiently operate multimodality, important increments on manufacturing and infrastructure investments must be accomplished. This type of service enhances the economic performance of a transport chain by using modes in the most productive manner and also increment operational performance for those services where transportation strategies play an important role in the enterprise logistic function (Lumsden et al. 1999).

Service fragmentation strategies have received a considerable attention from the literature, particularly hub-and-spoke (HS) structures, which are systems that employ centrally located hub facilities to transship flows between the nodes. HS structures have become popular with successful applications in ground and air transportation, communication networks, retailing and other logistic systems. This type of network organization allows the system to take advantage of the economies of scale and centralization of operations at hubs. The idea in hub location models is to provide the correct parameters for consolidation from different origins and send it directly or via another hub to different destinations (nodes that are not destined as hubs are referred to as spokes), thus achieving economy of scale on hub-to-hub links. To date, the design or redesign of large-scale distribution networks has been one of the most important activities assigned to the logistics function; hence, given the intensive competition in global markets, the performance of distribution logistics in the supply chain is considered a strategic issue in achieving and maintaining competitiveness seeking to achieve the goal of making the distribution channel more flexible and responsive to customer needs (Abdinnour-Helm, 1999).

In conclusion, Hub-and-Spoke service fragmentation strategies proposed by the literature around the world, are focused mostly on achieve results centered on accomplish competitive advantages, responding to the pressure of offering transportation services with high quality-levels and low tariffs that allows to compete in this aggressive air cargo environment.

The principal motivation of studying different general issues that could affect air cargo development is mainly to deploy those relevant situation retrieved from different literature sources and could be taken as an important element for logistics and distribution planning decisions in the promising air cargo industry that Mexico is starting to show up on these days as well as to inform the present trends for solving different air cargo issues.

3.2 ACTUAL SITUATION OF AIR CARGO

3.2.1. WORLD AIR CARGO FORECAST [3]

Air cargo markets linked to Asia will lead all other international geographic markets in average annual growth during the period of 2003 through 2023.

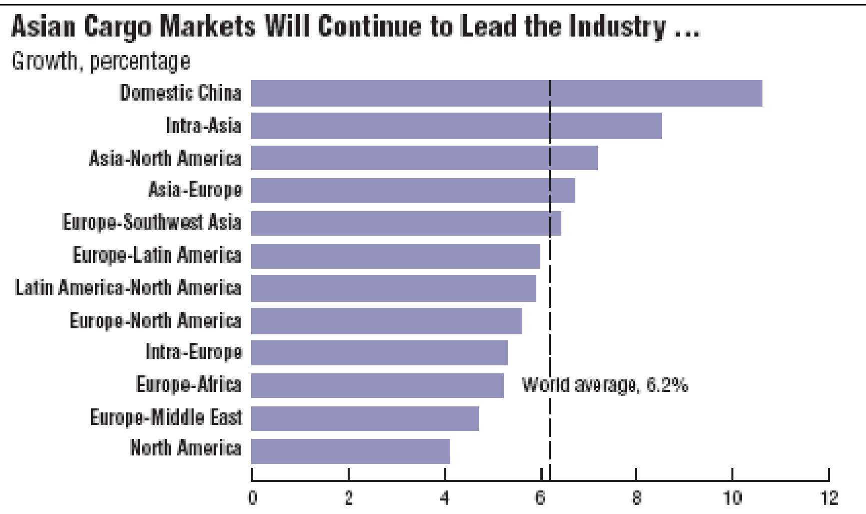

Fig.2: World Air Cargo Projected Growth by Regions (Boeing, 2004)

The North America–Latin America market is forecasted to grow 5.9% per year. Also projected to lag behind the world average growth rate are trade lanes linking Europe to Latin America (at 6.0% growth), North America (at 5.6% growth), Africa (at 5.2% growth), and the Middle East (at 4.7% growth). Market shares will continue to change as a result of varying regional growth rates.

3 [7] Report presented by Boeing: World Air Cargo Forecast 2004/2005

3.2.2 AIR TRADE BEHAVIOR IN LATIN AMERICA [4]

Latin America displayed uneven growth during 2002 and 2003 periods. Of the 1.1 million tons of cargo transported in 2003, South America accounts for 65.3% of air trade, followed by Central America with 26.4% and the Caribbean accounting for the remaining 8.2%. This data is concerning about trading and cargo transportation activities between US and Canada with Latin America markets.

Actually, air commerce between Central America (including Mexico) and North America (US and Canada) contracted 6.6% in 2003, following growth of 6.7% in 2002. Specifically for Mexico, North America's most important air trade partner, during 2003 suffers an air commerce contraction of 10.5% in 2003. This is motivated mainly for Mexican economy regulations that have a remarked trend of dependency on the US economy. South America air trade with North America grew 5.6% in 2003, comparing on a contraction behavior of 2.2% in 2002. In spite of this positive behavior, not all the countries that compose the southbound market have positive results. For example, Brazil contracted 3.1% in 2003, Colombia grew 10.6%, and Chile saw a two-year period growth of 3.5% and 5.8% during 2003 and 2002 respectively.

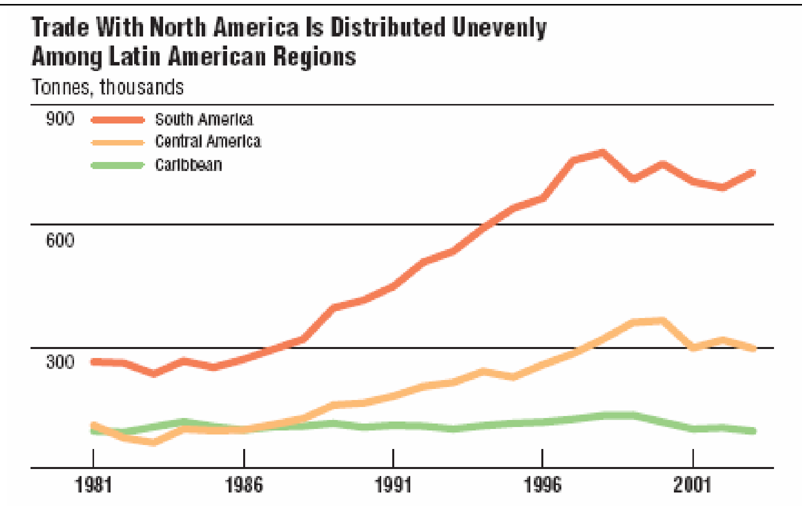

Fig.3: Air cargo behavior between North America and Latin America during 20 year span (Boeing, 2004)

4 Report presented by Boeing: World Air Cargo Forecast 2004/2005

A few major items dominate air commerce between the major trading partners. Most air tonnage moves from Latin America to northern markets, with southbound flows representing higher value commodities. Perishables, apparel, and footwear compose most goods moving north. Southbound flow includes packages, documents, computers, office machines, telecommunication equipment, and industrial equipment. Maquila goods represent a substantial portion of this traffic. Semi finished products move south to the Caribbean, Central America, and Mexico for final assembly. Upon assembly, the finished goods return to northern markets.

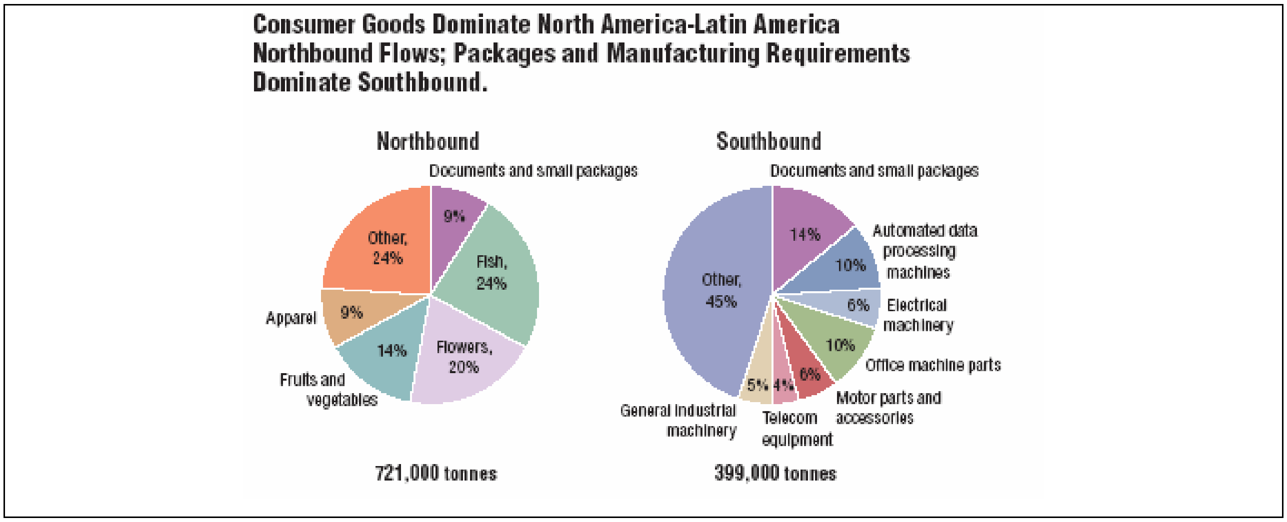

Fig.4: Principal commodities transported by air cargo between North America and Latin American countries (Boeing, 2004)

Colombian air trade with North America grew 10.6% in 2003, following a contraction of 1.7% in 2002. Colombia is the largest exporter to North America of cut flowers, with vegetables and apparel representing other popular air exports. Apparel, electronic goods, and equipment parts and accessories are common air imports to Colombia. Air trade between Brazil and North America contracted 3.1% in 2003 and 3.5% in 2002. Footwear remains Brazil's largest air export (accounting for up to 16.7% of the market), though competitive pressure from Asian manufacturers has affected volumes. Increases in air exports of fish, fresh and dried fruits, and accessories for motor vehicles have, however, partially offset the impact of competition in the footwear market.

Exports from Mexico to North America contracted 4.2% in 2003, following growth of 0.7% in 2002. Mexican imports contracted 15.4% in 2003 after growing 9.1% in 2002. Overall air trade between Mexico and North America contracted 10.5% in 2003, following growth of 5.2% in 2002.

Despite of the actual contraction of Mexican air commerce, cargo market is expected to grow in the country, mainly fueled by important increments on manufacturing and infrastructure investments, as well as a favorable political climate and steady growth of US economy.

4. MEXICAN AIR TRANSPORTATION INDUSTRY

4.1 HISTORICAL DEVELOPMENT OF AIR TRANSPORTATION INDUSTRY IN MEXICO

At the beginnings of last century, around 1920´s, civil aviation industry started its operations in Mexico; mainly operated by foreign industries like Pan Am, international companies dominated the air transportation sector in the country. During the 1960´s, the Mexican government took the control of the industry: all the existent infrastructure and companies were nationalized, emerging two important national institutions for air transportation management; they were called the Department of National Airports Management (DGA)[5] and the Airports and Auxiliary Services of Mexico (ASA)[6]. During the 1970´s, the industry received important investments from the Mexican government that resulted in a significant development of the sector. National airports began to incorporate to ASA. Another consideration was that main air transportation companies operated with drawbacks and losses during those years. For that reason, their operations were supported economically by several government investments and subsidies.

In the 1980´s many airports were incorporated to ASA but it was a decade of many problems for civil aviation and in general for the complete public sector in Mexico. Economical devaluation of the Mexican peso and weak structure of financial institutions related to international liabilities and debts with several creditors. Structural changes got underway with national deregulation and privatization of several sectors, being the air transportation the first among other transportation sectors to enter in this revolution of changes. The most recently sector to restructure were national airports, which entered in a privatization process on 1998. Until 1998, ASA managed and operated the entire Mexican airport system.

During the presidential period of Dr. Ernesto Zedillo Ponce de Leon and based on the National Development Plan for the period 1995-2000 emitted by the government, Mexican airports began to restructure and develop in a process which main objective was to provide modern

5 DGA is the contraction in Spanish for "Direccion General de Aeropuertos".

6 ASA is the contraction in Spanish for "Aeropuertos y Servicios Auxiliares".

infrastructure as well as to built and operate efficient airports and provide stability to the complete national air transportation system. Based on the last statement, on February 9th, 1998, Mexican Government officially published the general guidelines for investment aperture to the Mexican Airport system.

4.2 RESTRUCTURE OF AIR TRANSPORTATION SYSTEM IN MEXICO: CURRENT MEXICAN AIRPORT STRUCTURE

Following the announcement of the investment aperture and privatization for national airport system, several alternatives were evaluated; from the conception of one majority group that could manage the entire system to the concession of an independent group for each of the airports that compose the Mexican airport structure. Finally, a distribution was chosen in four different regional groups: an independent group that manage the International Airport of Mexico City (AICM)[7], Southeast Airports Corporation (ASUR)[8], independent group that manage 9 airports, Central-North Airports Group (OMA)[9] having 13 airports, Pacific Coast Airports Group consisted on 12 airports and finally there were other airports that are still being operated and managed by ASA Group. Nowadays, there are 65 airports that are incorporated in any of the groups that manage and operate the national airport infrastructure (Secretariat of Communications and Transportation, 2003).

7 AICM is the contraction in Spanish for "Aeropuerto Internacional de la Ciudad de Mexico".
8 ASUR is the contraction in Spanish for "Aeropuertos Del Sureste".
9 OMA is the Corporative contraction in Spanish of "Grupo Aeroportuario Centro-Norte"

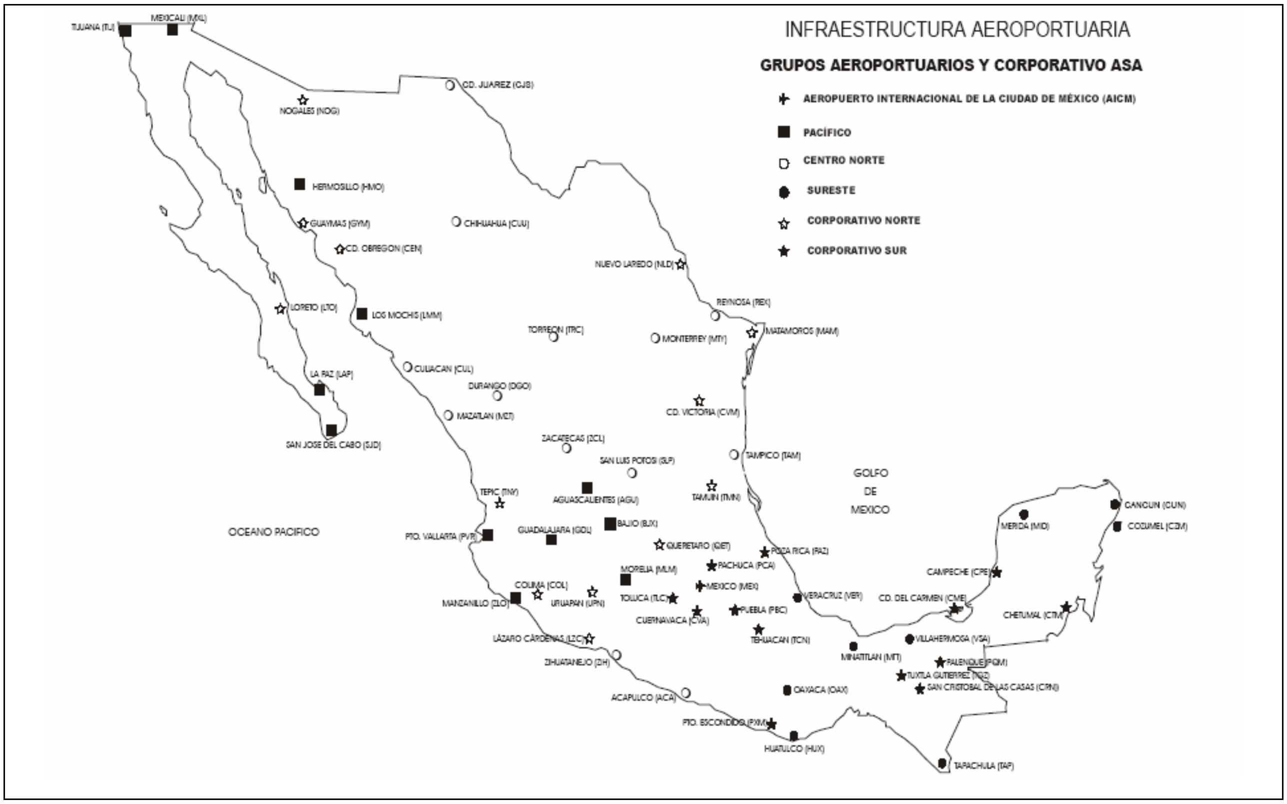

Fig. 5: Structure of Mexican Airports System by corporative group
Modified from Balbuena, et al (2003) Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003, Aeropuertos y Servicios Auxiliares (ASA)

4.3 CLASSIFICATION OF MEXICAN AIRPORTS BY CORPORATIVE GROUP AND RANGE[10]

Grupo Aeroportuario del Sureste ASUR *(Southeast Airports Corporation)*	
AIRPORT NAME AND LOCATION	***RANGE***
Cancun International Airport, Cancun, QR.	International-Tourism-Large Scale
Cozumel International Airport, Cozumel, QR.	International-Tourism-Medium Scale
Bahias de Huatulco Airport, Huatulco, Oax.	International-Tourism-Large Scale
Manuel Crescencio Rejon, Merida, Yuc.	International-Tourism-Large Scale
Minatitlan Airport, Minatitlan, Ver.	Regional- Medium Scale
Xoxocotlan Airport, Oaxaca, Oax.	International- Large Scale
Tapachula Airport, Tapachula, Chis.	International-Border-Medium Scale
Gral.Humberto Jara, Veracruz, Ver.	International-Tourism-Medium Scale
Capt. Carlos Rovirosa, Villahermosa, Tab.	International- Medium Scale

Table 1: Airports that compose the Southeast Airports Corporation (ASUR)

Grupo Aeroportuario del Pacífico *(Pacific Coast Airports Group)*	
AIRPORT NAME AND LOCATION	***RANGE***
Jesus Teran Peredo, Aguascalientes, Ags.	International- Medium Scale
Guanajuato International Airport, Leon, Gto.	International- Medium Scale
Miguel Hidalgo y Costilla, Guadalajara, Jal.	International- Metropolitan-Large Scale
Gral. Ignacio Pesquera, Hermosillo, Son.	International- Medium Scale
Gral. Manuel Enriquez De Leon, La Paz, BCS	International- Tourism- Large Scale
Los Mochis Airport, Los Mochis, Sin.	Regional- Medium Scale
Gral. Francisco J. Mujica, Morelia, Mich.	International- Medium Scale
Gral. Rodolfo Sanchez, Mexicali, BC	International- Border- Large Scale
Gustavo Diaz Ordaz, Puerto Vallarta, Jal.	International- Tourism- Large Scale
Los Cabos Intl, Los Cabos, BCS	International- Tourism- Large Scale
Gral. Abelardo L. Rodriguez, Tijuana, BC	International- Border- Large Scale
Playa de Oro Intl Airport, Manzanillo, Col.	International- Tourism- Large Scale

Table 2: Airports that compose the Pacific Coast Airports Group

[10] Information provided by the Airport and Auxiliary Service ("Aeropuertos y Servicios Auxiliares") ASA, consulted on webpage www.asa.gob.mx, March 2005.

Grupo Aeroportuario Centro-Norte (OMA) *(Central-North Airports Group)*	
AIRPORT NAME AND LOCATION	***RANGE***
Gral. Juan N. Alvarez, Acapulco, Gro.	International- Tourism- Large Scale
Abraham Gonzalez, Juarez, Chih.	International- Border- Medium Scale
Culiacan Airport, Culiacan, Sin.	International- Medium Scale
Gral. Roberto Fierro, Chihuahua, Chih.	International- Medium Scale
Guadalupe Victoria, Durango, Dgo.	International- Medium Scale
Gral. Mariano Escobedo, Monterrey, NL	International- Metropolitan- Large Scale
Gral. Rafael Buelna, Mazatlan, Sin.	International- Tourism- Large Scale
Gral. Lucio Blanco, Reynosa, Tam.	International- Border- Medium Scale
Gral. Francisco Javier Mina, Tampico, Tam.	International- Medium Scale
Francisco Sarabia, Torreon, Coah.	International- Medium Scale
Gral. Leobardo C. Ruiz, Zacatecas, Zac.	International- Medium Scale
Ixtapa-Zihuatanejo Airport, Ixtapa, Gro.	International- Medium Scale
Ponciano Arriaga, San Luis Potosi, SLP	International- Medium Scale

Table 3: Airports that compose the Central-North Airports Group (OMA)

Mexico City International Airport (AICM) International- Metropolitan- Large Scale
Hermanos Serdan Airport, Puebla, Pue. *REGIONAL AIRPORT, Managed by State Government* Medium Scale
Ixtepec Airport, Ixtepec, Oax. *MILITAR AIRPORT*

Table 4: Airports that composed the National Airport System and do not belong to a corporative group.

ASA Corporative Group	
AIRPORT NAME AND LOCATION	***RANGE***
Ciudad Obregon Airport, Obregon, Son.	International- Medium Scale
Ciudad del Carmen Airport, Del Carmen, Cam.	Regional- Medium Scale
Miguel de la Madrid Hurtado, Colima, Col.	Regional- Medium Scale
Copalar Airport, Comitan, Chis.	Regional- Short Scale
Alberto Acuna Ongay, Campeche, Cam.	International- Medium Scale
San Cristobal Airport, San Cristobal, Chis.	Local
Chetumal Intl, Chetumal, QR	International- Border- Medium Scale
Cuernavaca Airport, Cuernavaca, Mor.	Regional- Short Scale
Gral. Pedro J. Mendez, Victoria, Tam.	Regional- Medium Scale
Gral. Jose Maria Yanez, Guaymas, Son.	International- Medium Scale
Loma Bonita Airport, Loma Bonita, Oax.	Regional- Not defined
Loreto Intl, Loreto, BCS	International- Tourism- Medium Scale
Lazaro Cardenas Airport, Lazaro Cardenas, Mich.	Local
Servando Canales, Matamoros, Tam.	International- Border- Medium Scale
Quetzalcoatl, Laredo, Tam.	International- Border- Medium Scale
Nogales Airport, Nogales, Son.	International- Border- Short Scale
El Tajin, Poza Rica, Ver.	Regional- Medium Scale
Pachuca Airport, Pachuca, Hgo.	Local
Puerto Escondido Airport, Puerto Escondido, Oax.	International- Tourism- Medium Scale
Gerardo Espinoza Gutierrez, Queretaro, Qro.	International- Short Scale
Tehuacan Airport, Tehuacan, Pue.	Regional- Short Scale
Tuxtla Gutierrez Airport, Tuxtla Gutierrez,Chis.	Regional- Medium Scale
Adolfo Lopez Mateos, Toluca, Mex.	International- Metropolitan- Medium Scale
Tamuin Airport, Tamuin, SLP	Regional- Short Scale
Amado Nervo, Tepic, Nay.	Regional- Short Scale
Ignacio Lopez Rayon, Uruapan, Mich.	Regional- Medium Scale

Table 5: Airports that compose ASA Corporative Group

4.4 OPERATIONS REALIZED BY MEXICAN AIRPORTS

The Mexican Airports System is actually composed by 5 independent corporative groups that managed almost the 98.5% of the total operations realized by the entire airports in the country. During 2003, Pacific Coast Airports Group with 12 airports integrated to the corporation, centered the 26.6% of the total of air transportation operations in the country, being Guadalajara, Tijuana and Hermosillo the airports that have the most operations realized by this corporative.

Code	Pacific Coast Operations by airport	%
Guadalajara	107747	35.04%
Tijuana	40822	13.28%
Hermosillo	32699	10.63%
Puerto Vallarta	27255	8.86%
Bajio Intl	20997	6.83%
Los Cabos	19567	6.36%
La Paz	13292	4.32%
Morelia	11836	3.85%
Los Mochis	11269	3.66%
Aguascalientes	8697	2.83%
Mexicali	7705	2.51%
Manzanillo	5598	1.82%
TOTAL	**307484**	**100.00%**

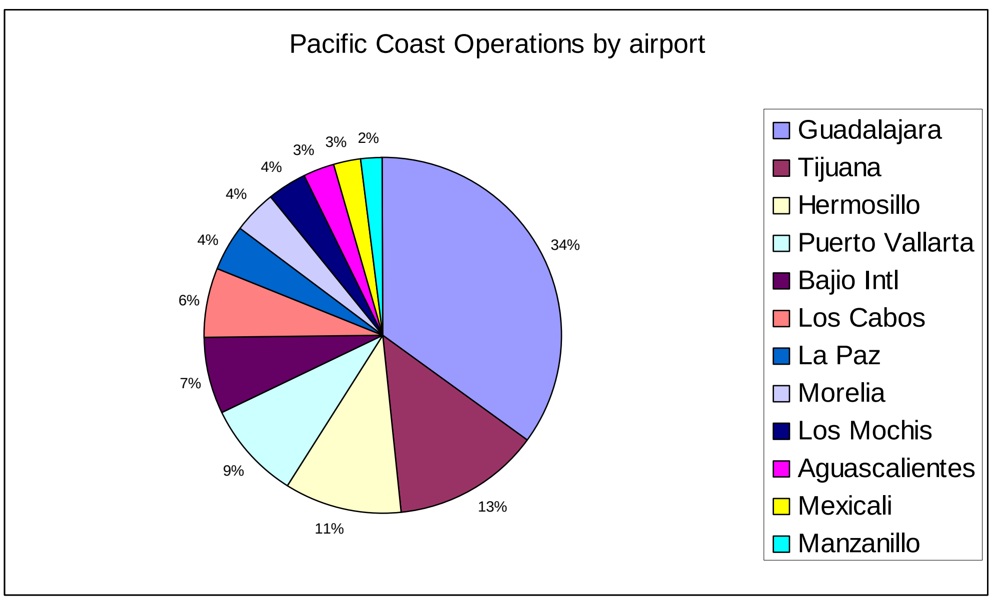

Table 6: Air operations realized by Pacific Coast Airports Group during 2003.*Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003*

The Central-North Airports Group (OMA) during 2003, counted with almost the 22% of the entire operations realized by Mexican Airports. Monterrey is the most important airport not only of this group consisted on 13 airports, but actually it is consider the third most busiest airport in the country, just back of Mexico City International and Guadalajara International.

Code	OMA Operations by airport	%
Monterrey	82286	32.41%
Chihuahua	25994	10.24%
Culiacan	24588	9.69%
Torreon	16837	6.63%
Acapulco	15994	6.30%
Mazatlan	15940	6.28%
Tampico	14402	5.67%
San Luis Potosi	14209	5.60%
Juarez	12830	5.05%
Durango	10783	4.25%
Zihuatanejo	10191	4.01%
Zacatecas	6221	2.45%
Reynosa	3590	1.41%
TOTAL	**253865**	**100.00%**

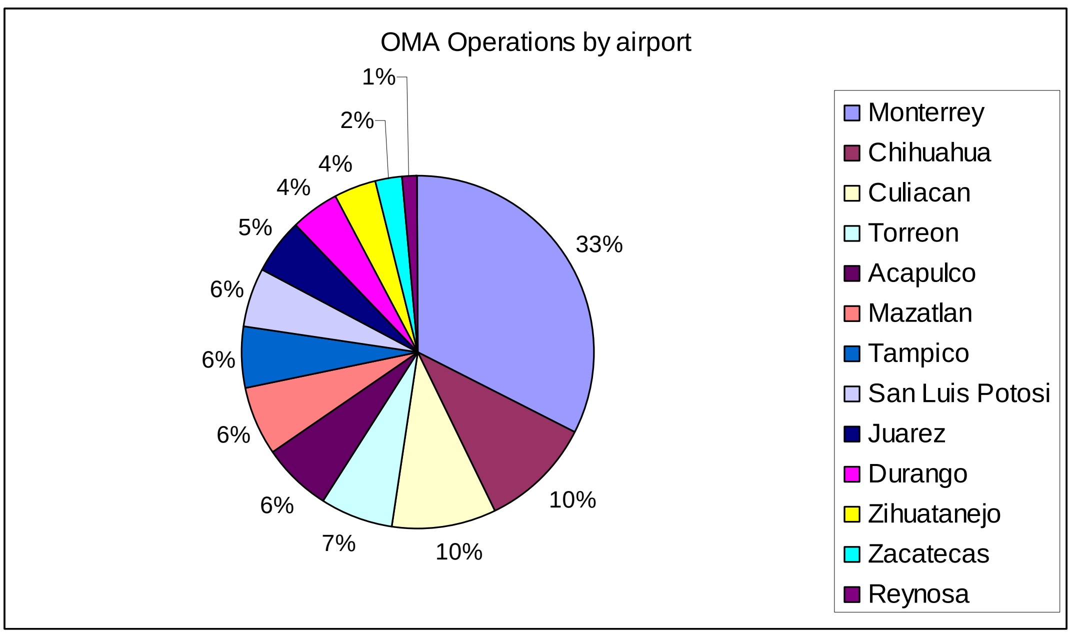

Table 7: Air operations realized by Central-North Airports Group (OMA) during 2003.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003

Southeast Airports Corporation composed by 9 airports, managed the 14.4% of the national air transportation operations, considering Cancun as is busiest airport mainly focus to tourism passenger movement.

Code	ASUR Operations by airport	%
Cancun	80832	48.60%
Merida	18811	11.31%
Villahermosa	18317	11.01%
Veracruz	14607	8.78%
Oaxaca	12020	7.23%
Cozumel	9829	5.91%
Huatulco	4643	2.79%
Minatitlan	3835	2.31%
Tapachula	3424	2.06%
TOTAL	**166318**	**100.00%**

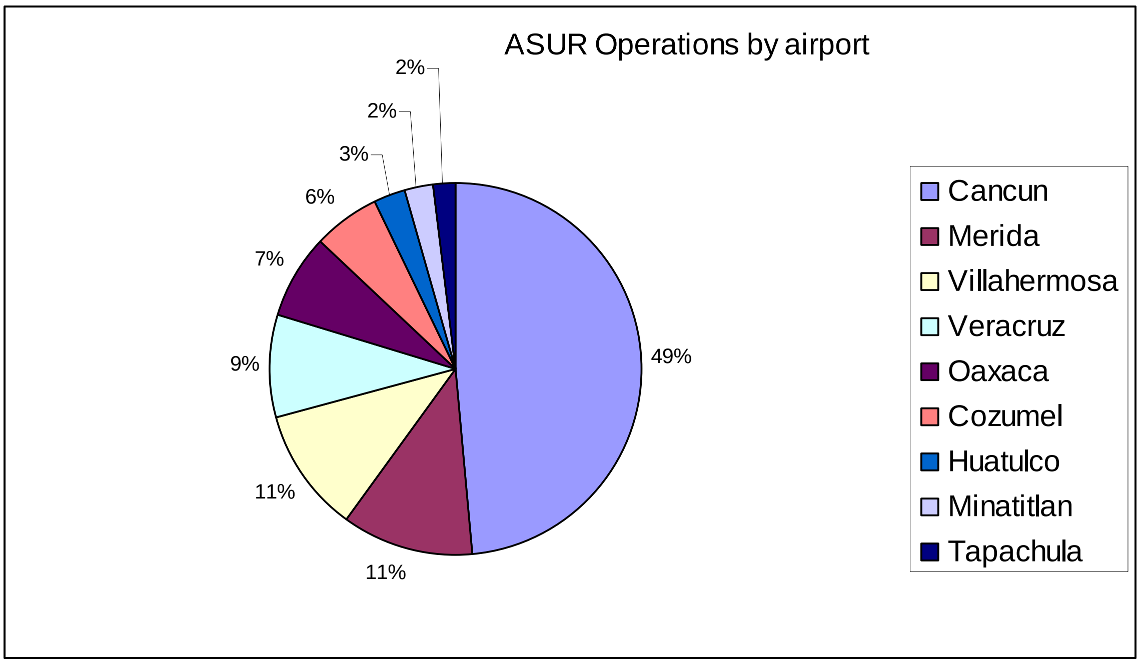

Table 8: Air operations realized by Southeast Airports Corporation (ASUR) during 2003.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003

Mexico City International Airport (AICM) is considered the most important airport in the country. This airport realizes almost the 25% of the air transportation operations realized nationally and it is well known as the main passenger and cargo hub by national and international airlines and carriers that flight in Mexico.

Code	AICM Operations	%
Mexico City	**288436**	**100%**

Table 9: Air operations realized by the Mexico City International Airport (AICM) during 2003.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003

Finally, ASA Corporation, which controls almost the 40% of the entire airports in the system, just contributed with the 11% of national air transportation movement and also has limited resources for managing its entire structure. Del Carmen City Airport and Toluca International are the most important airports in this corporation.

Code	ASA Operations by airport	%
Del Carmen	34325	27.02%
Toluca	33735	26.56%
Poza Rica	7480	5.89%
Obregon	7161	5.64%
Queretaro	6590	5.19%
Tepic	5087	4.00%
Chetumal	3699	2.91%
Victoria	3200	2.52%
Cuernavaca	2978	2.34%
Colima	2828	2.23%
Loreto	2686	2.11%
Puerto Escondido	2648	2.08%
Laredo	2400	1.89%
Matamoros	2377	1.87%
Uruapan	2326	1.83%
Guaymas	1891	1.49%
Campeche	1878	1.48%
San Cristobal	1132	0.89%
Tuxtla Gutierrez	1041	0.82%
Tehuacan	627	0.49%
Comitan	564	0.44%
Nogales	205	0.16%
Tamuin	162	0.13%
TOTAL	**127020**	**100.00%**

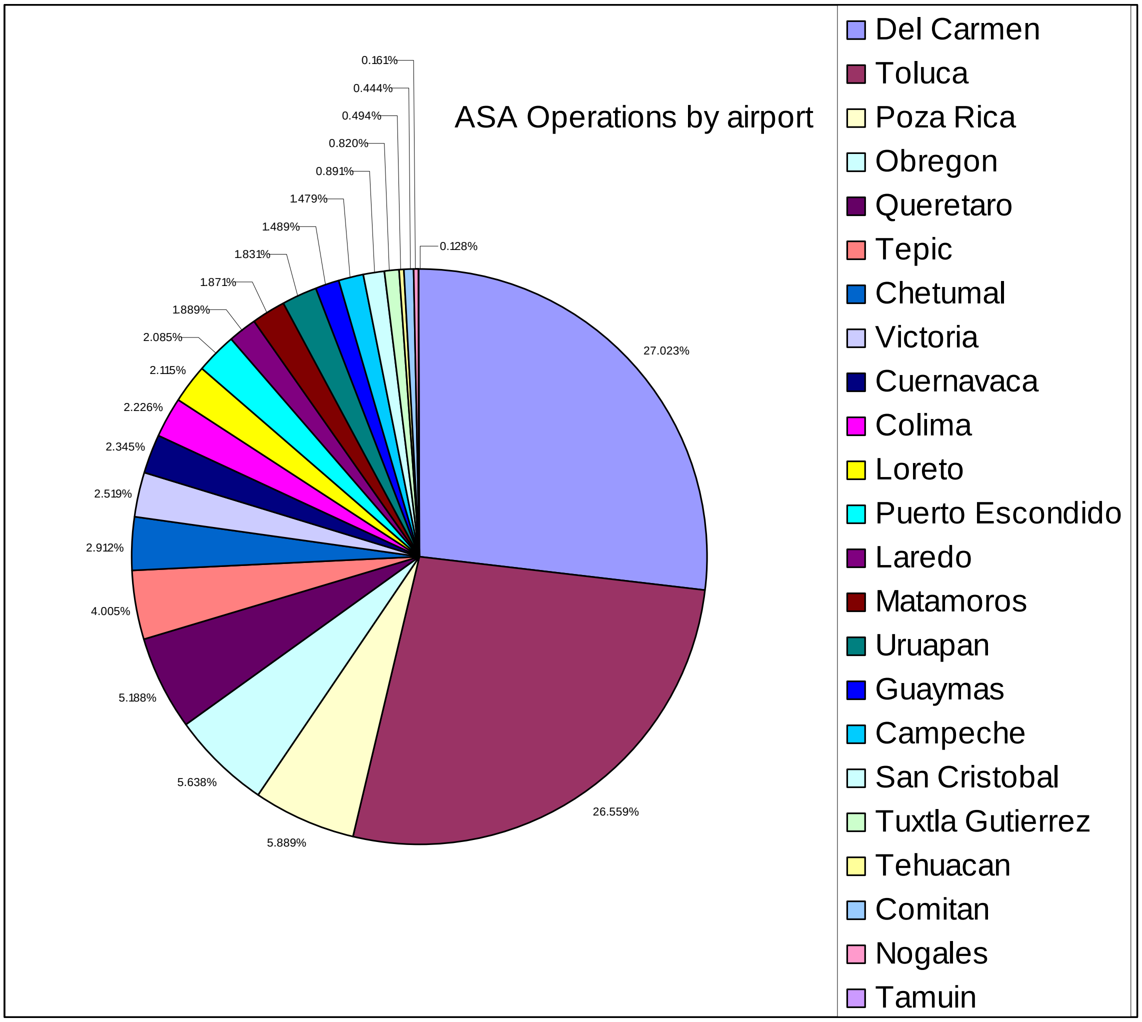

Table 10: Air operations realized by ASA Corporation during 2003.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003

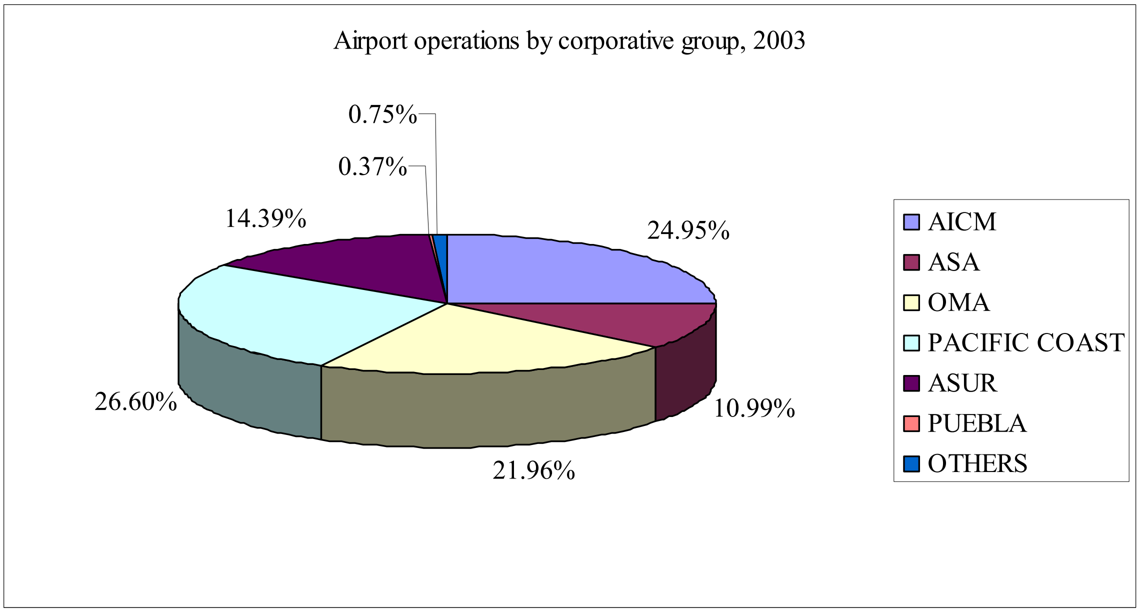

Fig 6: Distribution of air transportation operations by corporative group in Mexico during 2003.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003

4.5 PARTICIPATION OF AIR CARGO IN MEXICO

4.5.1 OVERVIEW OF AIR CARGO OPERATIONS IN MEXICO

In Mexico, the utilization of air transportation in cargo operations, either in national or international commerce, is highly reduced comparing with other means of transportation (Balbuena et al, 2003). Actually, cargo movements realized by airports represents the 2.02% of the total operations that were registered during 2004 (DGAC, 2004).

Air transportation operations realized by Mexican airports in 2004			
	TYPE OF SERVICE	***OPERATIONS REALIZED***	**%**
Commercial Flights	National	744,028	60.74%
	International	217,663	17.77%
	Charter	33,774	2.76%
	Cargo	24,688	2.02%
	Commercial B*	204,801	16.72%
	TOTAL	**1,224,954**	**100.00%**

* Commercial B service is considered by ASA as local regular flights realized by different airports in Mexico

Table 11: Air transportation operations in Mexico during 2004.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

Current situation reflects that some means of transportation in Mexico have incurred in low utilization and could be improved based on current worldwide development needs. In spite of the actual low utilization of air transportation for cargo purposes, in Mexico, a slowly development of infrastructure for handling and transportation of air cargo have been implemented, specially for international cargo; this has been contributing to the growth of cargo services as well as increasing the amount of items transported, integrating the air transportation industry with air cargo movements. This growth is based on the current issue that the transportation of cargo by air is conducted directly by the current demands of commerce and industry.

Users define when and how to utilize this mean of transportation, either to receive a special assembly for production and manufacturing purposes or to send a product that must satisfy customer needs in a specific span of time, so, depending on the characteristics and value of the product that is going to be carried, air transportation could offer more advantages like diminishing transit time as well as affecting direct cost of transportation (Rubio, 1997).

During 2004, more than 550,000 total tons were transported by air transportation. It reflects a 3-year period growth, recovering from an important drop of air cargo movement in 2001, basically generated by the terrorism acts of September and affecting the most on international movement of cargo. Also, from this amount of cargo, approximately 60% were transported outside the country (Secretariat of Communications and Transportation, 2003).

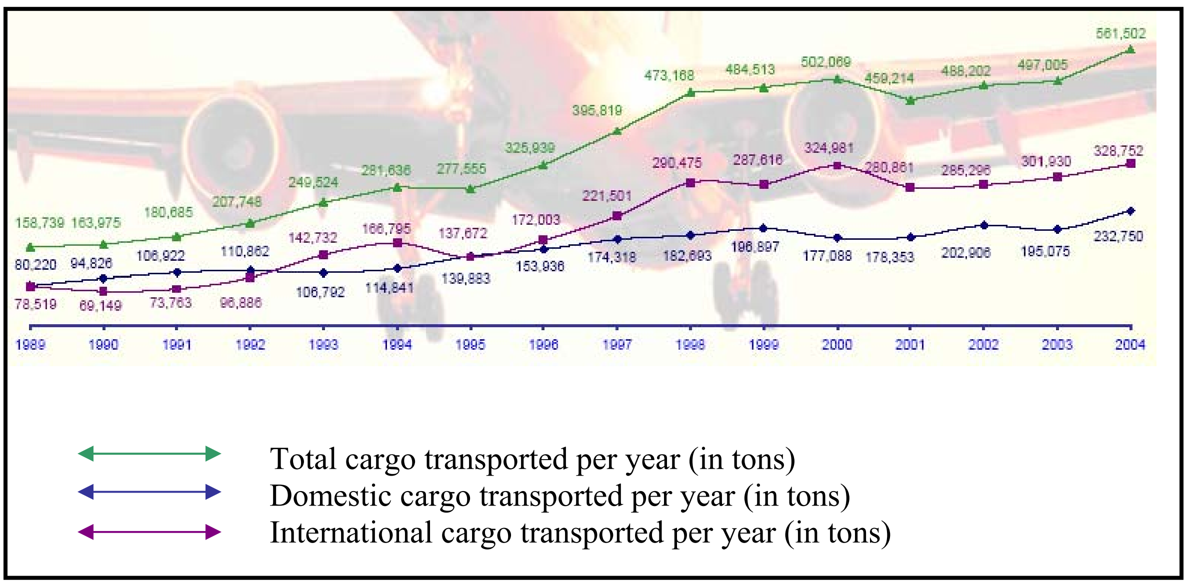

Fig 7: Total cargo in tons transported during the period 1989-2004.

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

4.5.2 PRINCIPAL SETS OF MERCHANDISES IMPORTED AND EXPORTED IN MEXICO BY AIR TRANSPORTATION

According to globalization, worldwide trade and commerce behavior, transportation plays a primary role in either imports or exports of products; the different means of transportation (truck, rail, sea and air transportation), allows to several industrial sectors of each country to buy raw materials for their production (imports) as well as sell a great variety of products to different countries (exports). Nowadays, Mexico intends to be an important point of trade throughout the world. Mexico is considered in the 2000 Annual Report by the WTO[11] as the seventh most active country in worldwide trade issues. Annual average growth of amount value for imported merchandise has suffered different performances year per year during the period 1996-2000, where air transportation experienced the highest annual average growth percentage, reaching almost a 30% of growth in both imports and exports movements.

Although this increment on air transportation activities, highway transportation (truck) remains as the most important way to move merchandises from import perspective with a total value of 103 thousand million of dollars, which represents the 59% of the total amount of cargo transported; the five most important sets of products transported by this mean of transportation are related to manufacturing industry items. Next, sea transportation is the second-most important mean of transportation used for import purposes, followed by air transportation which has a participation of 10% (~ 17 thousand million dollars) of the total value of merchandises moved by the different means. The five most important sets of products imported and moved by this mean of transportation are related to high-value manufacturing industry items with a total value of almost 14 thousand million dollars. Finally, rail transportation is the least utilize mean for products' transportation (in thousand million of dollars terms).

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11 Contraction of World Trade Organization (WTO).

From exports perspective, air transportation has also experienced the highest annual average growth percentage during the period 1996-2000 among all the other possible means of transportation cited above, with a total growth of 27%, then highway transportation presented an annual average growth of 17%, and finally rail and sea transportation had an 11% and 7% annual growth respectively. However, in total value for the amount of items transported, it is positioned on last place among the remaining means of transportation with a participation of only 6% of the total. The five most important sets of products exported and transported by this mean are related to manufacturing items, pharmaceutical products and high-value metals and stones.

PRINCIPAL SET OF MERCHANDISES IMPORTED BY AIR TRANSPORTATION IN MEXICO
1. Machine devices and electric material; recording devices or sound reproducers; recording, image and sound display on TV with corresponding accessories. 2. Nuclear reactors, boilers, machines, mechanical devices and corresponding accessories. 3. Temporal imports for maquiladora processes. 4. Optical instruments and devices, photography and cinematography devices, precision machines and instruments, medical instruments and machines.

Table 12: Principal Set of merchandises imported in Mexico by air transportation during the period 1996-2000, ordered by the value per item in millions of dollars. *Modified from Balbuena, et al (2003) Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003, Aeropuertos y Servicios Auxiliares (ASA)*

PRINCIPAL SET OF MERCHANDISES EXPORTED BY AIR TRANSPORTATION IN MEXICO
1. Nuclear reactors, boilers, machines, mechanical devices and corresponding accessories. 2. Machine devices and electric material; recording devices or sound reproducers; recording, image and sound display on TV with corresponding accessories. 3. Pharmaceutical products 4. Natural perlites, high-value stones, metals and coins. 5. Optical instruments and devices, photography and cinematography devices

Table 13: Principal set of merchandises exported in Mexico by air transportation during the period 1996-2000, ordered by the value per item in millions of dollars. *Modified from Balbuena, et al (2003) Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2003, Aeropuertos y Servicios Auxiliares (ASA)*

4.6 IMPLICATION OF FREE-TRADE AGREEMENTS IN AIR CARGO INDUSTRY

Velocity and range of international businesses have changed during recent years and in consequence, companies must obtain their raw resources, operate and serve to different markets located around the world. Globalization and raise of trade agreements between the countries, has extended the supply chain of the organizations as well as demand efficiency from their diverse logistics systems. In answer of this competitiveness environment, air transportation has come out as an essential service for worldwide companies, providing fast and reliable transportation that could keep in pace of international commerce development, helping to global and regional companies to comply with the increasing demand of products, providing transportation and efficient logistics procedures. For this reason, companies from around the world have been incorporated this service to their enterprise initiatives and turn their supply chain out as a dynamic one, looking for decrease general production-to-market cost, improve their production processes and increase their competitiveness. Also, availability of infrastructure for air transportation and high quality services in particular regions turns out to be a necessary requirement (but not sufficient) for world-class companies to consider this issue into their planning process for possible allocation of manufacturing, handling and distribution infrastructure (PA Consulting Group, 2002).

Structural changes have been developing during recent years in Latin America and the Caribbean, mainly based on commerce and trade agreements between several regions – where the Common Market for South America (MERCOSUR) and the North America Free-Trade Agreement (NAFTA)- have been the most important players for economical integration, commerce and investments between countries in occidental hemisphere. Air commerce between United States and the Latin American Region reflect a remarkable importance. Air cargo trade between US and Latin America has an average value of $35.05/kilo; meanwhile in other non-aerial means of transportation, the average value per trade was $0.80/kilo.

Overall, products sent by Latin American countries have an average value of $25.99/kilo, compared to an average value of $0.51/kilo by non-aerial transportation. These costs reflect the high value-per-item carried by air transportation (PA Consulting Group, 2002). In general terms, profit amount of air cargo transportation is around 15% of the total profit generated by fixed-itinerary airlines, but in volume air cargo is just a small portion of current worldwide commerce. Globally, 75% of the total amount of cargo transported is generated by exports and 25% are domestic movements (Martner, 2003).

4.7 CURRENT SITUATION OF MEXICAN AIR CARGO INDUSTRY RELATED TO NATIONAL FREE-TRADE AGREEMENTS

From the Mexican viewpoint, air cargo activities in Mexico are rising significantly, being international air cargo the most relevant source of freight movement; since the implementation of NAFTA in 1994, trade between Canada and United States has grown considerably, being the most important source of international trading. While the largest volume of trade is between the United States and Canada, trade with Mexico exhibited the fastest growth rate over the past years; as a result, an efficient development of north-south transportation links has received noticeably attention (Prentice, et al., 2001). Also, actual location of Canada-US markets, with important demands of high-value, time sensitive and freight transportation has promoted more utilization of this type of transportation

However, as we can see across this document, air carriers located in Mexico- particularly Mexican air cargo carriers- move most of the domestic and international cargo in passenger airlines, and since the numbers of passengers and their baggage have increased dramatically during last years, there exists a remarkable constraint for expand operations dedicated to freight transportation. Another limited factor is the fact that, from the total amount of cargo carried in Mexico, 81.3% were handled in 12 of the 85 airports that integrate the national airport system, where Mexico City handled almost the 50% of the cargo movements registered by those 12 airports in recent years. This kind of system might not adequately serve the country as a whole and also do not encourage strategic development and economical growth for different regions across the country.

Despite the current fact of unbalanced operations for most of the Mexican airports, the true economical significance behind this mode of transportation is based on its capacity to transport perishable products and high-density value merchandises. Hence, based from the exposed before, nowadays there exists an important margin of airport capacity available in the entire system and also a possibility to improve air transportation system structure.

Finally, it is important to emphasize that cargo movement is part of multimodal transportation, where airplanes do not deliver the cargo directly to their clients, and the freight must be moved from airports by a multimodal system that is generally complemented by other means of transportation that carry out the items from and to the airports. For that reason, those airports that handle air cargo should assure an efficient access for other means of transportation as well as adequate infrastructure for cargo handling in order to be competitive.

4.8 TARIFFS AND REGULATIONS ON AIR TRANSPORTATION IN MEXICO

The Civil Aviation Law, established in May of 1995, created a new regulatory framework for air transportation in Mexico, which brought, among others, the liberation of domestic services fares. This law also established a mechanism of tariff vigilance, correction and regulation to avoid monopolistic practices by some of the airlines and to assure an effective competence in the market. Also, since 1988, the entry of new airlines to the market was facilitated, all of which defined a competitive market in terms of coverage, service, and prices (Heredia, 2000).

Even before the liberation of rates, the airlines made the fares rank bigger with the purpose of creating an increase of the demand. This, of course, caused the diversification of the rates application rules, and the price level descended because of the effect of greater discounts that were offered based on cargo consolidation. To avoid the entrance into the market of new businesses with lower costs in relation to those airlines that traditionally attended the market, the Mexican government assigned the following functions to the competent authorities:

- To keep the competition processes in the market using liberated tariffs
- To accomplish an equilibrium between the competition conditions and the development of the airlines
- To assure the permanence of favorable conditions in the services for the users

This procedure of vigilance contemplates the objectives that satisfy the needs of the different parties, this is, the authority receives opportune information to detect levels of rates that accuse contrary practices to the competence, the airlines are provided with information useful to watch and to predict the financial results of their operations, and the companies of economic control receive information related to the prices index. As it was expected, the fares scheme changed after the deregulation law mentioned above was established.

4.9 CURRENT AIR CARGO CARRIERS OPERATING IN MEXICAN AIRPORTS

Actually in Mexico, regular air flight services are still predominating as the more important mean of cargo transportation. However, since mid 1980´s international air cargo carriers started to realize operations in Mexico. Globalization trends concerning domestic and international commerce, manage of more complex supply chains and the essential requirement for constructing and operating exclusive air cargo infrastructure to handle freight operations and be competitive worldwide, started to be reflected with the allocation of air freight companies and infrastructure for handling cargo, around beginnings of 1990´s. Nowadays, there is still a high proportion of air cargo operations realized by international air freight companies during the past years. Based on records presented by the Secretariat of Communication and Transportation in its 2004 Annual Report, Mexican airlines transported about 40% of the entire total cargo carried during 2004, either in regular passenger flights, exclusive air cargo and charter services. The most important national companies for cargo movement in Mexico are shown below; they are classified as service style and the amount of cargo handled (in tons) during 2004.

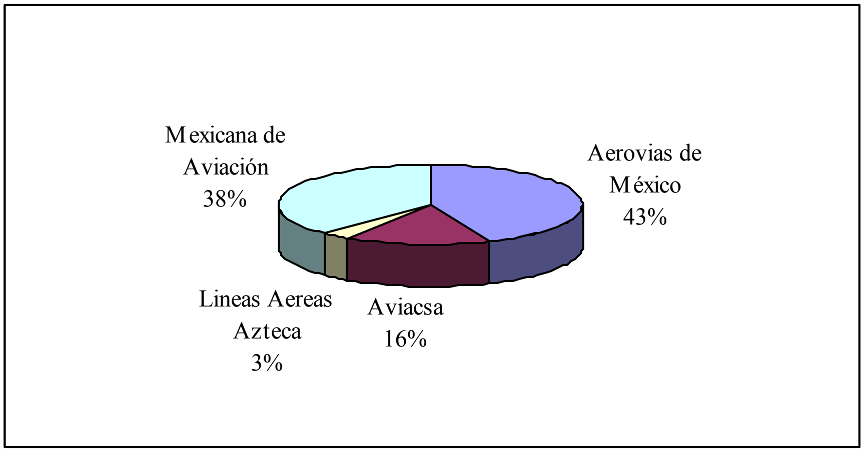


Fig 8: Participation of Regular Air Flights companies on cargo transportation during 2004 (tons)

Source : Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

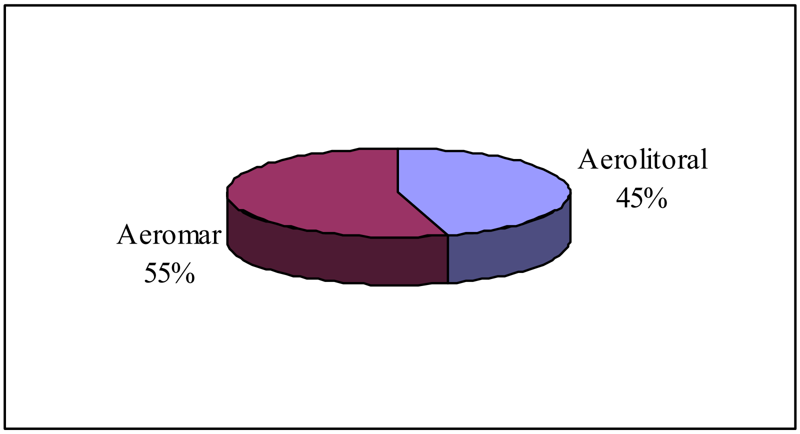


Fig 9: Participation of Regional Air Flights companies on cargo transportation during 2004 (tons)

Source : Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

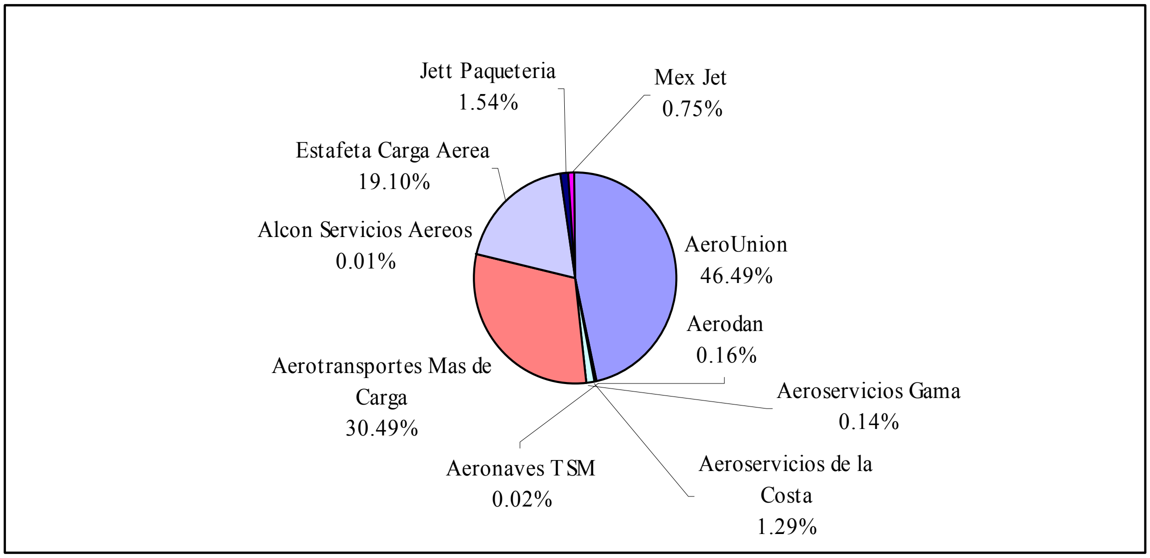


Fig 10: Participation of National exclusive air cargo companies on cargo transportation during 2004 *Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004*

Participation of Mexican regular air transportation companies

Company Name	Total Cargo transported in 2004 in tons
Aerovias de México	43,189
Aviacsa	15,590
Lineas Aereas Azteca	2,906
Mexicana de Aviación	37,429

Participation on cargo movement by Mexican regional companies

Company Name	Total Cargo transported in 2004 in tons
Aerolitoral	1,626
Aeromar	1,964

Participation of Mexican exclusive air cargo carriers

Company Name	Total Cargo transported in 2004 in tons
AeroUnion	60,464
Aerodan	206
Aeronaves TSM	30
Aeroservicios de la Costa	1,678
Aeroservicios Gama	187
Aerotransportes Mas de Carga	39,645
Alcon Servicios Aereos	17
Estafeta Carga Aerea	24,843
Jett Paqueteria	2,002
Mex Jet	974

Table 14: List of total cargo transported (in tons) by service style during 2004

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

Overall Participation by service style	
Participation of Mexican regular air transportation companies	99,114
Participation on cargo movement by Mexican regional companies	3,590
Participation of Mexican exclusive air cargo carriers	130,046
TOTAL	**232,750**

Table 15: Overall participation by Mexican companies that provided cargo during 2004 (tons).

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

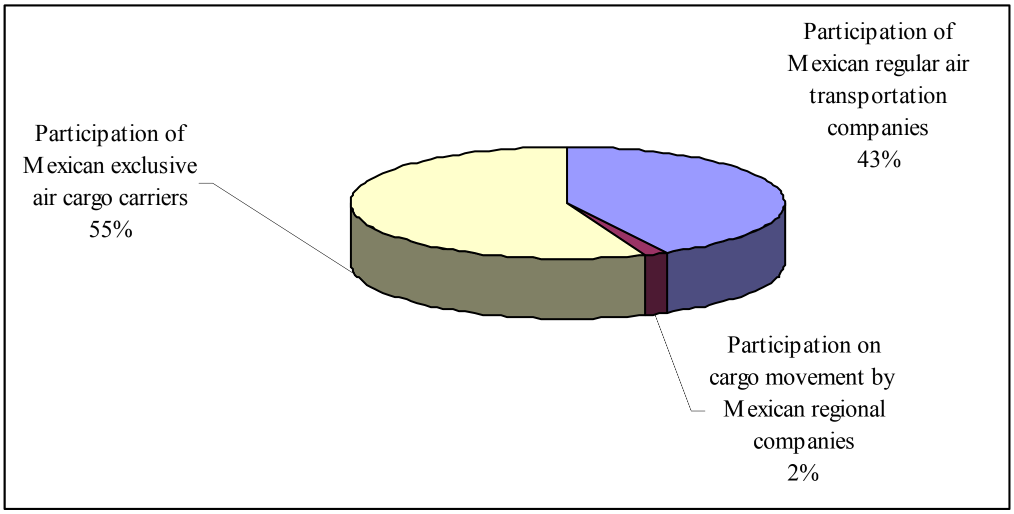


Fig 11: Participation of National air cargo companies classified by service style during 2004

Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004

In terms of international cargo movements, different foreign companies actually operate in Mexico with diverse levels of participation. Foreign-based companies are carrying the remaining 60% of the cargo that goes abroad, mainly realized by regular air flight and parcel service companies as well as international charter services.

Participation of international exclusive air cargo companies	*Tons*	*% of participation*
Atlas Air	19,180	46.47%
Capital Cargo International	7,424	17.99%
Gemini Air Cargo	4,275	10.36%
Centurion	3,026	7.33%
Custom Air Transport	1,927	4.67%
USA Jet Airlines	1,252	3.03%
Florida West Airlines	1,012	2.45%
Ameristar Air Cargo	855	2.07%
Contract Air Cargo	426	1.03%
C&M Airways	342	0.83%
Ameristar Airways	318	0.77%
Murray Air	315	0.76%
Cielos de Peru	221	0.54%
Air Comet Plus	134	0.32%
Ryan International	121	0.29%
Heavylift Cargo Airlines	119	0.29%
Kalitta Charters II	77	0.19%
Euro Fly	69	0.17%
Nord Aviation	67	0.16%
Skyway	52	0.13%
Kalitta Flying Service	29	0.07%
Zantop	12	0.03%
Aero Caribbean	10	0.02%
Geo Air	8	0.02%
Linder Air	4	0.01%
TOTAL	**41,275**	

Participation of international air transportation companies	*Tons*	*% of participation*
Federal Express	66,881	23.26%
United Parcel Service	29,395	10.23%
Air France	26,751	9.31%
Cargolux Airlines Inter	25,493	8.87%
Martin Air Holland	18,058	6.28%
Kim	17,910	6.23%
Astar Air Cargo	15,964	5.55%
Amerijet International	11,628	4.04%
Varig	8,615	3.00%
Iberia	8,336	2.90%
American Airlines	7,997	2.78%
Lufthansa	7,715	2.68%
DHL Guatemala	5,959	2.07%
Delta	4,592	1.60%
Continental	4,280	1.49%
British Airways	3,458	1.20%
Lan Chile	3,199	1.11%
Alaska	2,836	0.99%
Express Net	2,614	0.91%
Air Canada	2,385	0.83%
Avianca	1,991	0.69%
Tampa	1,965	0.68%
Japan	1,647	0.57%
Panameña de Aviación	1,289	0.45%
United Airlines	1,112	0.39%
Cubana de Aviación	1,101	0.38%
Aviateca	1,013	0.35%
Taca	914	0.32%
LTU Lufthansport Unter	811	0.28%
Lloyd Aereo Boliviano	550	0.19%
Lacsa	342	0.12%
Trans American Airlines	186	0.06%
America West	134	0.05%
Comair	118	0.04%
Lauda Air	77	0.03%
Tikal Jets	57	0.02%
Express Jet	52	0.02%
Northwest	52	0.02%
TOTAL	**287,477**	

Table 16: List of total cargo transported (in tons) by international air transportation companies during 2004. *Source: Secretariat of Communications and Transportation, Direccion General de Aeronautica Civil (DGAC), 2004*

4.10 ANALYSIS OF AIR CARGO CONNECTIONS IN MEXICO

4.10.1 ANALYSIS OF ORIGIN - DESTINATION FLOWS FOR DOMESTIC AIR CARGO TRANSACTIONS.

During 2004, 232,750 tons of domestic cargo was handled by operations between Mexican airports. According to the historical development of domestic air cargo transportation, this amount registered in 2004 reflected an important increment of 19.31% comparing to last year results.

According to the data provided by the Secretariat of Communications and Transportation, during 2004 there exists 170 links that were registered realizing air cargo transportation in 59 different airports located in the country. From this table it could be inferred the most important corridors for air cargo transportation in the country.

Actually there exists a disproportion on the amount of cargo handled by diverse airports located along the country. One important characteristic of transportation chains based on origin-destination links that could be analyzed is the distribution of cargo flow between the two points, named **directional symmetry** (Rico, 2001).

In general terms, the most desirably situation for directional symmetry between two points could be found in their balance of flow produced by those links, looking for equal amount of cargo transported between origin and destination, decreasing empty trips and operative costs. Those links that observe better directional symmetry conditions lead to reduce operative problems and raise profitability margins associated with the specific activity realized by the company in cargo transportation terms. Also, if directional symmetry in transportation chains increase, there exists more balance on transactions (at least in volume) and possibly more diversification on productive activities. Directional asymmetry in cargo terminals mean that there are a remarkable dependency in the system based on a few amount of airports that serves as cargo distributors and leaving the remaining terminals just as freight receptors.

In the case of air cargo transportation in Mexico, there exists an important direction asymmetry during 2004 in domestic cargo transportation terms, considering this characteristic as a descriptive one for domestic air cargo transportation system. From the total amount of links, just around 10 pairs have an equilibrated distribution of cargo flow, mentioning Guadalajara-Mexico (22,075 tons), La Paz-Mexico (1,077 tons), Mexico-Tijuana (8,369 tons) and Mexico-Tapachula (1,454 tons) as the most important pair links based on their amount of cargo transported in 2004.

In addition, 45 origin-destination pairs that represents just the 25% of the total amount of cargo transportation links registered during 2004 have a 60/40 cargo distribution, which could be established as the upper limit to consider those links as relative equilibrated; it is important to mention that for setting this upper level statement, if cargo flow between each connection reach a 66.6/33.3 distribution, the amount of cargo transported by one connection is the double compared to the other link. Based on this comment, 105 of the 168 connections (60%) have at least 66.6/33.3 cargo flow behavior, 77 connections have a 75/25 proportion and 55 of them perform as 80/20 proportion. Relation 90/10 and 100/0 give asymmetry directions with not significant amounts and do not have any transcendence in more of the cases.

In order to identify the most important links with strong directional asymmetry, the next table will shown those connections with cargo flow above 1,000 tons of cargo moved and their proportion between links have a relation 66.6/33.3.

ORIGIN	DESTINATION	CARGO ORIGIN (In kgs)	CARGO DESTINATION (In kgs)	PARTICIPATION ORIGIN	PARTICIPACION DESTINATION	TOTAL (In kgs)
GUADALAJARA	MEXICO	11,589,875.00	10,485,087.00	52.50%	47.50%	22,074,962.00
GUADALAJARA	MONTERREY	4,257,283.00	7,745,739.00	35.47%	64.53%	12,003,022.00
MEXICO	MONTERREY	5,433,020.00	3,162,259.00	63.21%	36.79%	8,595,279.00
MEXICO	TIJUANA	4,676,100.00	3,692,453.00	55.88%	44.12%	8,368,553.00
MERIDA	MEXICO	1,981,400.00	3,240,959.00	37.94%	62.06%	5,222,359.00
CANCUN	MEXICO	1,090,785.00	3,601,099.00	23.25%	76.75%	4,691,884.00
MEXICO	VILLAHERMOSA	1,865,352.00	496,326.00	78.98%	21.02%	2,361,678.00
HERMOSILLO	MEXICO	475,890.00	1,631,150.00	22.59%	77.41%	2,107,040.00
CHIHUAHUA	MEXICO	804,500.00	1,229,049.00	39.56%	60.44%	2,033,549.00
GUADALAJARA	TIJUANA	1,095,307.00	765,541.00	58.86%	41.14%	1,860,848.00
MEXICALI	MEXICO	506,634.00	1,227,627.00	29.21%	70.79%	1,734,261.00
CULIACAN	MEXICO	600,146.00	1,023,766.00	36.96%	63.04%	1,623,912.00
CD. JUAREZ	MEXICO	543,291.00	1,036,352.00	34.39%	65.61%	1,579,643.00
MEXICO	OAXACA	911,165.00	586,463.00	60.84%	39.16%	1,497,628.00
MEXICO	TUXTLA GUTIERREZ	1,260,533.00	215,435.00	85.40%	14.60%	1,475,968.00
MEXICO	TAPACHULA	652,877.00	800,836.00	44.91%	55.09%	1,453,713.00
MEXICO	PTO. VALLARTA	1,215,533.00	196,946.00	86.06%	13.94%	1,412,479.00
MEXICO	SAN JOSE DEL CABO	1,168,662.00	168,154.00	87.42%	12.58%	1,336,816.00
ACAPULCO	MEXICO	168,002.00	1,053,388.00	13.75%	86.25%	1,221,390.00
DEL BAJIO	MEXICO	362,898.00	842,727.00	30.10%	69.90%	1,205,625.00
MEXICO	VERACRUZ	1,002,707.00	160,810.00	86.18%	13.82%	1,163,517.00
LA PAZ	MEXICO	547,577.00	529,114.00	50.86%	49.14%	1,076,691.00

Table 17: Air cargo links with important asymmetry directions

From this table, it is important to remark the importance of Mexico City and evidence its functionality as main distributor of cargo in the entire system, participating on 21 of 22 connections mentioned in last table and just in two of the links where Mexico City participates as a cargo connection, Tapachula and La Paz dominate by a small margin the flow between them and Mexico City. This situation could be explained basically by the geographical position of these cities in respect to Mexico City, where both links realize the function of supply and distribution centers as well as remarks the comment posted before based on the balance between cargo connections and equilibrium of transactions between pair links.

The behavior of Mexico City as the most important hub inside Mexican air cargo transportation industry could be a result of different factors:

a) An important need of agile supply of goods from the most important population and industrial center in the country (Mexico City).
b) A relative inaccessibility (related to distance between pair nodes, time and costs) using other transportation means, particularly truck mode.
c) Absence of possible cargo that could be transported by this mean of transportation based on lack of industrial and services development in different regions.

Although these factors might be similar for all the cases, the way they are generated are not the same. For example, Cancun, Acapulco, Puerto Vallarta, San Jose del Cabo are destinations where tourism is the main activity of the city and there exists a strong need of supply of consumption goods from Mexico City fundamentally to hotel industry and tourism centers based on the deficiency of other economical activities realized locally that could guide to satisfy their needs. In the case of Mexicali, Hermosillo, Oaxaca, Tuxtla Gutierrez, Chihuahua, Culiacan, Merida, Villahermosa and La Paz, they are the political center and the most populated cities of their states as well as their inaccessibility by different means of transportation and the distance that separates Mexico City to those cities make air transportation a reasonable choice for cargo movement.

Finally, in the case of Veracruz, Tapachula and Leon (Del Bajio), they should be treated as special cases. Tapachula is the most populated city in Chiapas and its distance with Mexico City along with lack of reliable highway infrastructure could explain the huge amount of cargo observed during 2004. Veracruz, Tampico and Leon are three difficult cases to describe because they are completely accessible from Mexico City not only by highway infrastructure, also by rail transportation and both have a good diversity of economical activities in their conurbation.

Additionally, significant positive development on cargo movement is realized by Monterrey, Guadalajara and Tijuana. A main reason to their extraordinary augmentation is based on the industry development exposed in those areas. Also, infrastructure investment designated to increase air cargo operations have been emerging like the development of a distribution center for cargo movements built in San Luis Potosi or the design of a central warehouse for cargo operations based in Mariano Escobedo International Airport of Monterrey.

As mentioned before, there are 170 different connections from 59 airports that handle cargo during 2004. A complete table with all the information about total cargo handled by each airport as well as number of connections per airport, cargo sent and received by airport and accumulated participation by airport is shown below. It is important to comment that Toluca International Airport, which is one of the most important airports in the country, did not register any domestic cargo operation during 2004.

	TERMINAL	NUMBER OF CONNECTIONS	CARGO FROM ORIGIN	CARGO FROM DESTINATION	TOTAL CARGO	ACCUMULATED PARTICIPATION
1	MEXICO	54	51,396,003	30,901,785	82,297,788	38.9224%
2	GUADALAJARA	24	18,386,650	19,620,332	38,006,982	56.8977%
3	MONTERREY	25	12,577,204	10,664,979	23,242,183	67.8900%
4	TIJUANA	19	5,848,779	8,061,907	13,910,686	74.4690%
5	MERIDA	8	2,090,376	3,332,091	5,422,467	77.0335%
6	CANCUN	6	1,163,894	3,815,705	4,979,599	79.3886%
7	HERMOSILLO	18	955,313	2,368,149	3,323,462	80.9604%
8	CHIHUAHUA	7	1,232,891	1,648,664	2,881,555	82.3232%
9	VILLAHERMOSA	11	553,682	2,004,225	2,557,907	83.5330%
10	CD. JUAREZ	12	1,007,336	1,545,651	2,552,987	84.7404%
11	MEXICALI	6	648,735	1,724,302	2,373,037	85.8627%
12	CULIACAN	9	918,099	1,419,704	2,337,803	86.9684%
13	OAXACA	4	1,200,845	948,601	2,149,446	87.9850%
14	SAN JOSE DEL CABO	3	250,440	1,885,412	2,135,852	88.9951%
15	LA PAZ	8	914,098	907,064	1,821,162	89.8564%
16	MAZATLAN	11	1,049,156	682,788	1,731,944	90.6755%
17	DEL BAJIO	10	640,167	1,060,887	1,701,054	91.4800%
18	PTO. VALLARTA	7	229,793	1,283,403	1,513,196	92.1957%
19	TUXTLA GUTIERREZ	3	226,448	1,264,044	1,490,492	92.9006%
20	TAPACHULA	2	804,347	664,651	1,468,998	93.5954%
21	VERACRUZ	7	214,215	1,051,381	1,265,596	94.1939%
22	ACAPULCO	7	179,297	1,067,099	1,246,396	94.7834%
23	TAMPICO	5	186,585	821,226	1,007,811	95.2601%
24	TORREON	8	301,195	605,775	906,970	95.6890%
25	REYNOSA	3	356,174	377,986	734,160	96.0362%
26	AGUASCALIENTES	6	163,242	543,241	706,483	96.3704%
27	ZIHUATANEJO	2	38,975	654,255	693,230	96.6982%
28	CIUDAD DEL CARMEN	6	115,768	455,959	571,727	96.9686%
29	MATAMOROS	3	282,523	217,838	500,361	97.2053%
30	CIUDAD OBREGON	8	194,918	296,192	491,110	97.4375%
31	BAHIAS DE HUATULCO	1	117,917	372,194	490,111	97.6693%
32	MINATITLAN	1	93,131	391,920	485,051	97.8987%
33	NUEVO LAREDO	2	331,024	146,542	477,566	98.1246%
34	CHETUMAL	1	49,822	372,805	422,627	98.3245%
35	LOS MOCHIS	7	156,881	245,076	401,957	98.5146%
36	MORELIA	6	112,863	237,818	350,681	98.6804%
37	SAN LUIS POTOSI	5	97,132	232,500	329,632	98.8363%
38	ZACATECAS	3	48,703	240,402	289,105	98.9731%
39	SALTILLO	1	110,871	167,697	278,568	99.1048%
40	DURANGO	5	30,299	236,447	266,746	99.2310%
41	QUERETARO	4	86,233	142,969	229,202	99.3394%
42	MANZANILLO	1	70,055	141,272	211,327	99.4393%
43	CIUDAD VICTORIA	1	17,411	160,462	177,873	99.5234%
44	LAZARO CARDENAS	1	40,276	103,976	144,252	99.5917%
45	POZA RICA	5	42,534	90,977	133,511	99.6548%
46	URUAPAN	3	26,267	100,552	126,819	99.7148%
47	PUEBLA	3	56,328	63,244	119,572	99.7713%
48	SALINA CRUZ	1	6,180	102,622	108,802	99.8228%
49	TEPIC	1	7,580	89,068	96,648	99.8685%
50	COLIMA	1	23,074	52,111	75,185	99.9041%
51	CUERNAVACA	2	45,973	12,885	58,858	99.9319%
52	JALAPA	1	3,553	47,926	51,479	99.9562%
53	SAN CRISTOBAL DE LAS CASAS	1	2,814	26,983	29,797	99.9703%
54	LORETO	2	9,008	12,885	21,893	99.9807%
56	COZUMEL	1	3,483	17,110	20,593	99.9904%
57	PIEDRAS NEGRAS	2	2,142	9,460	11,602	99.9959%
58	MONCLOVA	2	687	3,708	4,395	99.9980%
59	CAMPECHE	2	2,454	1,793	4,247	100.0000%

Table 18: Airports that registered domestic air cargo operations during 2004.

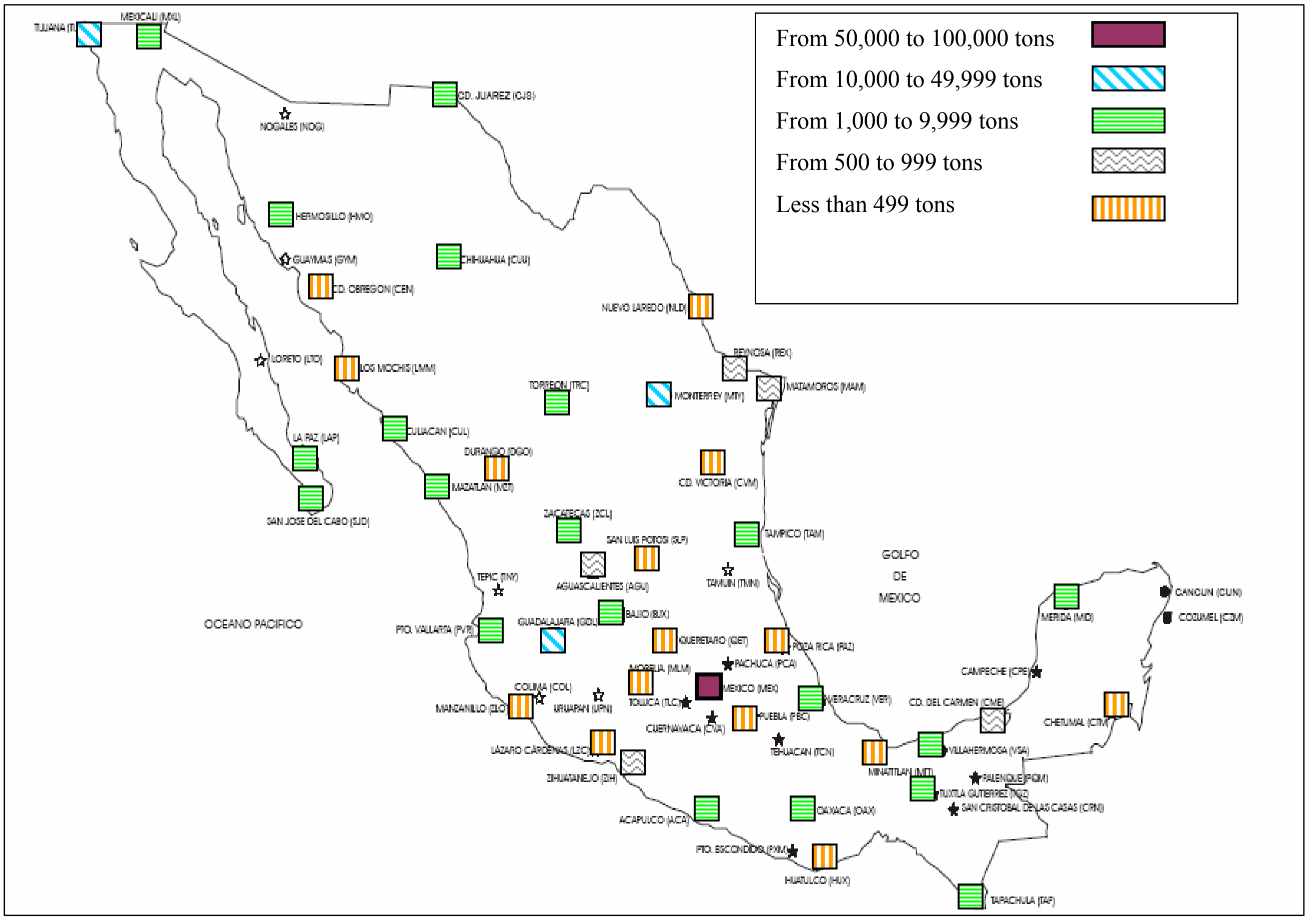


Figure 12: Airports with domestic cargo movements during 2004 distinguished by amount of cargo handled by cargo unit.

From this map we could observe the dispersion of air cargo infrastructure located in the country, with lack of homogeneousness in its path. It could be observed the amount of cargo handled by airports that are distant from Mexico City. Also, 22 airports that registered domestic air cargo movement are located on seaport zones and almost the half of the entire system (28 airports) is located either in coastal or international border sites. It is important to observe that terminals with major movements of cargo are located in significant population concentrations and main cities of Mexico. Some airports that are located on conurbations with low infrastructure investment, relative inaccessible but have some relation with any industrial and primary activities with some air cargo movement are Guerrero Negro, Monclova, Loreto and Piedras Negras.

From the data provided on table 18 it could be established some hierarchy levels based on the amount of cargo handled by airport in domestic cargo terms. Two fundamental elements that provide some insight are the total volume of cargo managed by the airport as well as their amount of air cargo connections.

Based on this criterion, Mexico City arises as the most important hub terminal for cargo movements in the country, leading by an important margin over the other terminals located in Mexico with its 54 connections to different destinations in the country and more than 82,000 tons moved during 2004. Mexico City moves almost 3 more times the amount of cargo handled by Guadalajara, the second most important airport in the country, 4 more times the cargo registered in Monterrey.

Another three important terminals are Guadalajara, Monterrey and Tijuana not only by their amount of cargo handled during 2004, but also for their connectivity with the entire system, that reach the 50%. A second hierarchy level could be composed by those airports that managed an important quantity of cargo (around 1,000 to 9,999 tons annually), where two nearby cities in the Yucatan Peninsula, Merida and Cancun, are the most important cargo connections in this level but with a share characteristic of do not provide important connectivity (around 15% of the entire airport system) but with important amounts of freight basically by its importance as tourist centers. Hermosillo, which is the third most important airport in this group, gives an important connectivity to the northwestern part of Mexico (more than 30% of the national airport system). The remaining airports that composed lower hierarchy levels are terminals that move relative small amounts of cargo and with low levels of connectivity which and are closely related to connect those conurbations with Mexico City.

From the data obtained in the amount of cargo sent and received by the different aircargo terminals, it could be confirmed that the most important function of Mexico City airport is related to distribution; 62% of the freight handled by this terminal was associated to external allocation of cargo.

This characteristic is common just in 9 terminals (15% from total) in the country besides Mexico City: Monterrey, Oaxaca, La Paz, Mazatlan, Tapachula, Matamoros, Nuevo Laredo, Cuernavaca and Campeche, being Monterrey the most notable origin connection based on the amount of cargo managed by this point; five terminals (8% from total) have an equilibrated directional asymmetry and the remaining 45 connections (around 77% from total) are considered as receiver terminals of cargo, being the most important ones in cargo managed (33.3/66.6 path and more than 1,000 tons) is exposed in the next table:

TERMINAL	NUMBER OF CONNECTIONS	CARGO FROM ORIGIN	CARGO FROM DESTINATION	TOTAL CARGO	ACCUMULATED PARTICIPATION	PARTICIPATION ORIGIN	PARTICIPATION DESTINATION
TIJUANA	19	5,848,779	8,061,907	13,910,686	78.5032%	42%	58%
MERIDA	8	2,090,376	3,332,091	5,422,467	81.0677%	39%	61%
CANCUN	6	1,163,894	3,815,705	4,979,599	83.4228%	23%	77%
HERMOSILLO	18	955,313	2,368,149	3,323,462	84.9946%	29%	71%
CHIHUAHUA	7	1,232,891	1,648,664	2,881,555	86.3574%	43%	57%
VILLAHERMOSA	11	553,682	2,004,225	2,557,907	87.5672%	22%	78%
CD. JUAREZ	12	1,007,336	1,545,651	2,552,987	88.7746%	39%	61%
MEXICALI	6	648,735	1,724,302	2,373,037	89.8969%	27%	73%
CULIACAN	9	918,099	1,419,704	2,337,803	91.0026%	39%	61%
SAN JOSE DEL CABO	3	250,440	1,885,412	2,135,852	92.0127%	12%	88%
DEL BAJIO	10	640,167	1,060,887	1,701,054	92.8172%	38%	62%
PTO. VALLARTA	7	229,793	1,283,403	1,513,196	93.5329%	15%	85%
TUXTLA GUTIERREZ	3	226,448	1,264,044	1,490,492	94.2378%	15%	85%
VERACRUZ	7	214,215	1,051,381	1,265,596	94.8364%	17%	83%
ACAPULCO	7	179,297	1,067,099	1,246,396	95.4258%	14%	86%
TAMPICO	5	186,585	821,226	1,007,811	95.9025%	19%	81%

Table 19: Airports that registered domestic air cargo flows with more than 1,000 tons and expose a remarkable directional asymmetry in 2004.

In conclusion, directional asymmetry flows are mainly caused by the differences in economical and political activities between diverse regions and Mexico City. This characteristic is generalized in the entire system where the majority of air cargo terminals work as dependant reception centers. Nowadays, this situation makes cargo operations more difficult to handle, emphasizing the imposition of a different tariff for cargo managed according to the unbalance weight of cargo and moreover, the unbalance behavior of cargo transportation between pair cities involving Mexico City, as origin or destination, decreases profitability of any air cargo service derived from the important percentage of under-utilization from the other node.

4.10.2 ANALYSIS OF ORIGIN - DESTINATION FLOWS FOR INTERNATIONAL AIR CARGO TRANSACTIONS.

International air cargo movement actually has more relevance than current domestic air cargo. In fact, international freight managed by national airports almost double comparing to the quantity of cargo transported for domestic purposes.

During 2004, 328,752 tons of international cargo was handled by operations between Mexican airports. According to the historical development of domestic air cargo transportation, this amount registered in 2004 reflected an increment of approximately 9% comparing to last year results.

According to the data provided by the Secretariat of Communications and Transportation, during 2004 there exists 230 links that were registered realizing international air cargo operations in 33 different airports located in the country.

Similar to the domestic cargo case, actually there exists a disproportion on the amount of cargo handled by airports that handled international cargo in the country. Directional symmetry is analyzed according to airports´ behavior and some interesting results come out from the study.

For international air cargo transportation in Mexico, there exists an interesting performance by Louisville, KY, place where diverse parcel services are installed. This terminal is the only connection where cargo sent in the entire link is 100% handled by this point as well as receives 100% of the total cargo managed by another connection and the amount of cargo is remarkable (more than 1000 tons managed). This path is not unknown in air cargo transportation, where important airports used to manage all the cargo in different links; however, the amount of cargo sent and received by this terminal is the differentiator as well as describes completely the operative manner and strategy that this terminal is functioning out. Guadalajara is the direct connection to this terminal, sending more than 4,000 tons of cargo to this city and likewise, Louisville sends an approximate amount of cargo (4,200 tons) to Mexico City. This is the most important directional asymmetry case, but there are other notable cases. For instance, Madrid, one of the most important hubs in the Europe Union, participates with the 90% of the total cargo managed within Mexico City (more than 10,000 tons); also, Amsterdam, the most important seaport in EU and also one of the busiest airports in the world, dominates with the 75% of the total cargo established with Mexico City (32,000 tons during 2004). The most important international links with strong directional asymmetry will be shown by the next table with cargo flow above 1,000 tons of cargo moved and their proportion between links have a relation 66.6/33.3.

ORIGIN	DESTINATION	CARGO SENT (In kgs)	CARGO RECEIVED (In kgs)	PARTICIPATION ORIGIN	PARTICIPATION DESTINATION	TOTAL CARGO
AMSTERDAM	MEXICO	22,478,693	7,714,775	74.449%	25.551%	30,193,468
MEXICO	PARIS	7,472,413	17,314,906	30.146%	69.854%	24,787,319
LUXEMBURGO	MEXICO	14,881,519	3,676,412	80.190%	19.810%	18,557,931
MADRID	MEXICO	9,453,401	953,426	90.838%	9.162%	10,406,827
HOUSTON	MEXICO	1,629,916	7,929,779	17.050%	82.950%	9,559,695
MERIDA	MIAMI	5,936,450	1,375,671	81.186%	18.814%	7,312,121
MEXICO	SAO PAULO	1,637,181	5,636,870	22.507%	77.493%	7,274,051
GUADALAJARA	LUXEMBURGO	2,099,258	4,835,427	30.272%	69.728%	6,934,685
MEXICO	SAO PAULO	1,557,801	4,559,746	25.464%	74.536%	6,117,547
MEXICO	SANTIAGO DE CHILE	1,786,334	4,113,858	30.276%	69.724%	5,900,192
LOUISVILLE	MEXICO	4,282,685		100.000%	0.000%	4,282,685
GUADALAJARA	LOUISVILLE	4,080,375		100.000%	0.000%	4,080,375
CHICAGO	MEXICO	2,770,576	1,294,632	68.153%	31.847%	4,065,208
GUADALAJARA	SAN ANTONIO	333	3,539,776	0.009%	99.991%	3,540,109
MEXICO	SAO PAULO	497,735	2,704,813	15.542%	84.458%	3,202,548
MEXICO	NEW YORK	2,361,275	403,285	85.412%	14.588%	2,764,560
BUENOS AIRES	MEXICO	1,542,355	278,051	84.726%	15.274%	1,820,406
DALLAS	MEXICO	481,975	963,378	33.347%	66.653%	1,445,353
LIMA	MEXICO	1,117,611	246,668	81.920%	18.080%	1,364,279
ATLANTA	CANCUN	32,675	1,320,887	2.414%	97.586%	1,353,562
CANCUN	MIAMI	208,639	975,681	17.617%	82.383%	1,184,320
MEXICO	NEW YORK	1,080,912	37,909	96.612%	3.388%	1,118,821
GUADALAJARA	MIAMI	1,070,886	2,730	99.746%	0.254%	1,073,616
CARACAS	MEXICO	146,773	904,015	13.968%	86.032%	1,050,788

Table 20: International air cargo links with important asymmetry directions

From this table it could be identified that Mexico City is the most important hub for international cargo operations, participating in the 70% of the operations that contain an important directional asymmetry. Differing from the domestic cargo behavior in where this airport is considered as the national distributor of cargo, for international cargo operations this terminal is the main receptor of cargo in the country. This affirmation is initially reaffirmed because during last year, just in 5 of the 17 links in where Mexico participates, its function is considered as distributor.

From the total amount of links, just 4 pairs have an equilibrated distribution of cargo flow, being Memphis-Toluca (19,311 tons), Dayton-Monterrey (9,985 tons), Mexico-Guatemala (8,550 tons) and Cincinnati-Guadalajara (4,860 tons) the most important pairs based on their amount of cargo transported in 2004.

In summary, 35 origin-destination pairs representing 15.2% of the total amount of cargo transportation links registered during 2004 have a 60/40 cargo distribution, which could be established as the upper limit to consider those links as relative equilibrated. 184 of the 230 connections (80%) have at least 66.6/33.3 cargo flow behavior, 161 connections have a 75/25 proportion and 153 of them perform as 80/20 proportion. Relation 90/10 incurs on 120 cases being Atlanta-Cancun (2.4% - 97.6% relation, 1354 tons respectively), Madrid- Mexico (91% - 9%, 10,407 tons) and Guadalajara- San Antonio (0.01% - 99.99%, 3450 tons) the most outstanding connections that incur in this category, and 100/0 give asymmetry directions with 76 cases, where significant amounts are located on the connections Louisville - Guadalajara (4,080 tons), Mexico - Louisville (4,300 tons) and San Jose, CR – Guadalajara (850 tons).

A complete table with all the information about total international cargo handled by each national airport as well as number of connections per airport, cargo sent and received by airport and accumulated participation by airport is shown below. It is important to comment that Toluca International Airport, which did not register any domestic cargo operation during 2004, registered an important amount of international cargo managed by its terminal.

TERMINAL	NUMBER OF CONNECTIONS FROM ORIGIN	CARGO SENT BY AIRPORT	NUMBER OF CONNECTIONS WHERE PARTICIPATES AS DESTINATION	CARGO RECEIVED BY AIRPORT	TOTAL CARGO BY AIRPORT	PARTICIPATION BY AIRPORT
MEXICO	58	72,430,284	25	71,648,544	**144,078,828**	58.943257%
GUADALAJARA	26	40,514,412	11	5,382,037	**45,896,449**	18.776431%
MONTERREY	10	11,195,767	10	11,119,104	**22,314,871**	9.129108%
TOLUCA	1	9,759,113	2	9,552,186	**19,311,299**	7.900334%
MERIDA	3	6,451,606	2	83,347	**6,534,953**	2.673477%
CANCUN	13	2,762,722	12	112,355	**2,875,077**	1.176206%
SAN JOSE DEL CABO	10	974,257	9	183,533	**1,157,790**	0.473657%
PTO. VALLARTA	7	888,366	8	164,307	**1,052,673**	0.430653%
MAZATLAN	4	140,238	3	552,105	**692,343**	0.283240%
DEL BAJIO	6	277,559	2	5,931	**283,490**	0.115977%
CIUDAD DEL CARMEN			2	88,904	**88,904**	0.036371%
TIJUANA	1	34,976			**34,976**	0.014309%
ZIHUATANEJO	3	14,370	4	8,053	**22,423**	0.009173%
ZACATECAS	3	3,084	3	15,519	**18,603**	0.007611%
MORELIA	3	600	3	17,516	**18,116**	0.007411%
COZUMEL	1	11,815	2	967	**12,782**	0.005229%
OAXACA			2	8,274	**8,274**	0.003385%
ACAPULCO	2	3,480	4	4,387	**7,867**	0.003218%
DURANGO	1	400	2	6,925	**7,325**	0.002997%
MANZANILLO	2	5,519	2	1,187	**6,706**	0.002743%
HERMOSILLO	5	3,816			**3,816**	0.001561%
VERACRUZ	1	1,544	1	1,346	**2,890**	0.001182%
MEXICALI	3	1,435			**1,435**	0.000587%
AGUASCALIENTES	1	477	1	511	**988**	0.000404%
VILLAHERMOSA	1	135	1	645	**780**	0.000319%
SAN LUIS POTOSI			3	678	**678**	0.000277%
CHIHUAHUA	1	150	1	334	**484**	0.000198%
TAMPICO			1	461	**461**	0.000189%
MONCLOVA			1	352	**352**	0.000144%
LORETO			1	340	**340**	0.000139%
TORREON			1	286	**286**	0.000117%
SALTILLO	1	45	1	91	**136**	0.000056%
PUEBLA			1	68	**68**	0.000028%
CULIACAN	1	26			**26**	0.000011%

Table 21: National airports that registered movements of international air cargo during 2004.

Once more, Mexico City is the most important hub on international air cargo transportation operations based on its amount of cargo handled by this terminal. Some reasons for this achievement are:

a) An important capacity and agility to supply and receive goods from the most important airport as well as most significant population and industrial center in the country (same reason as domestic cargo).
b) An important connectivity of the airport with different destinations in the world as well as domestic destinations.
c) Restriction in transportation modes to realize trade between countries as well as inefficiency for handling cargo by the origin and/or destination country.

Also, from this table it could be observed that Guadalajara emerges as one of the most important worldwide distributor mainly based on its participation as a supplier of an important amount of cargo compared to its reception of cargo during 2004.

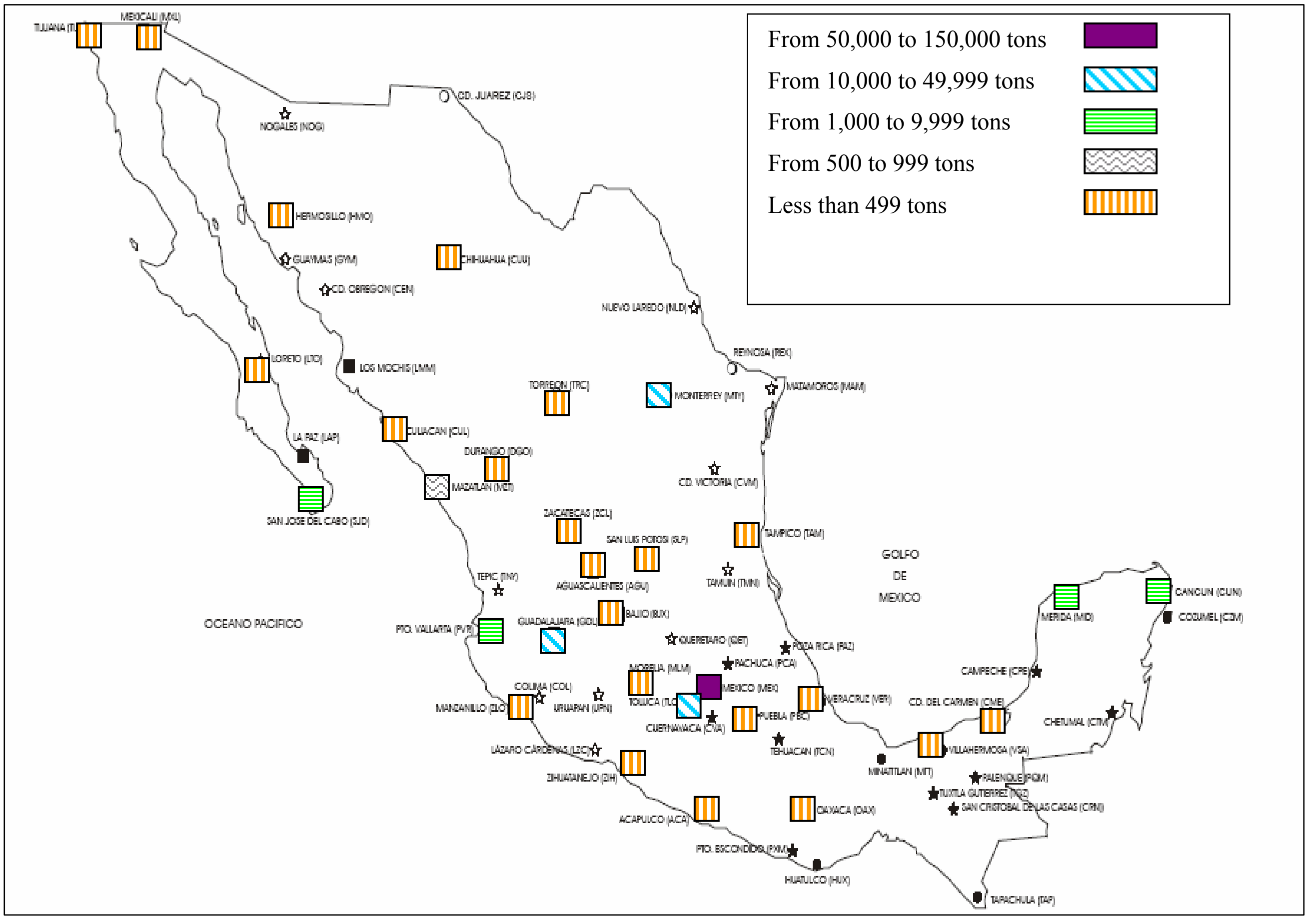


Figure 13: Airports with international cargo movements during 2004 distinguished by amount of cargo handled by cargo unit.

From this map we could observe the dispersion of air cargo infrastructure located in the country as well as the diminishment of international cargo operations by airports in Mexico. Lack of geographical homogeneousness could be observed in this map. Also, in comparison with domestic air cargo in where airports that registered domestic air cargo movement were mainly located on seaport zones and almost the half of the entire system were located either in coastal or international border sites, on international cargo terms this path does not perform in the same manner. From an observation described before, international movement of cargo is dominated by the connectivity of the airport, which is a sparse characteristic of the entire system, as well as other implications that could be cited.

For example, an important amount of cargo is located in significant population concentrations as well as tourist centers in Mexico. Another distinction is the availability of custom areas for reception of international cargo in addition to important infrastructure of port/entry zones.

Also from this analysis, it can be exposed the most important international airports that realized cargo movement with Mexico. In North America, Memphis (31,150 tons) and Los Angeles (23,430 tons) are the most remarkable airports in cargo managed terms. From the European Union, Amsterdam (22,800 tons) and Luxembourg (19,720 tons) are the most significant cargo providers and Sao Paulo (13,000 tons) is the most significant terminal that sends cargo from South America. Curiously, important amount of cargo from Asia is not reflected in this study, being only Tokyo (500 tons) the most notable terminal from this part of the world. An easy explanation for this behavior is derived from the important distance and cost to sent cargo by this mean of transportation.

Conversely, the major international destinations of air cargo transportation realized in Mexico are: Memphis, TN (22,790 tons), Los Angeles (10,800 tons) and Miami (10,950 tons) in North America; Paris (7,500 tons) and Luxembourg (2,100 tons) in EU, Tokyo (820 tons) for Asian destinations and finally Sao Paulo (3,200 tons) and Santiago (1,800 tons) are the most remarkable destinations of international cargo generated by Mexican airports.

In conclusion, directional asymmetry flows appears one more time motivated by the capacity to receive international cargo by few national airports as well as diverse strategies realized by companies that could be inferred from the direction of cargo flows and destinations in which companies allocate their operations (for example, the major hub of UPS located in Memphis which receives cargo only by Guadalajara International). In overall terms, based on a quantitative analysis of the 2004 domestic and international freight flows, the most important links and nodes that take part on the air cargo transportation network are identified. Next, their major operative characteristics are attempted to be determined base on numerical models and performance evaluations looking to find those terminals that achieve efficient movement of cargo identifying factors that might influence the behavior of Mexican air cargo industry.

5. DESCRIPTIVE ANALYSIS OF OPERATIONAL PERFORMANCE IN MEXICAN AIR TRANSPORTATION SYSTEM

5.1 INTRODUCTION

Following with the descriptive analysis mentioned on chapter 4, the intention of this section is to replicate the behavior of cargo movement in Mexico by the application of mathematical techniques that intent to deploy the functioning of the national air cargo system.

The proposal of this section is to realize a numerical representation that intent to describe the performance of the air cargo activities existed among the national air cargo nodes. The variables used for the calculations will be chosen according to environmental parameters that could affect the performance of the system and they will be tested by the utilization of mathematical techniques based on regression analysis looking to define if the variables selected to integrate the model have the capability to describe or predict the performance of cargo flows generated by the terminals and possible changes in the values of the independent variables.

The main premise of this numerical analysis is to determine if the application of the mathematical analysis with the variables selected provide the capability to generate useful information for the descrption of the amount of cargo generated by a specific node based on the behavior of the independent variables chosen for this analysis. As a result, it could lead to air cargo service providers to analyze possible investments as well as aid to stimulate the development of cargo operations on diverse regions of Mexico by the national government that could lead to facilitate the mobility of cargo along and outside the country.

A model is a simplified and measurable representation of the real life. Its purpose is to replicate the functioning of that reality, considering it as a system based on the identification of the most relevant relations that could exist, either in the components of the system or the environment, and therefore to utilize those possible relations and have valid conclusions about the behavior of the system according to a group of determined conditions (Rico, 2001).

Ackoff (1987) define three different classes of representations: models that represent the reality by images and graphs. Some examples of this category could be engineering plots, maps, scale models of airplanes, cars, and so on. Another type of models are those that are characterized by "functioning" in a similar way to the observable fact that try to describe. An example could be the hydraulic models. Finally the exists symbolic models that utilize letters and numbers for building mathematical functions composed by constants and variables that reproduce the current relations that interact with the components or the environment of the system. This is the type of model that is going to be proposed in this study, trying to incorporate the adequate number of variables and relations for feasibly represent the occurrences in the domestic air cargo industry.

Rico (2001) defines that the main purpose of a model that attempts to represent the mobility of the human society is to imitate or reproduce the performance of people and/or merchandise flows and the behavior of transportation systems. This type of representations are defined as demand models mainly because they represent the behavior of the transportation elements trying to foresee the performance of the different users and/or commodities flows inside a transportation system.

Manheim (1979) established that particular characteristics from transportation demand (i.e. mobility), can be recognized based on factors that belong to a pair of systems in particular: the economical and social activities in a determined place in where this particular characteristic takes part and the transportation system in which demand is attended.

Mathematical models of transportation demand have a functional structure in which the independent variables have relation, explain and determine the values of the dependant variable (Rico, 2001). The diverse types of independent variable that could take place on the activities of transportation systems and could be used to give an explanation about the behavior of a variable closely related to the transportation demand, depend on the structure of the model and the availability of information. Generally, economical, operative and technological characteristics are taken from transportation systems to be added in the model.

There are an extensive literature concerning about problems for air cargo industry. From the quantitative analysis perspective, there are several studies relating to urban systems flows, focusing on population and industrial transportation in the domestic or international perspective. Matsumoto (2004) analyzed some environmental factors that could affect international air passenger and cargo flows in the context of the relationships or connectivity across major cities for determined geographical zones. Those factors used are GDP per capita, population of selected cities and a measure of workload named “WLU”, based on the amount of passengers served and cargo freights managed by the airport. Some other research has analyzed particular urban systems from the viewpoint of international air traffic flows, including urban systems dealing with the US and Canada (Murayama, 1991), and Asian urban systems focusing in particular on Japan and Korea (Park, 1995).

From the Mexican perspective, there is an important study realized by Rico (2001); in this research, a quantitative analysis of the 1999 origin – destination freight flows were developed by the utilization of a Zipf’s Law based model, in where a functional nodes classification is proposed and structural relations among national airports are determined. Also, three different numerical models were constructed, based on multiple regression models and trying to replicate the air cargo flow phenomenon in addition with the spatial interaction among the cargo nodes using a logarithmic transformation.

Nowadays, the most important models used to represent cargo flows are those ones that are based on multiple regression analysis between the amount of cargo generated by each connection and a set of distinctive variables that describe the activities in each node (Rico, 2001; Ortuzar and Willumsen, 1994, referenced by Rico, 2001). Multiple regression analysis is a multivariate statistical technique used to examine the relationship between a single dependent variable and a set of independent variables (Hair et al., 1998).

The regression line or surface that is obtained in regression calculations using the least squares method of Gauss, attempt to find the best design that could be adjusted to the dispersion of the points (observations) in a way that the differences between the real values and the predicted by the equation of the model could be minimum from the mathematical perspective.

From this model, regression surface is defined taken the first derivate of the equation equal to zero and find every particular parameter of the function. The statistical approach for the relation keeping between variables is found and allow to calculated values for the dependant variable based on the proposed results on the independent variables.

According to the different literature background and based on the primarily objective of this study, some models that describe the behavior of cargo flows inside the domestic air transportation system will be made. These models could be divided according to the different situations that take place in the air transportation structure in Mexico. One model is focused on the cargo generation in every airport (metropolitan area) in the system and another model attempts to reproduce the cargo attraction per airport (cargo received from different conurbations/airports).

5.2 SUGGESTED PROCEDURE FOR DEVELOPMENT MATHEMATICAL MODELS IN THE STRATEGIC AIR TRANSPORTATION SYSTEM IN MEXICO

The suggested procedure for the development of a mathematical model is exposed next:

1. To define the research problem to confront and verify its appropriateness to solve it with multiple regression methods.

2. Independent variables are determined seeking for a possibly relationship within them and the response variable (air cargo generated/received by each airport) and trying to explain the particular behavior of each specific observation.

3. Review the conformity of each individual variable with the assumptions underlying multivariate regression. These assumptions will be explained during the model creation (section 5.3).

4. Correlation is calculated within the independent variables and with the dependent variable selected (cargo generated/received), and those variables that presumably have a good explicative relation with the dependent are chosen as candidates to integrate the model. Also it is important to verify the existent correlation within independent variables and do not incorporate to the model those variables that are highly correlated within them to avoid problems of multicollinearity.

5. Regression equations will be realized using a combinatorial approach in where initially each variable is tested in the regression model and then, those variables are combining looking for the best arrangement defined by the regression statistics calculated for each regression model resulted from the analysis.

6. Assumptions for complying with multiple regression statements are analyzed for the proposed model.

7. The analysis of variance (ANOVA) is performed in order to test the regression calculations and to proof its validation for the specific instance in where this technique is implemented.

8. A set of conclusions and experiences from the conception and realization of the models will be displayed at the end of the analysis.

5.3 MATHEMATICAL MODEL OF DOMESTIC CARGO GENERATION

Cargo generation models pretend to calculate the amount of freight that is derived or generated from specific terminals that compose the transportation system. The quantity of cargo produced by a connection is a result of the economical and social interaction of the geographical area that the terminal belongs and could be explained by the influence that a determined metropolitan area achieve in the area where the terminal is allocated. The model tries to determine those general relations in the system that could explain the occurrences in every particular case based on their individual values.

To initiate the process of modeling, the definition of the research problem to confront and verify its appropriateness to solve it with multiple regression method is the first step. The next paragraphs will cover this objective.

Hair et al. (1997) divide the application of multiple regression analysis in two main classes: predictive and descriptive problems. Application of multiple regression procedures can address either or both type of problems. For our discussion, the problem definition is primarily to describe the current generation of domestic cargo realized by national airports by multiple regression technique according to a series of independent variables that could portray the performance of the domestic air freight system.

The next step for the creation of the model continues when independent variables, that presumably have a strong relation with the cargo generated in each connection, are defined based on extensive judgment and available information. The selection of the dependent variable should be based on the accuracy and consistency that the selected variable adds to the defined problem. This concept is well known as **measurement error** (Hair et al., 1997). If the variable has considerable measurement error, even though when the best independent variables are chosen, the model might be unable to achieve acceptable levels of accuracy. Hair et al. (1997) defines that, for the independent variables selection, **specification error** is the most important issue to tackle; the inclusion of irrelevant variables or the omission of relevant variables could replace the effects of more useful variables and diminish the descriptive power while error increases.

Applying the concepts expressed above for our problem instance, the multiple regression function from Gauss and attempted to be applied to the cargo generation model is:

$$V_j = a + b_1\left(X_1\right)_j + b_2\left(X_2\right)_j + b_3\left(X_3\right)_j ... + b_n\left(X_n\right)_j$$

Where:

V_j = Amount of cargo generated by the j^{th} connection

a = Parameter calculated by the model and represents the intersection with the "x" axis.

b_i = Parameter to determine by the model which defines the rate of change of the dependent variable based on variations of the i^{th} independent variable.

$(X_i)_j$ = i^{th} independent variable in the j^{th} connection and determines the augmentation rate defined by the i^{th} coefficient.

Dependent variable V_j was chosen as the ***amount of cargo generated by each airport*** that integrates the entire national system, and the independent variables that were chosen initially, based on their explanation potential of cargo generation, are defined next:

- **X1: Simple average distance between origin-destination connections.** Defined as the simple average value between all the destinations that each airport serves in kilometers. It reflects the geographical characteristics of the node in respect with its connections. The data source is the description of the Mexican air transportation system provided by the Secretariat of Communication and Transportation (SCT) of Mexico.

- **X2: Number of connections by cargo generator.** Defined as the connectivity measure of the airport in cargo terms inside the national air cargo system. It is the number of destinations that each airport provides services nowadays. The data source is the description of the Mexican air transportation system provided by the Secretariat of Communication and Transportation (SCT) of Mexico.

- **X3: Total population by metropolitan area.** The data source is the National Statistical Office (INEGI) XII Census for 2000. All of the data was gathered for each of the cargo generators.

- **X4: Number of wholesale trade installed by metropolitan area (economical units).** The data source is the National Statistical Office (INEGI) XII Economical Census for 2000. It represents the number of wholesaler's industry allocated in the metropolitan area in where a particular airport serves.

- **X5: Number of manufacturing industries per metropolitan area (economical units).** The data source is the National Statistical Office (INEGI) XII Economical Census for 2000. It represents the number of manufacturing companies that are allocated in the metropolitan area where a particular airport serves. The manufacturing industries selected to be incorporated to this process and defined according to NAICS[12] code are:

    - ***Machinery manufacturing (333)***
    - ***Computer and Electronic product manufacturing(334)***
    - ***Electrical equipment, appliance and component manufacturing (335)***
    - ***Transportation equipment manufacturing (336)***
    - ***Furniture and related product manufacturing (337)***
    - ***Miscellaneous manufacturing (339)***

- **X6: Number of transportation and warehousing services established in metropolitan area (economical units).** The data source is the National Statistical Office (INEGI) XII Economical Census for 2000. It represents the number of transportation and warehousing services that are allocated in the metropolitan area where a particular airport serves. From the definition provided by NAICS, the economical units selected to be incorporated in this variable are:

[12] Abbreviation for North America Industry Classification System (NAICS)

- ***Postal Services (491)***
- ***Expedited Couriers (492)***
- ***Warehousing and storage services (493)***

Sample size is an important fact that must be addressed in order to achieve the generalizability of the results. Hair el al (1997), Devore (1998) define as a "thumb" rule that the ratio of observations to independent variables should never fall below 5 to 1, meaning that there should be five observations for each independent variable in the variate. When this level is reached the results should be generalizable. In this problem instance, there are 6 proposed independent variables to integrate the regression model and 55 airports were tested, leaving a 9 to 1 ratio that allows meeting the terms with the sample size assumption.

Before the realization of the regression model design, individual variables must meet the assumptions underlying multivariate regression. The assumptions to be examined are as follows (Hair et al., 1997):

- ***Normality:*** The most fundamental assumption in multivariate analysis is normality, referring to the shape of the data distribution for an individual metric variable and its correspondence to the normal distribution. If an important variation exists from the normal distribution, all statistical tests are invalid. Normality tests required the use of F and t statistics in order to obtain proper conclusions about the hypothesis tested.
- ***Homoscedasticity or Homogeneity of variance:*** Assumption related primarily to dependence relationships between variables and refers to the supposition that dependent variable exhibit equal levels of variance across the range of predictor variables. This characteristic is desirable because the variance of the dependent variable explained in their relationship do not be concentrated in only a limited range of independent values.
- ***Linearity:*** An implicit assumption of all multivariate techniques based on correlation measures of association is linearity. Because correlation represents only the linear association between variables, nonlinear effects will not be represented in the correlation value.

If individual variables do not meet the assumptions stated before, data transformation must be developed to correct violations of the statistical assumptions and to improve the relationship between variables. There are several techniques for data transformation according to the violation in which the individual variable is incurring. For this problem instance, analysis per individual variable will be realized and, if some violation is incurred, transformation of data should be developed. The first analysis to be conducted is the *normality test*, using normal probability plots for both dependent and independent variables:

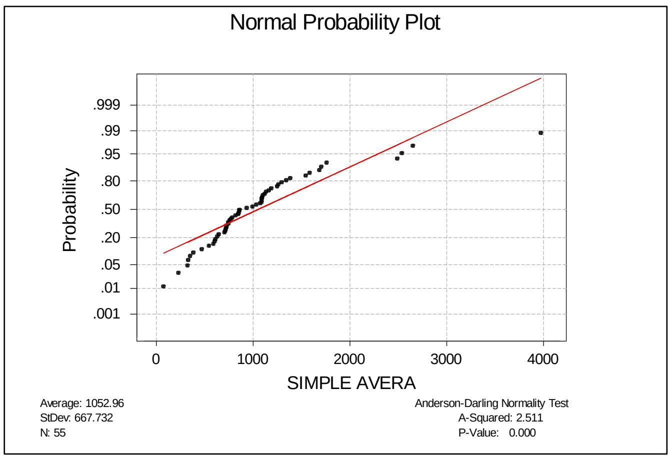


Figure 14: Normal probability plot of X1 (Simple average distance between origin-destination connections)

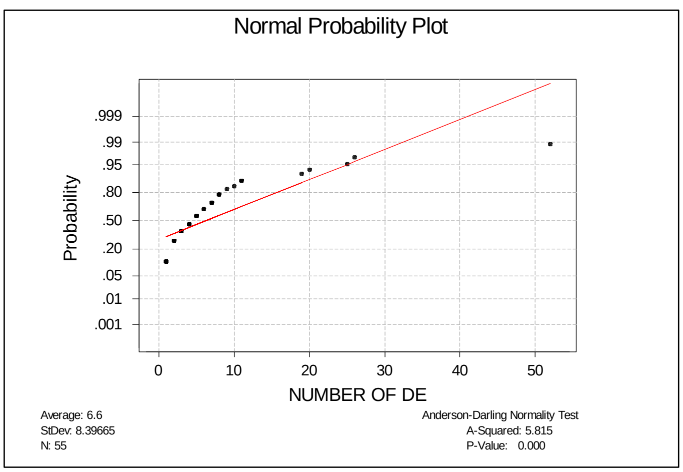


Figure 15: Normal probability plot of X2 (Number of connections by cargo generator)

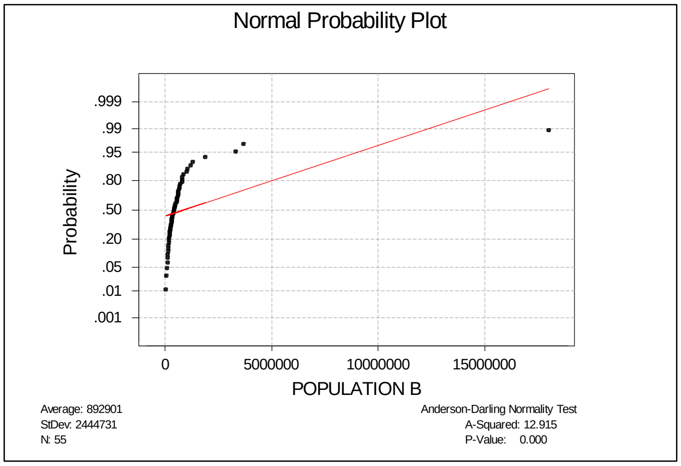


Figure 16: Normal probability plot of X3 (Total population by metropolitan area)

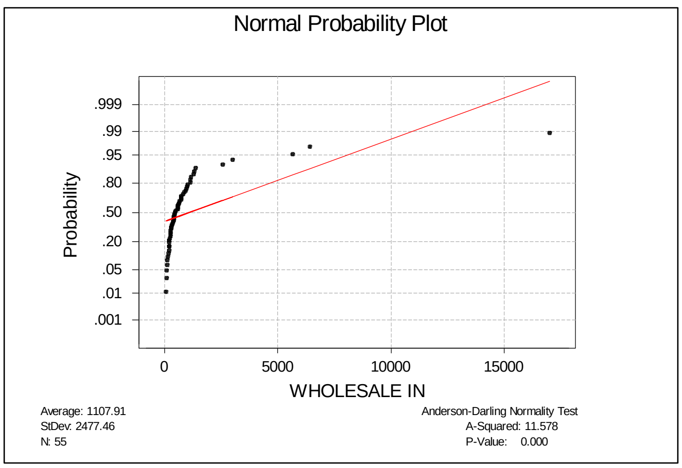


Figure 17: Normal probability plot of X4 (Number of wholesale trade industries installed by metropolitan area (economical units).

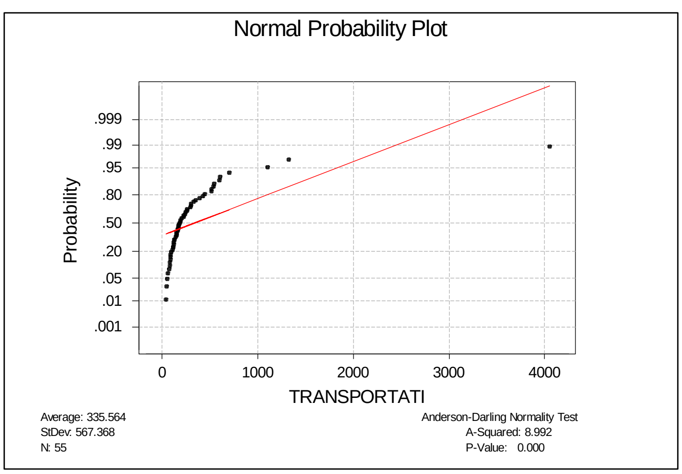


Figure 18: Normal probability plot of X5 (Number of transportation and warehousing services allocated by metropolitan area (economical units).

Figure 19: Normal probability plot of X6 (Number of manufacturing industries allocated by metropolitan area (economical units).

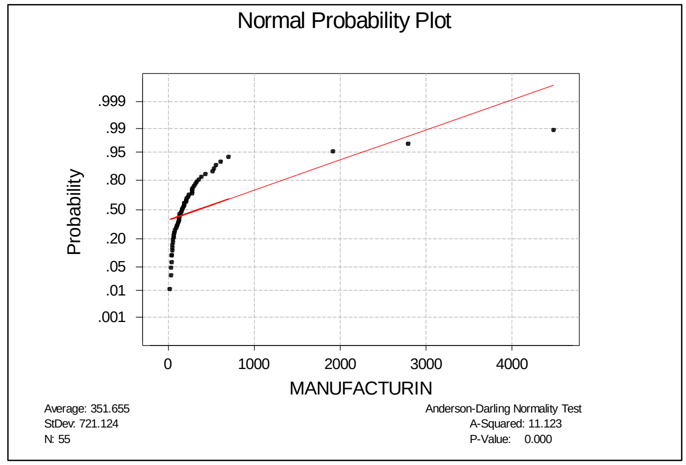
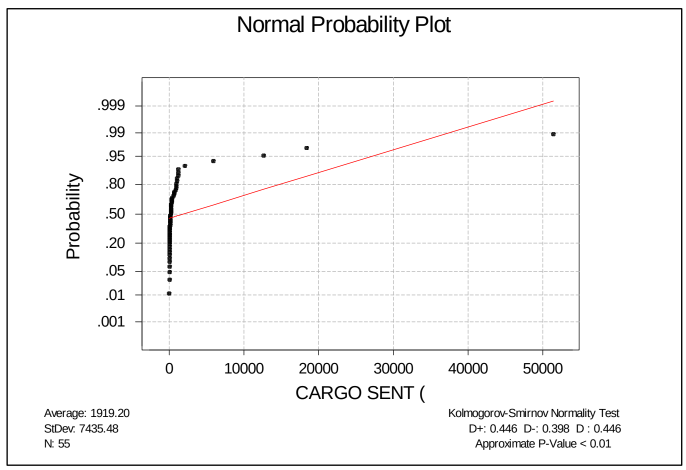


Figure 20: Normal probability plot of V_j (Cargo sent by airport).



From these graphs, it is evident the departure from the diagonal, indicative of lack of normality of the data. Simple statistical tests to reaffirm this statement could be shown by the skewness[13] and kurtosis[14] values of each variable as well as the graphical analysis per variable:

[13] Measure of symmetry in a distribution. A positively skewed distribution has relatively few large values and tails off to the right and a negatively skewed distribution has relatively few small values and tails off to the left.

[14] Measure of the peakedness or flatness of a distribution compared with a normal distribution. Positive values indicate a peakedness distribution and negative values indicate flatness in its distribution.

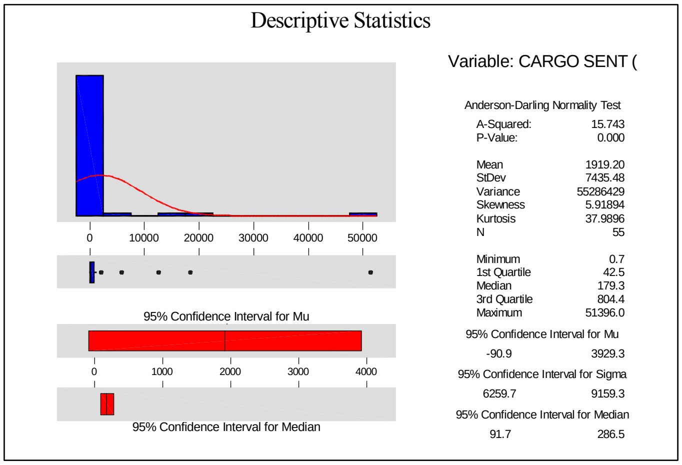


Figure 21: Descriptive statistics plot of V_j (Cargo Sent by airport).

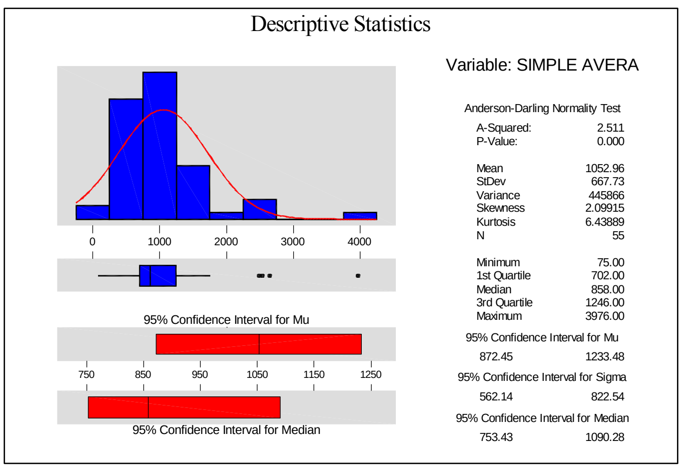


Figure 22: Descriptive statistics plot of X1 (Simple average distance between origin-destination connections).

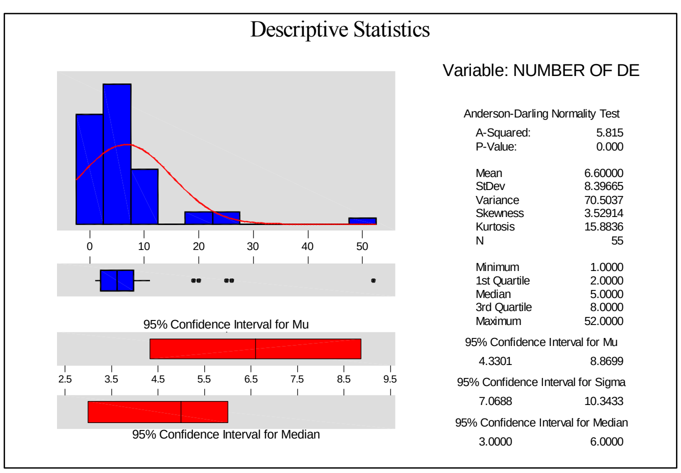


Figure 23: Descriptive statistics plot of X2 (Number of connections by cargo generator).

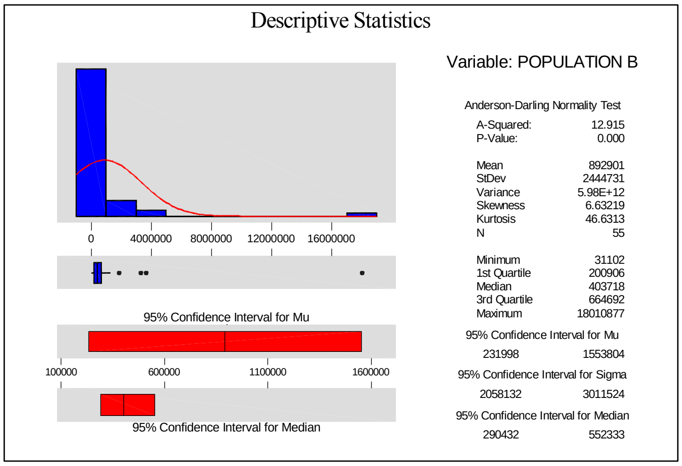


Figure 24: Descriptive statistics plot of X3 (Total population by metropolitan area).

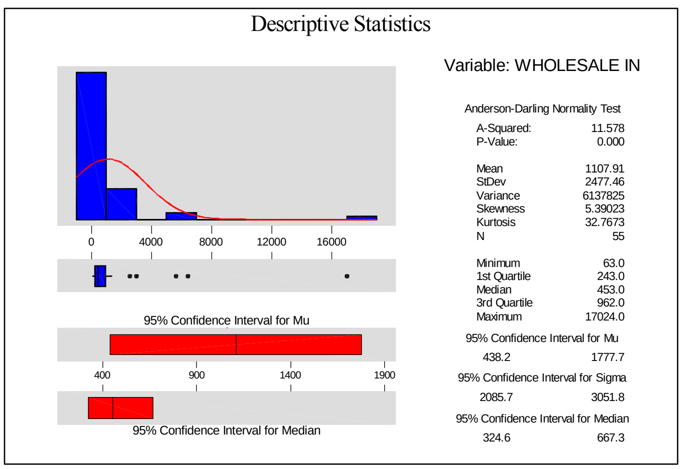


Figure 25: Descriptive statistics plot of X4 (Number of wholesale trade industries installed by metropolitan area (economical units).

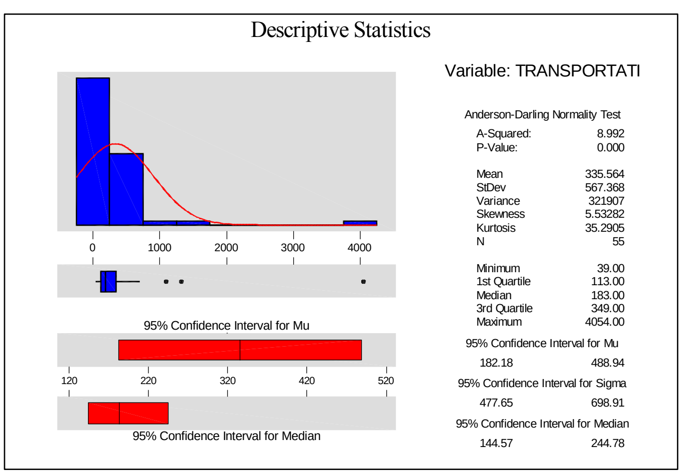


Figure 26: Descriptive statistics plot of X5 (Number of transportation and warehousing services allocated by metropolitan area (economical units).

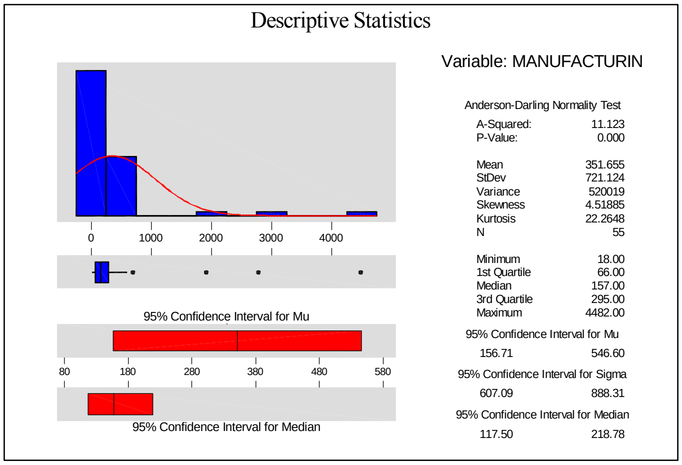


Figure 27: Descriptive statistics plot of X6 (Number of manufacturing industries allocated by metropolitan area (economical units).

From the graphical analysis of the data, independent variables as well as the dependent variable chosen for the analysis, perform with positive skewed and flatness in its distribution shape, just differing variable X1 (Simple average distance between origin-destination connections), which has a peakedness distribution shape. According to Hair et al (1997), for the homogeneity assumption measurement, most problems with unequal variances comes from two main sources; the first one in based on the type of variables incorporated into the model and has variable increases/decreases in value. There is a naturally wider range of possible answers for the larger values; the second case comes from skewed distribution results that create important dispersion patterns.

Hence, based on the deployed graphs for each variable, there are an unequal dispersion of the data caused by the skewness of each variable and transformation of data should be perform in order to make reliable calculations.

Data transformations provide the principal means of correcting non-normality and unequal dispersion of the data (Hair et al., 1997). There exist different types of transformations:

- For non-normal distributions, flat patterns could be transformed with the inverse value of each observation.
- Skewed distributions could be changed taking the square root, logarithms or inverse of each variable's observation.
- For positive skewed distributions, logarithm works well in these cases and
- For negative skeweness, square root transformation is proper to tackle this kind of distribution's shape (Hair et al., 1997).

Based on the stated before and the particular shapes that are shown by our variables, data transformation will be based taking the logarithms for each observation in the proposed variables, and then verifying if the change makes an appropriate modification to normality. Table 22 shows the results provided by the transformation of the real values of each variable using the logarithm of each observation and then, to corroborate the proper changes to normality generated by the transformation of the real values will be displayed by the plots 28 to 34.

CARGO SENT (Tons)	SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	NUMBER OF DESTINATIONS BY AIRPORT	POPULATION BY METROPOLITAN AREA, INEGI 2000	TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	WHOLESALE INDUSTRY (ECONOMICAL UNITS)
4.711	3.048	1.716	7.256	3.608	3.651	4.231
4.265	3.074	1.415	6.566	3.122	3.445	3.807
4.100	3.016	1.398	6.518	3.041	3.282	3.753
3.767	3.405	1.301	6.105	2.462	2.780	3.066
3.320	3.227	0.954	5.899	2.377	2.438	3.135
3.091	2.933	0.845	5.818	2.299	2.521	3.011
3.079	3.246	0.477	5.663	2.167	2.334	2.769
3.066	3.096	0.903	5.599	2.274	2.079	2.697
3.021	3.101	1.000	5.516	2.262	2.033	2.637
3.003	3.189	1.041	6.082	2.543	2.726	2.961
2.980	3.200	1.279	5.737	2.779	2.439	2.992
2.963	3.041	1.041	5.733	2.585	2.310	2.934
2.961	2.508	0.903	5.212	2.223	1.568	2.386
2.905	2.895	0.699	5.255	1.964	2.161	2.515
2.812	3.232	0.602	5.740	2.624	2.360	2.858
2.806	2.912	0.845	6.012	2.649	2.636	3.477
2.743	2.971	1.041	5.779	2.104	2.377	2.857
2.552	3.031	0.699	5.606	2.344	2.196	2.618
2.520	3.035	0.301	5.490	2.708	2.121	2.316
2.479	2.798	0.903	6.003	2.470	2.581	2.983
2.451	2.671	0.000	5.576	2.412	2.255	2.563
2.399	3.599	0.477	4.493	2.079	1.255	1.991
2.361	3.054	0.845	5.197	2.155	1.778	2.292
2.355	2.933	0.301	5.694	2.210	2.262	2.801
2.331	2.855	0.699	5.773	2.708	2.225	2.863
2.290	3.036	0.845	5.399	2.196	1.708	2.262
2.271	2.769	0.699	5.823	2.734	2.312	2.914
2.254	3.113	0.602	5.793	2.407	2.243	2.783
2.213	2.846	0.699	5.850	2.509	2.470	3.058
2.196	2.850	0.845	5.303	2.086	1.806	2.389
2.064	2.860	0.778	5.100	1.898	1.519	2.292
2.053	2.997	0.903	5.749	2.348	2.547	3.109
2.045	2.929	0.000	5.791	2.476	2.496	2.815
1.987	2.518	0.778	5.930	2.726	2.742	3.115
1.969	2.810	0.000	5.510	1.908	1.663	2.431
1.936	2.579	0.602	5.896	2.845	2.435	3.058
1.845	2.925	0.301	4.977	2.230	1.568	2.117
1.751	2.784	0.477	6.275	2.776	2.846	3.407
1.697	3.129	0.000	5.085	2.143	1.820	1.869
1.688	3.064	0.477	5.367	2.276	1.973	2.500
1.663	3.397	0.602	5.899	2.243	2.111	2.755
1.629	2.781	0.699	5.466	2.053	2.049	2.600
1.605	3.423	0.000	5.103	1.724	1.681	2.220
1.481	2.735	0.699	5.631	2.384	2.447	2.764
1.419	3.037	0.477	5.361	2.161	2.711	2.603
1.363	2.872	0.000	5.324	1.924	1.898	2.403
1.241	2.858	0.000	5.396	1.845	2.076	2.465
0.880	2.879	0.000	5.535	2.033	1.991	2.616
0.791	2.870	0.000	4.859	1.690	1.544	1.949
0.551	3.141	0.000	5.640	2.104	2.173	2.656
0.542	1.875	0.000	4.773	1.613	1.699	1.799
0.449	3.039	0.000	5.051	1.591	2.086	2.301
0.390	2.887	0.301	5.281	1.929	1.820	2.417
0.331	2.540	0.301	5.179	1.869	1.477	2.037
-0.163	2.352	0.301	5.452	2.053	1.633	2.356

Table 22: Transformation of data for normality and homoscesdasticity in cargo generation model creation.

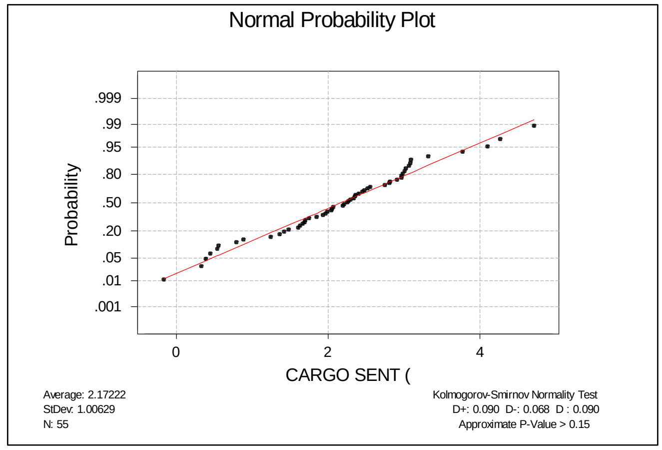


Figure 28: Normal probability plot of transformed V_j (Cargo sent by airport)

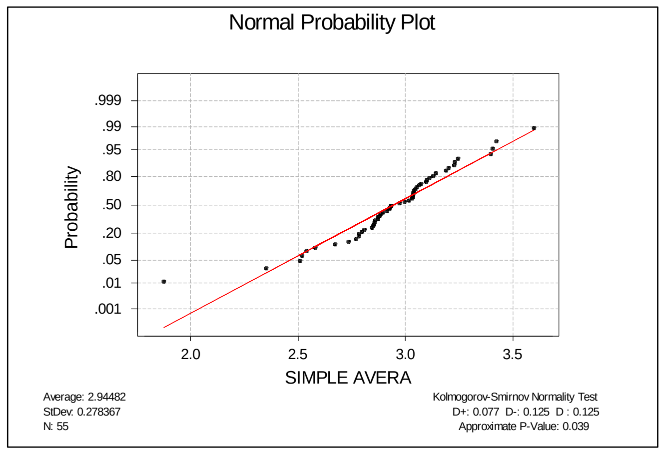


Figure 29: Normal probability plot of transformed X1 (Simple average distance between origin-destination connections)

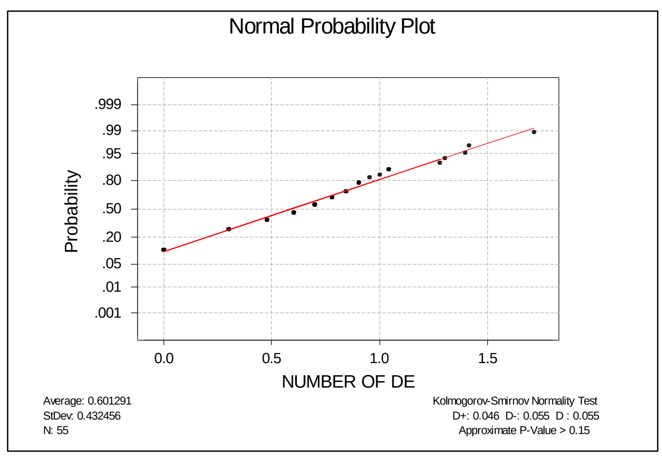


Figure 30: Normal probability plot of transformed X2 (Number of connections by cargo generator)

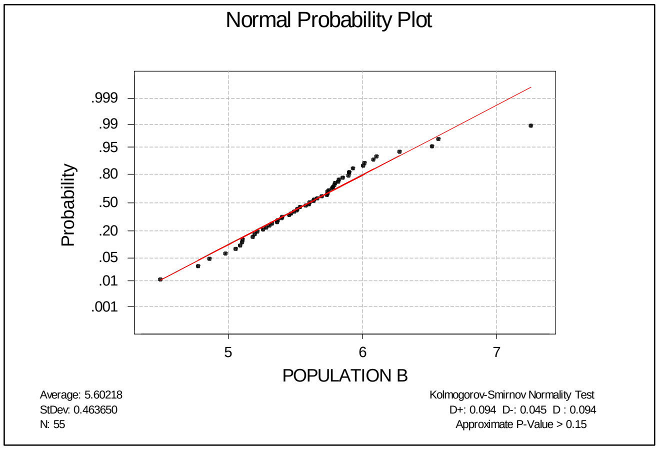


Figure 31: Normal probability plot of transformed X3 (Total population by metropolitan area).

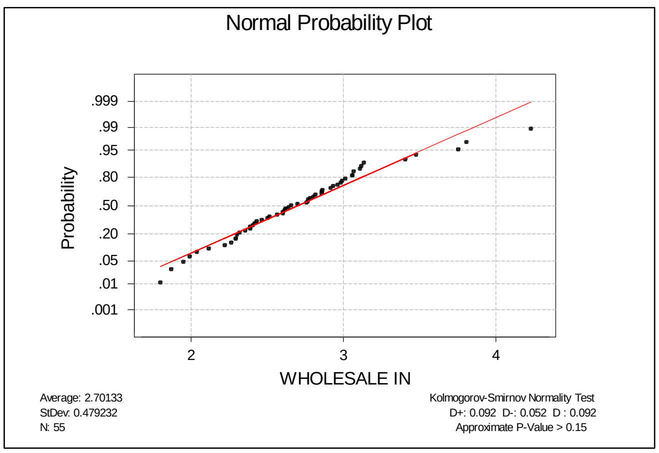


Figure 32: Normal probability plot of transformed X4 (Number of wholesale trade industries installed by metropolitan area (economical units).

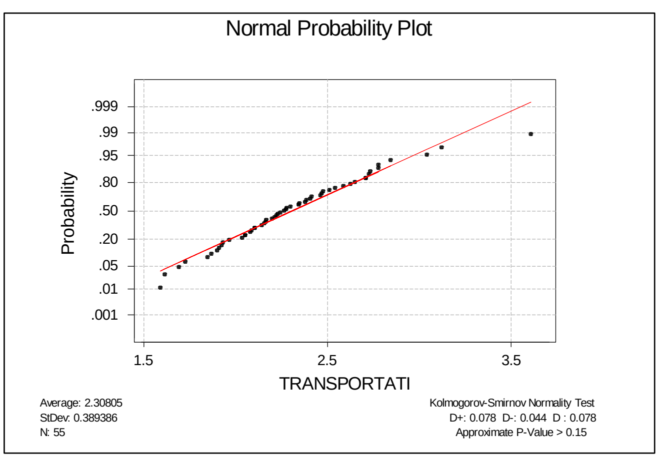


Figure 33: Normal probability plot of transformed X5 (Number of transportation and warehousing services allocated by metropolitan area (economical units).

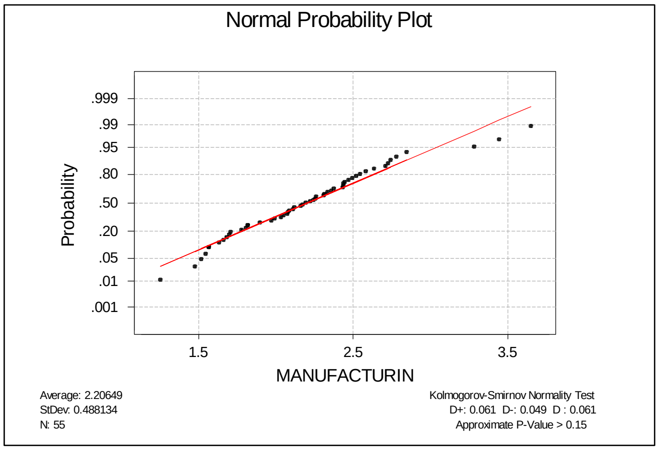


Figure 34: Normal probability plot of transformed X6 (Number of manufacturing industries allocated by metropolitan area (economical units).

From these graphs, it could be established that with the transformation of all the observations of the independent variables, normality shape is achieved in all of the cases. To reiterate this behavior, a descriptive statistical analysis for each variable is shown next:

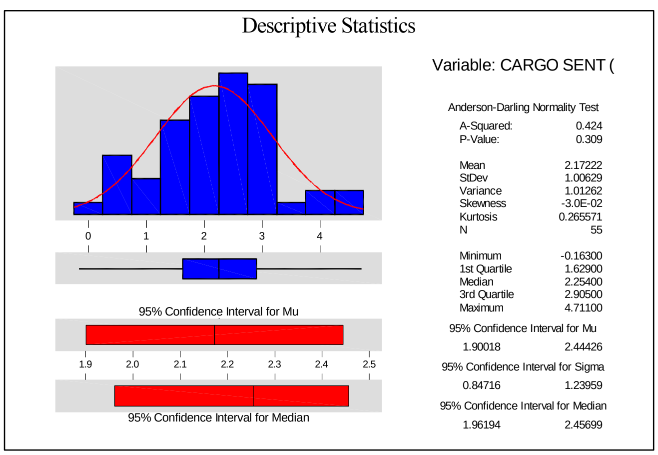


Figure 35: Descriptive statistics plot of transformed V_j (Cargo sent by airport).

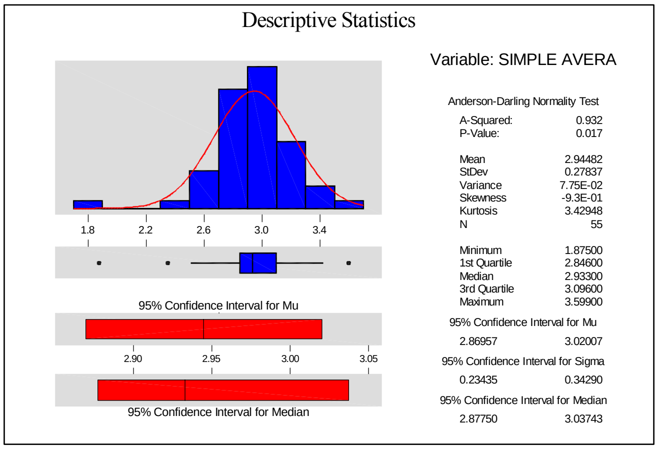


Figure 36: Descriptive statistics plot of transformed X1 (Simple average distance between origin-destination connections).

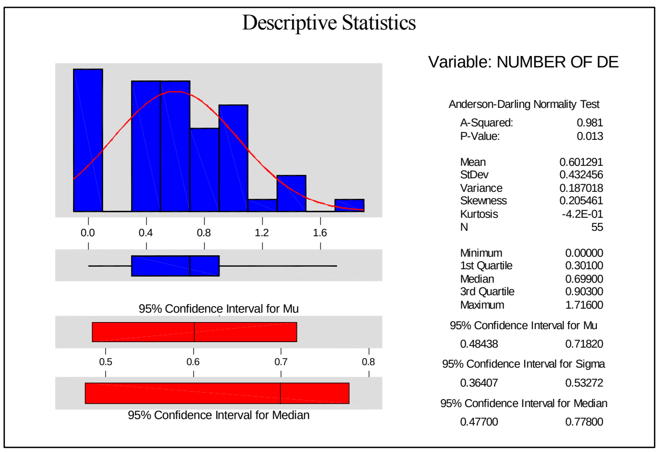


Figure 37: Descriptive statistics plot of transformed X2 (Number of connections by cargo generator).

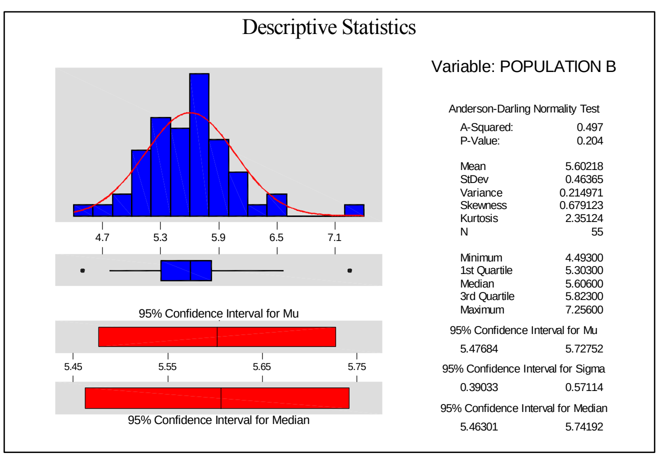


Figure 38: Descriptive statistics plot of transformed X3 (Total population by metropolitan area).

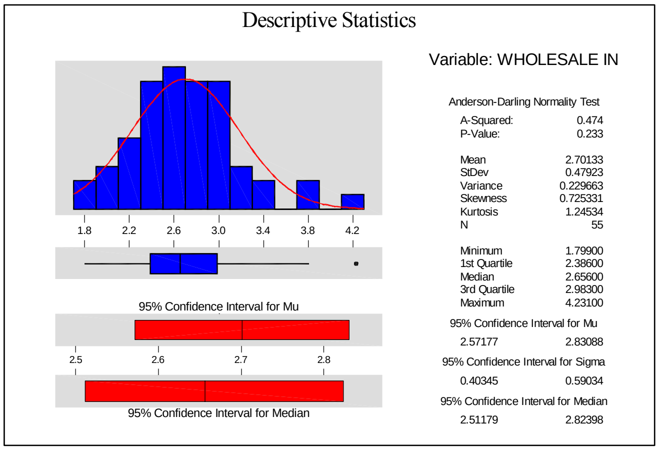


Figure 39: Descriptive statistics plot of transformed X4 (Number of wholesale trade industries installed by metropolitan area (economical units).

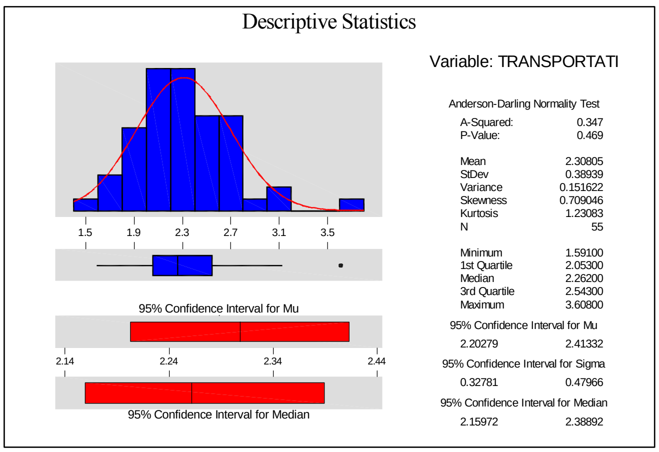


Figure 40: Descriptive statistics plot of transformed X5 (Number of transportation and warehousing services allocated by metropolitan area (economical units).

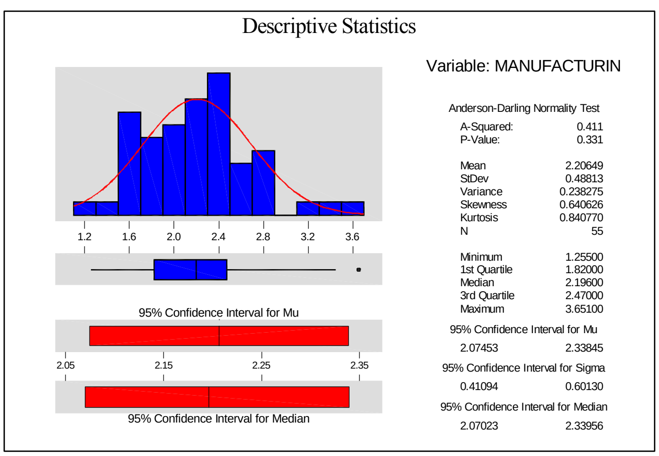


Figure 41: Descriptive statistics plot of transformed X6 (Number of manufacturing industries allocated by metropolitan area (economical units).

Following the improvement of variables by transforming them to represent linear relationships with normal distribution, the statistical power and size of sample must be appropriate in order to diminish possible impact in the calculations of the multiple regression analysis. Statistical power refers to the probability of detecting, as statistical significant, a determined level of R^2 or a regression coefficient at a specified significant level for a specific sample size. For this purpose, effects for each individual independent variable with dependent variable, as well as possible relations within independent and dependent variables must be measured by correlation.

Hair et al. (1997) defines that, mathematically speaking, a correlation is the remainder of variables´ covariance divided by the multiplication of the standard deviations of the variables. It is represented by the Greek letter “Rho” (ρ). Correlation, as a statistical index, has the advantage to be independent to the measurement units in which each variable is expressed. The ideal situation would be to have a number of independent variables highly correlated with the dependent variable, but little correlation among themselves to avoid **multicollinearity**. This phenomenon is concerned with the explanation and estimation of results provided by regression and could diminish the ability to represent and understand the effects of each independent variable in the regression procedure, basically because the effects between independent variables are “confounded” or mixed. High degrees of multicollinearity can result in regression coefficients incorrectly estimated and possibly with wrong signs.

For the problem instance, Pearson product-moment correlation coefficient was used to determine the degree of the linear relationship between the variables. The data utilized for the correlation analysis is the transformation of the data shown on table 22 giving the following results:

	CARGO SENT (Tons)	SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	NUMBER OF DESTINATIONS BY AIRPORT	POPULATION BY METROPOLITAN AREA, INEGI 2000	TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	WHOLESALE INDUSTRY (ECONOMICAL UNITS)
CARGO SENT (Tons)	1.000						
SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	0.413	1.000					
NUMBER OF DESTINATIONS BY AIRPORT	0.788	0.233	1.000				
POPULATION BY METROPOLITAN AREA, INEGI 2000	0.620	0.128	0.638	1.000			
TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	0.693	0.138	0.673	0.843	1.000		
MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	0.609	0.146	0.597	0.909	0.795	1.000	
WHOLESALE INDUSTRY (ECONOMICAL UNITS)	0.659	0.162	0.690	0.953	0.839	0.925	1.000

Table 23: Correlation matrix between dependent and independent variables for cargo generation model

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Initially, from the correlation analysis **it could be shown that the independent variables correlate from moderately to strongly with the dependent variable "Cargo sent".** We could also observe from this analysis, that there is a strong correlation between all the industrial variables with population per metropolitan area; consequently there is a high probability of multicollinearity in regression output if we consider integrating all these variables into the regression model; same thing happen between manufacturing industry and wholesale industry relation. To reduce multicollinearity, **search methods** for independent variable identification should be realized. Those methods provide an objective practice for variable selection that maximizes the prediction with the smallest number of variables employed (Hair et al, 1997).

Hair et al (1997) define two types of search approaches: ***sequential estimation and combinatorial approach.*** In the first one, an examination to determine the contribution of each independent variable to the regression model is developed. On the second approach, all possible combinations of independent variables are analyzed and the best fitting set of variables are identified. Nowadays, computerized estimation procedures allow managing considerable problems identifying the best overall regression equation. For this problem instance, Minitab 13 is used to realize calculations and provide reliable results according to multiple regression assumptions.

Using the combinatorial approach for variable selection, MINITAB displays the following data:

Best Subsets Regression: CARGO SENT (versus SIMPLE AVERA, TRANSPORTATI, ...

Response is CARGO SE

Vars	R-Sq	R-Sq(adj)	C-p	S	SIMPLE AVERA	TRANSPOR	MANUFACT	POPULATIO	NUMBER OL	WHOLESAL
1	62.1	61.4	16.4	0.62485					X	
2	67.7	66.5	8.5	0.58264	X				X	
3	70.6	68.9	5.4	0.56144	X		X		X	
4	72.8	70.6	3.4	0.54523	X	X		X	X	
5	73.0	70.3	5.0	0.54848	X	X	X	X	X	
6	73.0	69.7	7.0	0.55403	X	X	X	X	X	X

Table 24: Best subsets for cargo generation model independent variables selection.

The adjusted R^2 is essential in determine which is the best fit for the model. R^2 adjusted is a modified R^2 that has been adjusted for the number of terms in the model. If you include unnecessary terms, R^2 can be artificially high. Unlike R^2, adjusted R^2 may get smaller when you add needless terms to the model.

Considering the multicollinearity assumption in the data as well as the values presented by the adjusted R-square, the variables selected to model the cargo generation in the Mexican air transportation system are:

- ***Simple average distance between origin-destination connections***
- ***Number of connections by cargo generator***
- ***Number of manufacturing industries per metropolitan area (economical units).***
- ***Number of transportation and warehousing services established in metropolitan area (economical units).***

The variables obtained from the decision process were those ones that present a slightly less probability to incur on high correlation within the independent variables as well as correlate moderately with dependent variable.

From the total amount of variables initially proposed, this set of variables selected attempts to achieve the maximum prediction while maintaining a parsimonious model. However, the incorporation of another independent variable into the regression equation could obtain similar results.

Having specified the independent and dependent variables, addressed the issues of research design and check each variable to comply with regression assumptions, regression model is estimated using a significance level alpha = 0.05

Regression Statistics	
Multiple R	0.854
R Square	0.729
Adjusted R Square	0.707
Standard Error	0.545
Observations	55.000

```
S = 0.5446              R-Sq = 72.9%        R-Sq(adj) = 70.7%
PRESS = 18.2732         R-Sq(pred) = 66.58%
```

	Coefficients Value
Intercept	-3.0231
SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	0.8945
NUMBER OF DESTINATIONS BY AIRPORT	1.2097
TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	0.7035
MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	0.0952

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	39.84465	9.96116	33.56815	1.323E-13
Residual	50	14.83722	0.29674		
Total	54	54.68188			

Table 25: Regression analysis results for cargo generation model creation

Based on the results posted before, the model of cargo generation for national airports is:

$$V_j = -3.0231 + 0.8945(X_1)_i + 1.2097(X_2)_i + 0.7035(X_3)_i + 0.0952(X_4)_i$$

Where:

V_j = Amount of cargo generated by the j^{th} connection

$(X_1)_i$ = Simple average distance between connections for the i^{th} airport

$(X_2)_i$ = Number of destinations for the i^{th} airport

$(X_3)_i$ = Transportation and warehousing industries allocated at the i^{th} metropolitan area

$(X_4)_i$ = Manufacturing industries allocated at the i^{th} metropolitan area

Regression equation has a multiple correlation coefficient of 0.854, an R square coefficient of 0.729, and an R square adjusted of 70.7 %; this results explain that almost the 73% of the variation is explained by the set of independent variables chosen for the analysis. According to Montgomery (2001), larger values of R^2 are desired in order to increase the power of the explanation of the variability in the data used for the model. According to Rubinfeld (2003), there is not a strong position that could lead to a conclusion that the model is satisfactory, according to the values of R^2. He defines that typically, R^2 values in cross sectional studies where differences in individual behaviors are hard to explain based on possible factors that are not measured could lead to low rates in R^2. Conversely, in time-series studies, the event could be explained by the movement of aggregates over time and since most aggregate time series have substantial growth or trend, it would not be difficult to give explanation about it.

Looking for the validation of these results, the model will be tested by the Analysis of Variance (ANOVA); previous to this analysis, the regression model resulted has to be examined for meeting regression assumptions and assessing the significance of the overall model in predicting the dependent variable determining the existent of any observation that might influence the results (Hair, et al., 1997). The assumptions to be examined are:

- *Linearity of the phenomenon measured*
- *Constant variance of the error terms*
- *Normality of the error term distribution*
- *Independence of the error terms*

Linearity represents the degree to which the change in the dependent variable is associated with the independent variable. Regression coefficient should be constant across the range of values of the independent variable. Correlation is based on a linear relationship, making it a critical issue in regression analysis. In multiple regression, using ***partial regression plots***, it could be exposed the relationship of a single independent variable to the dependent variable. A curvilinear pattern of residuals indicates a nonlinear relationship between a specific independent variable and the dependent variable. The graphic results of partial regression plots is shown as follows, given satisfactory results for the regression model and assuming linear relationship between each independent variable with dependent variable.

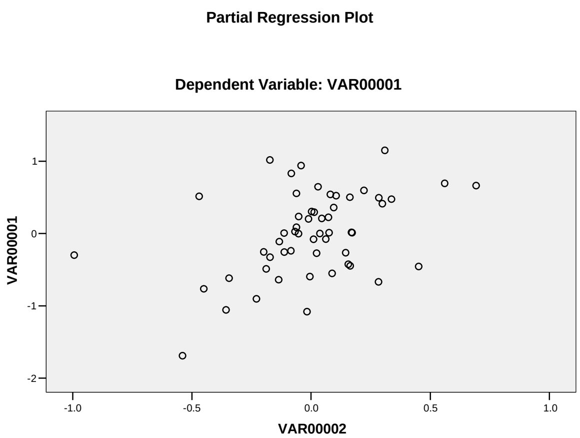


Fig 42: Graphical analysis of residuals between transformed X1 and V_j

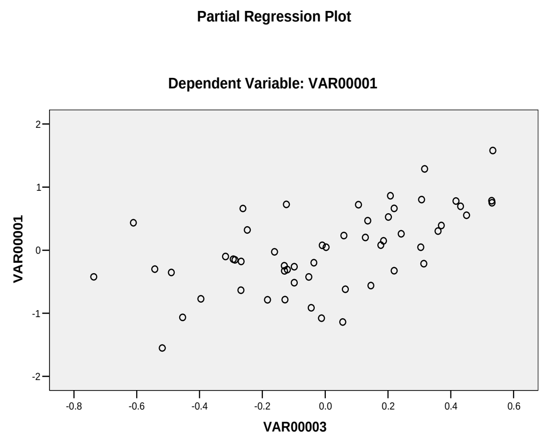


Fig 43: Graphical analysis of residuals between transformed X2 and V_j

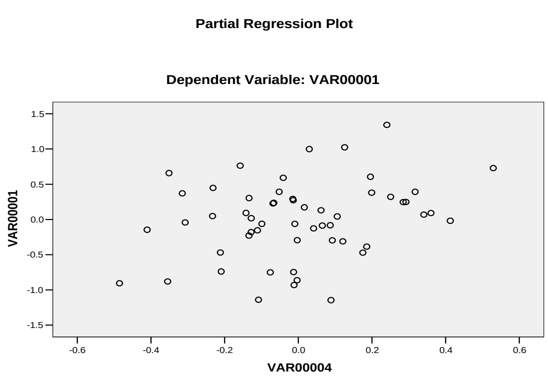


Fig 44: Graphical analysis of residuals between transformed X5 and V_j

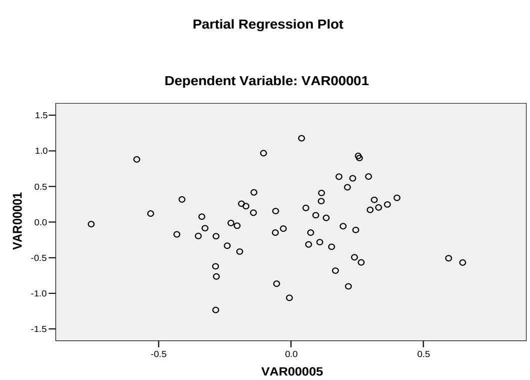


Fig 45: Graphical analysis of residuals between transformed X6 and V_j

The presence of unequal variances is another assumption that must be measured. To identify this pattern, it could be used residual plots or statistical tests. The graphical way to verify this assumption is to plot the residuals (studentized) against the predicted dependent values and compare with the desirable consistent pattern of variance called the ***null plot.*** For this problem instance there exists a slightly pattern of heteroscedasticity in residuals but according to the transformation realized to the original data, variance was stabilized.

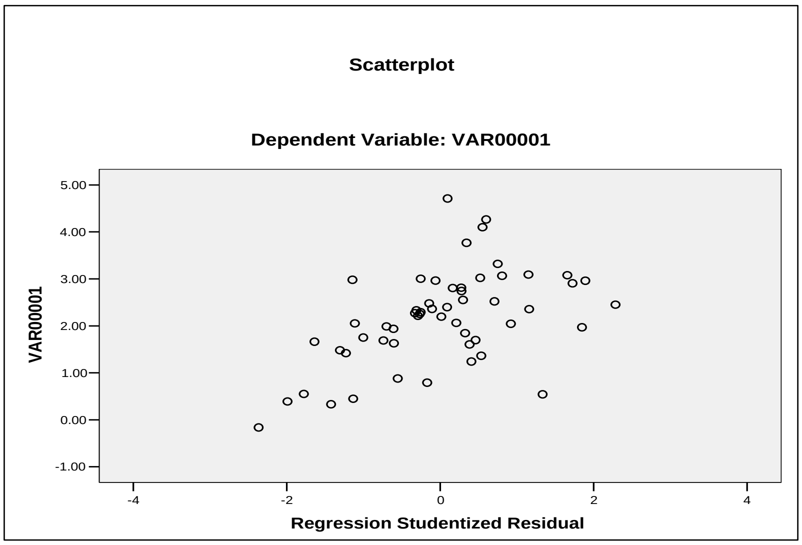


Figure 46: Graphical analysis of studentized residuals vs dependent variable V_j

For the normality of the error term distribution assumption, the simplest diagnostic for the set of independent variables in the equation is the ***histogram of residuals***, with a visual check for a distribution approximating to normal distribution. For this case, standardized residuals are plotted, giving a normal distribution shape according to the next graph:

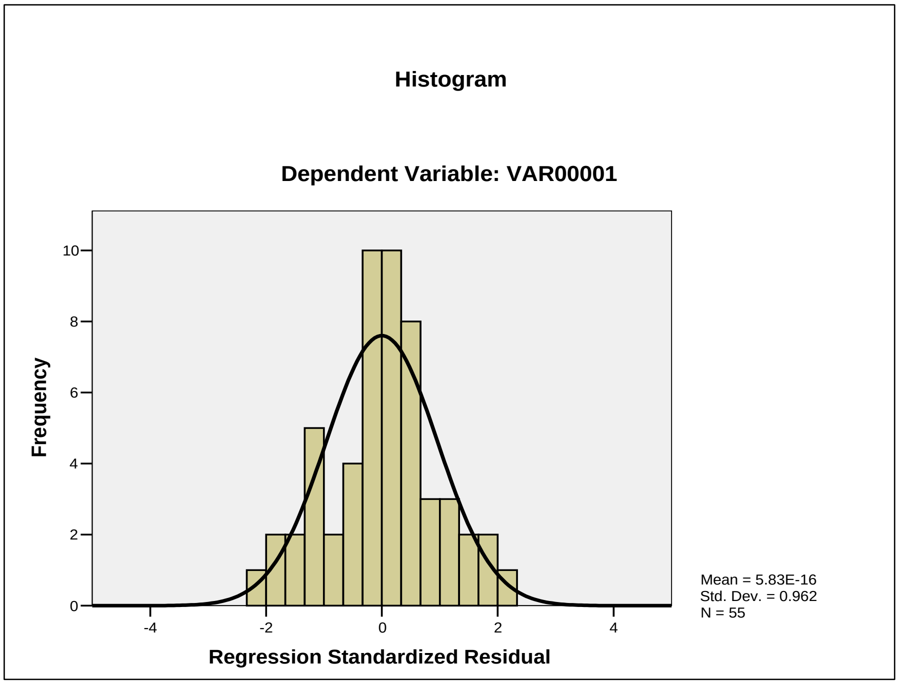


Figure 47: Histogram of standardized residuals

A final assumption is related to the independence of error terms; it assumes that each predicted value is independent and is not related to any other prediction or sequenced by any variable. If there is a consistent pattern in the residuals, violation to this assumption will be incurred. For this purposes, residual analysis of dependent variable is compared with each independent variable and check if any pattern emerges. It is mandatory to use the residuals in this analysis, not the original dependent variable values, because the focus is on the prediction errors, not the relationship captured in the regression equation. For this problem instance, the effect of carryover from one observation to another is not found and in conclusion residuals are independent based upon the behavior of each variable vs fits in where it could be observed that there is not any influential pattern within each observation.

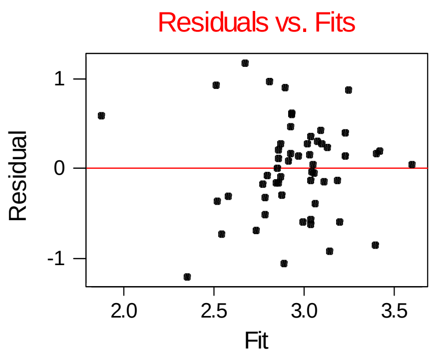


Fig 48: Standardized partial regression plot

Residuals vs X1

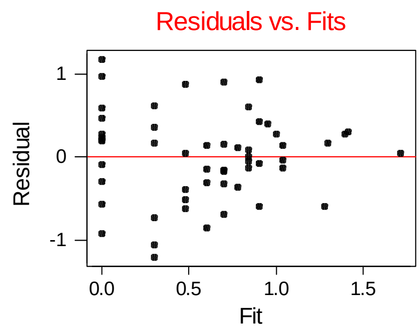


Fig 49: Standardized partial regression plot

Residuals vs X2

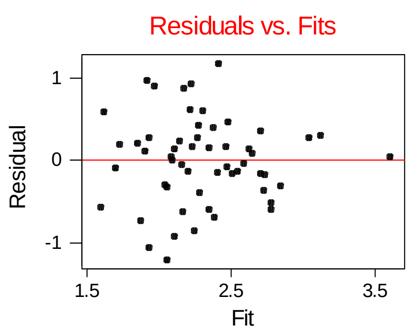


Fig 50: Standardized partial regression plot

Residuals vs X5

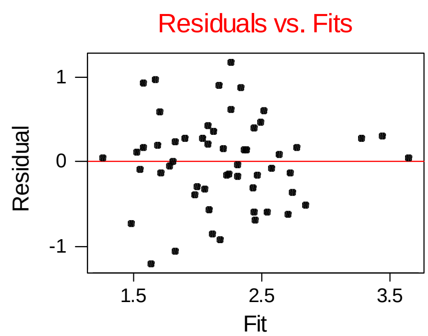


Fig 51: Standardized partial regression plot

Residuals vs X6

Final analysis for this problem is the identification of any observations that are influential and/or with disproportionate impact on the regression analysis. The most basic diagnostic tool involves the residuals vs fits graph. Upper and lower limits can be set once the desired confidence interval has been established. The most widely used level is 95 percent confidence (Hair et al., 1997). The corresponding *t* value is 1.96, thus identifying statistically significant results as those, observations could be classified as ***outliers***. For this problem instance, residuals vs fits graph shows that there is not any significant result from the analysis and all the observations are represented by the regression equation proposed by this technique.

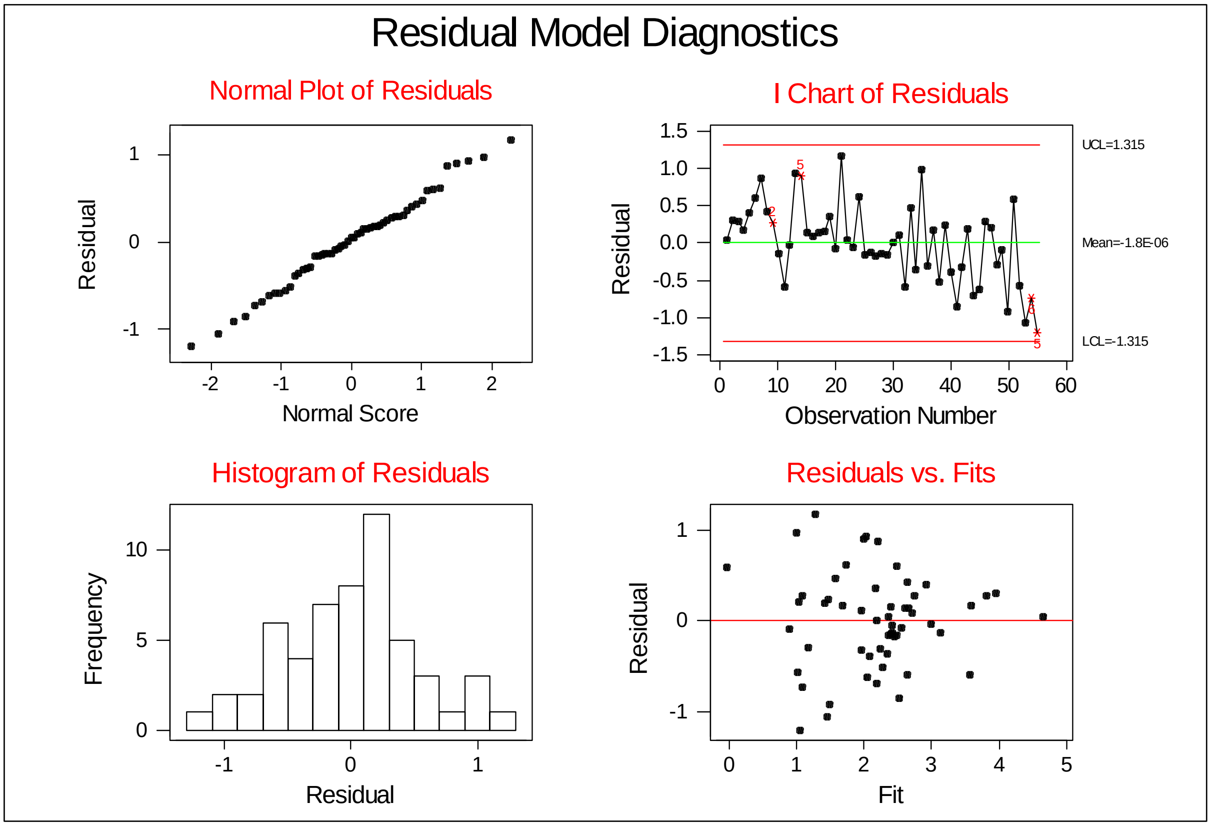


Figure 52: Plot of studentized residuals

With model estimation completed, regression coefficients determined and assumptions verified, the analysis of variance (ANOVA) from table 24 will be explained. ANOVA is developed with the intention of corroborate the significance level of the regression, based on statistical tests which define a ***null hypothesis*** for the case in which coefficients for independent variables are equal to zero and an ***alternative hypothesis*** that implicates the opposite. For the case in where F value is less than critical value F_0 for a determined confidence level, means that the null hypothesis could not be rejected.

This implication associates that there is not a causal relation between dependent and independent variables or that relation is not linear. For this problem instance, F_0 is less than F value, which concludes that **there is not a statistical element to reject regression calculations**.

Finally, to validate the results predicted by the regression model and to ensure that results could be generalized to the entire population, the next graph reveal a comparison between the transformed Y1 values (dependent variable denominated cargo sent by airport) and the predicted values resulted from the model.

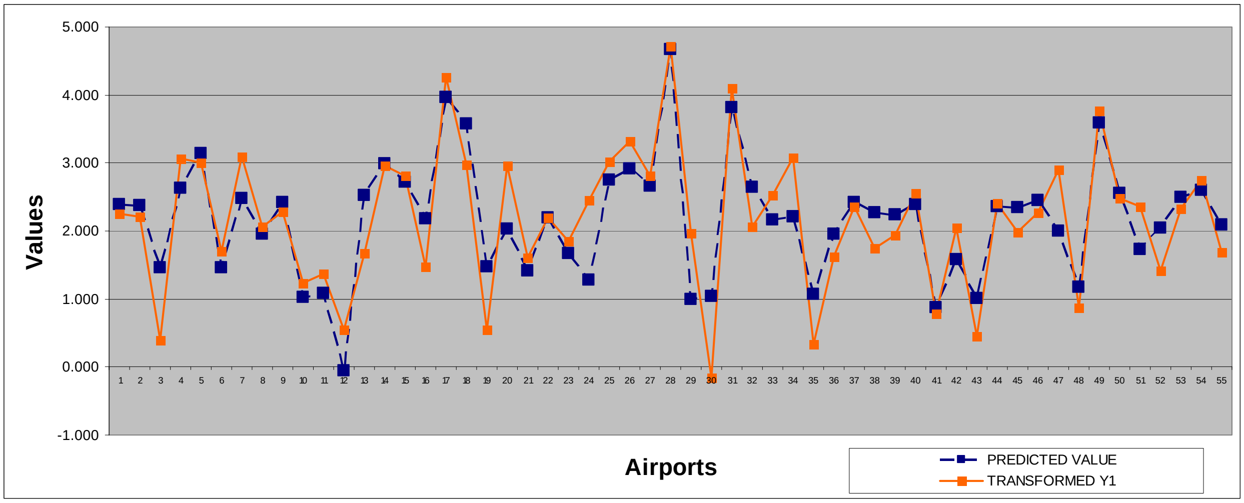


Figure 53: Validation of predicted values vs transformed V_j results

It could be observed that the comparison between the transformed Y1 values and predicted does not present significant differences but just in three airports (Cozumel, Monclova and Piedras Negras). In those cases where results from regression model behave in an atypical manner, is mainly based on their unique characteristics that differ from the entire population. For example, in the case of Cozumel, it is expected to have less amount of cargo moved in order to its industrial and services´ development. Contradictory, Piedras Negras and Monclova have a lack of movement of cargo according to their industrial development. In the first case, the principal explanation could be its importance as a tourist center in the country; for the second case, its nearby location to the United States makes a more feasible point of cargo generator the city of Eagle Pass, TX or Del Rio, TX rather than Piedras Negras; and finally, Monclova and its proximity to a pair of important cities that could generate its cargo (Saltillo and Monterrey).

In the next section, a similar analysis will be conducted, looking for modeling the attraction of cargo generated by the airports that composed the national airports system. For simplification purposes, the procedures realized in this section will be enumerated and resumed accordingly to the explained in this analysis.

5.4 MATHEMATICAL MODEL OF DOMESTIC CARGO ATTRACTION

A mathematical model to represent the "attraction" of freight in a specific airport, tries to find the amount of cargo received by each of the connections that takes part of the air transportation system. In this case, the theoretical foundation of the generation model of cargo and also the utilization of the same independent variables are going to take place. The only difference is the dependent variable which changes for the amount of cargo received by the terminal. For that reason, the multiple regression function will be constructed similarly to the generation model, shifting exclusively the denomination of the dependent variable:

$$A_j = a + b_1(X_1)_j + b_2(X_2)_j + b_3(X_3)_j ... + b_n(X_n)_j$$

Where:

A_j = Amount of cargo received by the j^{th} connection
a = Parameter calculated by the model and represents the intersection with the "x" axis.
b_i = Parameter to determine by the model and defines the increment rate of the dependent variable based on the i^{th} independent variable.
$(X_i)_j$ = i^{th} independent variable in the j^{th} connection and determines the augmentation rate defined by the i^{th} coefficient.

The procedure for the realization of the model is similar to the cargo generation model: starts when independent variables, that presumably have a strong relation with the cargo attraction in each connection, are defined based on information availability. Then, dependent and independent variables must meet the assumptions underlying multivariate regression; data transformations are realized in case of non-normality and unequal dispersion of the data.

Following the improvement of variables by transforming them to represent linear relationships with normal distribution, the statistical power and size of sample must be done based on the correlation between independent variables and the dependent variable, identifying possible effects for each individual independent variable with dependent variable, as well as possible effects between independent variables, all of them measured by correlation. Multicollinearity must be the primal objective to identify in this analysis.

After correlation and multicollinearity analysis, search methods for independent variable identification and aggregation to regression model should be realized. Those methods provide an objective practice for variable selection that maximizes the prediction with the smallest number of variables employed. When the independent variables are finally selected, regression coefficients are estimated and the proposed model must be initially review to comply with multiple regression statements. A final analysis to be realized is the observation of possible influential observations and decides if they should be out of the analysis and recalculate a new regression model without outliers. In conclusion, the analysis of variance (ANOVA) would be explained and validation of results must be deployed.

a) ***Identification of dependent and independent variables for modeling cargo attraction per airport.***

Dependent variable A_j was chosen as the ***amount of cargo received by each airport*** that integrates the entire national system, and the independent variables that were chosen initially, based on their explanation potential of cargo generation, are defined next:

- **X1: Simple average distance between origin-destination connections.** Defined as the simple average value between the i^{th} airport and the cargo generators from where each airport receives cargo, deployed in kilometers. It reflects the geographical distance of the node in respect with its connections.

- **X2: Number of cargo generators received by airport.** Defined as an "attraction" measurement for each airport, computed in tons of cargo received by each airport of the national air cargo system.

- **X3: Total population by metropolitan area.** The data source is the National Statistical Office (INEGI) XII Census for 2000. All of the data was gathered for each of the cargo receptors.

- **X4: Number of wholesale trade installed by metropolitan area (economical units).** The data source is the National Statistical Office (INEGI) XII Economical Census for 2000. It represents the number of wholesaler's industry allocated in the metropolitan area in where a particular airport is allocated.

- **X5: Number of manufacturing industries per metropolitan area (economical units).** The data source is the National Statistical Office (INEGI) XII Economical Census for 2000. It represents the number of manufacturing companies that are allocated in the metropolitan area where a particular airport is allocated. The manufacturing industries selected to be incorporated to this process and defined according to NAICS[15] code are:

    - ***Machinery manufacturing (333)***
    - ***Computer and Electronic product manufacturing(334)***
    - ***Electrical equipment, appliance and component manufacturing (335)***
    - ***Transportation equipment manufacturing (336)***
    - ***Furniture and related product manufacturing (337)***
    - ***Miscellaneous manufacturing (339)***

- **X6: Number of transportation and warehousing services established in metropolitan area (economical units).** The data source is the National Statistical Office (INEGI) XII Economical Census for 2000. It represents the number of transportation and warehousing services that are allocated in the metropolitan area where a particular airport is installed. From the definition provided by NAICS, the economical units selected to be incorporated in this variable are:

15 Abbreviation for North America Industry Classification System (NAICS)

- *Postal Services (491)*
- *Expedited Couriers (492)*
- *Warehousing and storage services (493)*

b) Analysis of individual assumptions underlying multivariate regression for dependent and independent variables.

Before the realization of the regression model design, individual variables must meet the assumptions underlying multivariate regression that were described in the cargo generation model.

For this problem instance, analysis per individual variable will be realized and, if some violation is incurred, transformation of data should be developed. The first analysis to be conducted is the *normality test*, using normal probability plots for both dependent and independent variables.

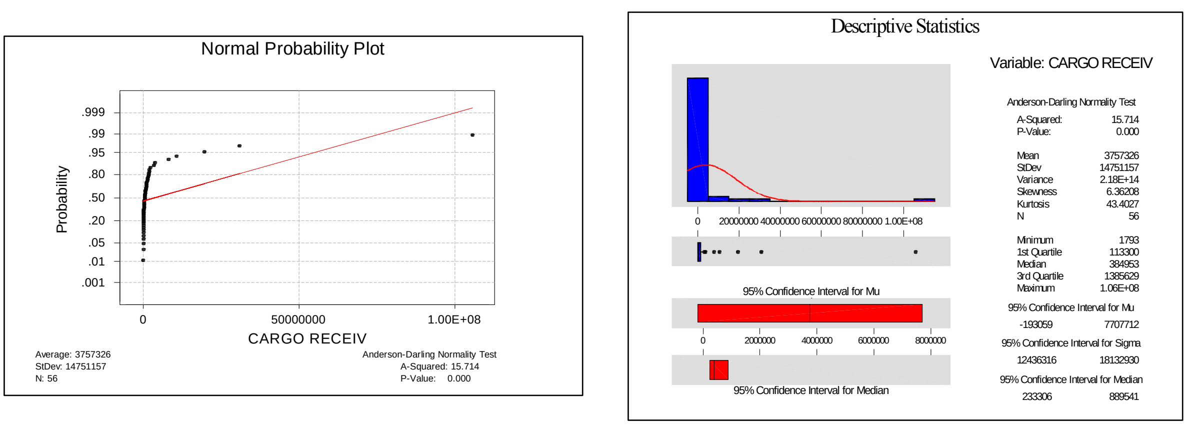


Figure 54: Normal probability and descriptive analysis plots for A_j

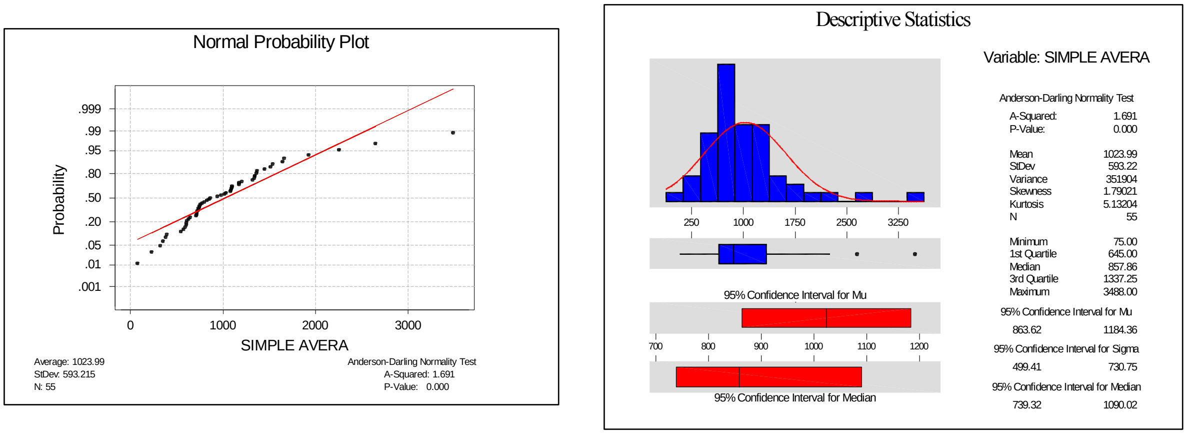


Figure 55: Normal probability and descriptive analysis plots for X1

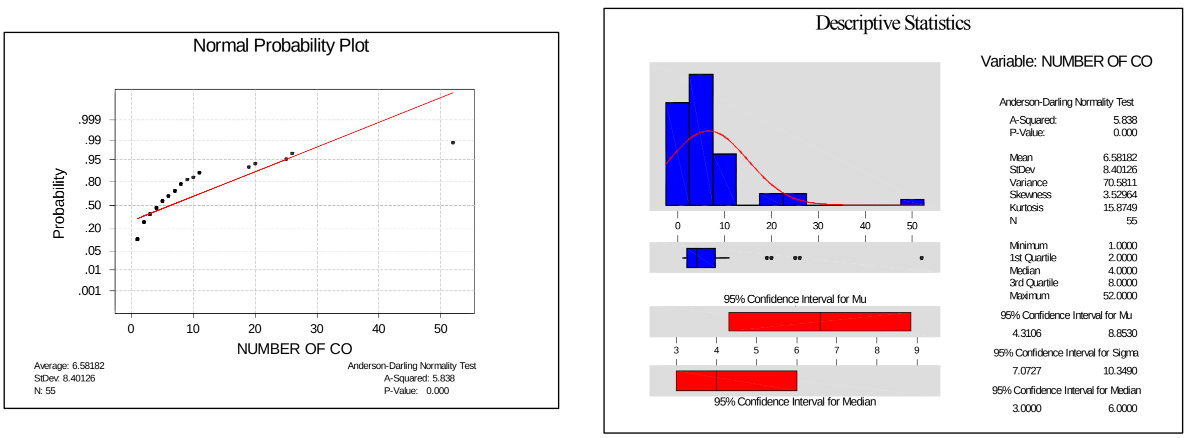


Figure 56: Normal probability and descriptive analysis plots for X2

From the graphical analysis presented in Fig. 54, 55 and 56, and taking the results posted for X3, X4, X5 and X6 posted on the cargo generation model developed before, A_j performs with positive skewed and flatness in its distribution shape, differing on results posted for variable X1 and X2 which has a relative peakedness distribution shape. According to Hair et al (1997), for the homogeneity assumption measurement, most problems with unequal variances comes from two main sources; the first one in based on the type of variables incorporated into the model and has variable increases/decreases in value. There is a naturally wider range of possible answers for the larger values; the second case comes from skewed distribution results that create important dispersion patterns.

Hence, based on the deployed graphs for each variable, there are an unequal dispersion of the data caused by the skewness of each variable and transformation of data should be perform in order to make reliable calculations.

According to the definition of Hair et al. (1997) for data transformations that allows the correction of non-normality and unequal dispersion of the data, data transformation will be based taking the logarithms for each observation in the proposed variables, and then verifying if the change makes an appropriate modification to normality.

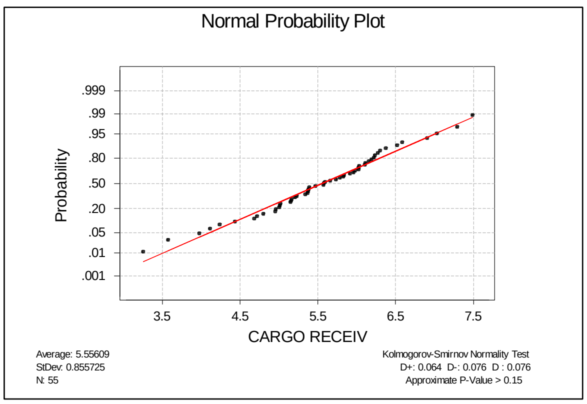
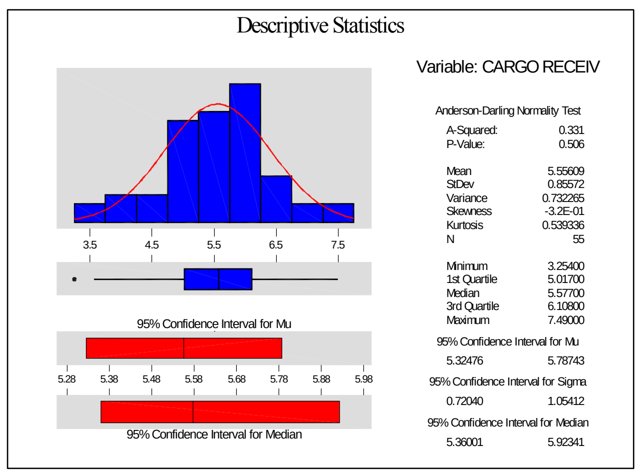


Fig 57: Normal probability and descriptive analysis plots for transformed Y1



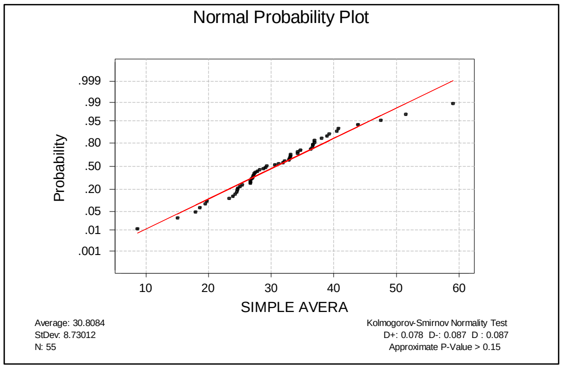
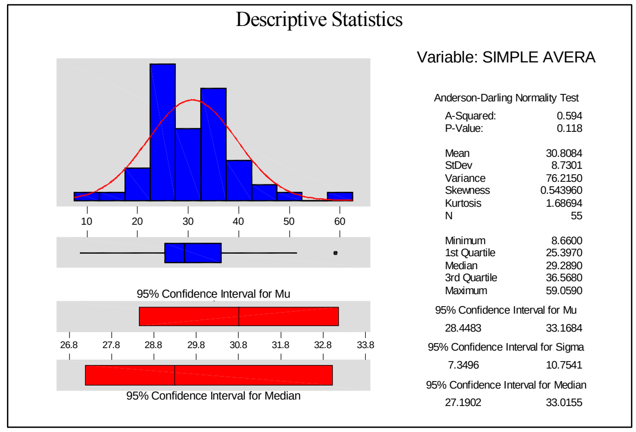


Fig 58: Normal probability and descriptive analysis plots for transformed X1



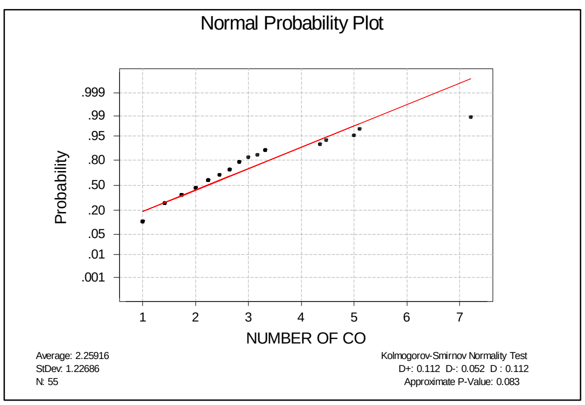


Fig 59: Normal probability and descriptive analysis plots for transformed X2

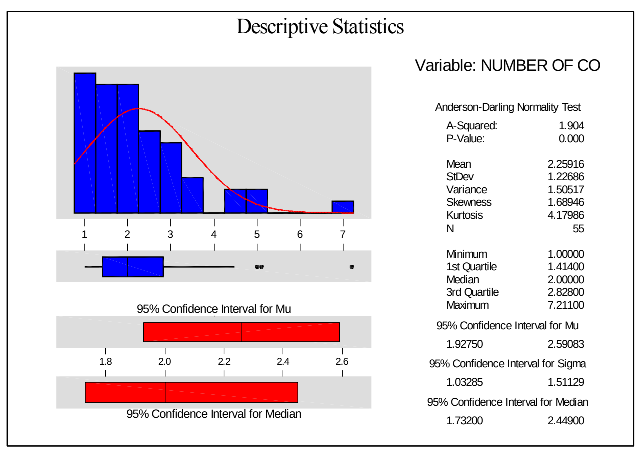


Table 25 shows the results provided by the transformation of the real values of each variable using the logarithm of each observation and then, to corroborate the proper changes to normality generated by the transformation of the real values will be displayed by the plots 57 to 59 in addition with the results posted on plots 32 to 34 in the cargo generation model creation process.

c) *Estimation of regression model.*

DESTINATION	SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	CARGO RECEIVED (Tons)	NUMBER OF CONNECTIONS IN WHICH CARGO IS RECEIVED	POPULATION BY METROPOLITAN AREA, INEGI 2000	TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	WHOLESALE INDUSTRY (ECONOMICAL UNITS)
ACAPULCO	36.568	6.028	2.000	5.793	2.407	2.243	2.783
AGUASCALIENTES	28.167	5.735	2.236	5.850	2.509	2.470	3.058
CAMPECHE	27.767	3.254	1.414	5.281	1.929	1.820	2.417
CANCUN	40.495	6.582	2.828	5.599	2.274	2.079	2.697
CD. JUAREZ	38.894	6.189	3.317	6.082	2.543	2.726	2.961
CHETUMAL	36.674	5.571	1.000	5.085	2.143	1.820	1.869
CHIHUAHUA	29.289	6.217	2.646	5.818	2.299	2.521	3.011
CIUDAD DEL CARMEN	27.077	5.659	2.449	5.100	1.898	1.519	2.292
CIUDAD OBREGON	34.676	5.472	2.646	5.399	2.196	1.708	2.262
CIUDAD VICTORIA	26.851	5.205	1.000	5.396	1.845	2.076	2.465
COLIMA	27.276	4.717	1.000	5.324	1.924	1.898	2.403
COZUMEL	8.660	4.233	1.000	4.773	1.613	1.699	1.799
CUERNAVACA	36.674	4.110	2.000	5.899	2.243	2.111	2.755
CULIACAN	31.870	6.152	3.317	5.733	2.585	2.310	2.934
DEL BAJIO	34.189	6.026	2.646	6.012	2.649	2.636	3.477
DURANGO	23.302	5.374	2.236	5.631	2.384	2.447	2.764
GUADALAJARA	34.246	7.293	5.099	6.566	3.122	3.445	3.807
HERMOSILLO	36.891	6.374	4.359	5.737	2.779	2.439	2.992
JALAPA	17.944	4.681	1.000	5.640	2.104	2.173	2.656
LA PAZ	51.477	5.958	2.828	5.212	2.223	1.568	2.386
LAZARO CARDENAS	26.702	5.017	1.000	5.103	1.724	1.681	2.220
LOS MOCHIS	27.042	5.389	2.646	5.303	2.086	1.806	2.389
MANZANILLO	23.896	5.150	1.414	4.977	2.230	1.568	2.117
MATAMOROS	31.225	5.338	1.000	5.576	2.412	2.255	2.563
MAZATLAN	36.943	5.834	3.162	5.516	2.262	2.033	2.637
MERIDA	40.761	6.523	3.000	5.899	2.377	2.438	3.135
MEXICALI	43.886	6.237	2.000	5.740	2.624	2.360	2.858
MEXICO	32.832	7.490	7.211	7.256	3.608	3.651	4.231
MINATITLAN	25.397	5.593	1.000	5.510	1.908	1.663	2.431
MONCLOVA	15.000	3.569	1.414	5.452	2.053	1.633	2.356
MONTERREY	32.128	7.028	5.000	6.518	3.041	3.282	3.753
MORELIA	28.732	5.376	2.828	5.749	2.348	2.547	3.109
NUEVO LAREDO	32.939	5.166	1.414	5.490	2.708	2.121	2.316
OAXACA	39.226	5.977	1.732	5.663	2.167	2.334	2.769
PIEDRAS NEGRAS	18.628	3.976	1.414	5.179	1.869	1.477	2.037
POZA RICA	24.568	4.959	2.236	5.466	2.053	2.049	2.600
PTO. VALLARTA	36.277	6.108	2.646	5.197	2.155	1.778	2.292
PUEBLA	24.658	4.801	1.732	6.275	2.776	2.846	3.407
QUERETARO	19.481	5.155	2.000	5.896	2.845	2.435	3.058
REYNOSA	26.638	5.577	2.236	5.606	2.344	2.196	2.618
SALINA CRUZ	27.221	5.011	1.000	4.859	1.690	1.544	1.949
SALTILLO	29.138	5.225	1.000	5.791	2.476	2.496	2.815
SAN CRISTOBAL DE LAS CASAS	33.091	4.431	1.000	5.051	1.591	2.086	2.301
SAN JOSE DEL CABO	59.059	6.275	1.732	4.493	2.079	1.255	1.991
SAN LUIS POTOSI	19.761	5.366	2.449	5.930	2.726	2.742	3.115
TAMPICO	24.232	5.914	2.236	5.823	2.734	2.312	2.914
TAPACHULA	38.059	5.823	2.000	5.255	1.964	2.161	2.515
TEPIC	27.495	4.950	1.000	5.535	2.033	1.991	2.616
TIJUANA	47.493	6.906	4.472	6.105	2.462	2.780	3.066
TORREON	25.047	5.782	2.828	6.003	2.470	2.581	2.983
TUXTLA GUTIERREZ	26.711	6.102	1.414	5.694	2.210	2.262	2.801
URUAPAN	32.995	5.002	1.732	5.361	2.161	2.711	2.603
VERACRUZ	24.528	6.022	2.236	5.773	2.708	2.225	2.863
VILLAHERMOSA	30.578	6.302	3.317	5.779	2.104	2.377	2.857
ZACATECAS	33.106	5.381	1.732	5.367	2.276	1.973	2.500

Table 26: Transformation of data for normality and homoscesdasticity in cargo attraction model creation.

Data transformation was realized taking the logarithms for each observation in the proposed variables and verifying that the modifications make an appropriate adjustment to normality. In result, the transformed dependent and independent variables that will be used for correlation analysis are exposed in Table 25.

Pearson product-moment correlation coefficient was used to determine the degree of linear relationship between the variables. The data utilized for the correlation analysis is the transformation of the data shown on table 25 and results are placed next.

	CARGO RECEIVED (Tons)	POPULATION BY METROPOLITAN AREA, INEGI 2000	NUMBER OF CONNECTIONS IN WHICH CARGO IS RECEIVED	TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	WHOLESALE INDUSTRY (ECONOMICAL UNITS)
CARGO RECEIVED (Tons)	1.000						
POPULATION BY METROPOLITAN AREA, INEGI 2000	0.521	1.000					
NUMBER OF CONNECTIONS IN WHICH CARGO IS RECEIVED	0.733	0.711	1.000				
TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	0.603	0.843	0.711	1.000			
MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	0.539	0.909	0.671	0.795	1.000		
SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	0.548	0.014	0.319	0.148	0.050	1.000	
WHOLESALE INDUSTRY (ECONOMICAL UNITS)	0.583	0.953	0.738	0.839	0.925	0.088	1.000

Table 27: Correlation matrix between dependent and independent variables for cargo attraction model

From the correlation analysis it could be shown that the independent variables correlate moderately with the dependent variable **"Cargo received"**. We could also observe from this analysis, that there is a strong correlation between all the industrial variables with population per metropolitan area; consequently there is a high probability of multicollinearity in regression output if we consider integrating all these variables into the regression model; same thing happen between manufacturing industry and wholesale industry relation. Search methods for independent variable identification should be realized. Minitab 13 is used to realize calculations and provide reliable results according to multiple regression assumptions.

Best Subsets Regression: CARGO RECEIV versus POPULATION B, NUMBER OF CO, ...

Response is CARGO RE

Vars	R-Sq	R-Sq(adj)	C-p	S	POPULATI	NUMBER O	TRANSPORT	MANUFACT	SIMPLE A	WHOLESAL
1	53.8	52.9	18.7	0.58721		X				
2	58.8	57.2	13.1	0.55954					X	X
3	66.9	64.9	3.0	0.50669		X		X	X	
4	67.6	65.0	3.8	0.50595		X	X	X	X	
4	67.5	64.9	4.0	0.50704		X	X		X	X
5	67.9	64.6	5.4	0.50890	X	X	X		X	X
6	68.2	64.2	3.0	0.51195	X	X	X	X	X	X

Table 28: Table 24: Best subsets for cargo attraction model independent variables selection.

Using the combinatorial approach for variable selection and consider the observations of possible multicollinearity in the data, the variables selected to model the cargo attraction in the Mexican air transportation system are:

- ***Simple average distance between origin-destination connections***
- ***Number of origin from which cargo is received***
- ***Number of manufacturing industries per metropolitan area (economical units).***
- ***Number of transportation and warehousing services established in metropolitan area (economical units).***

The variables obtained from decision process were those ones that present less probability to incur on high correlation within the independent variables as well as correlate moderately with dependent variable. As the generation cargo model case, the incorporation of another independent variable into the regression equation could obtain similar results. Having specified the independent and dependent variables, addressed the issues of research design and check each variable to comply with regression assumptions, regression model is estimated using a significance level alpha = 0.05:

Regression Statistics	
Multiple R	0.82235
R Square	0.67626
Adjusted R Square	0.65036
Standard Error	0.50600
Observations	55

	Coefficients Value
Intercept	2.511878575
NUMBER OF CONNECTIONS IN WHICH CARGO IS RECEIVED	0.297478916
TRANSPORTATION AND WAREHOUSING INDUSTRIES (ECONOMICAL UNITS)	0.339150573
MANUFACTURING INDUSTRIES (ECONOMICAL UNITS)	0.195111436
SIMPLE AVERAGE DISTANCE BETWEEN CONNECTIONS (KM)	0.037615033

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	26.74137327	6.6853433	26.111378	1.01831E-11
Residual	50	12.80159022	0.2560318		
Total	54	39.54296349			

Table 29: Regression analysis results for cargo generation model creation

Based on the results posted before, the model of cargo attraction for national airports is:

$$A_j = 2.512 + 0.038(X_1)_i + 0.297(X_2)_i + 0.339(X_3)_i + 0.195(X_4)_i$$

Where:

A_j = *Amount of cargo received by the* j^{th} *connection*

$(X_1)_i$ = *Simple average distance between connections for the* i^{th} *airport*

$(X_2)_i$ = *Number of connection in which cargo is received for the* i^{th} *airport*

$(X_3)_i$ = *Transportation and warehousing industries allocated at the* i^{th} *metropolitan area*

$(X_4)_i$ = *Manufacturing industries allocated at the* i^{th} *metropolitan area*

Regression equation has a multiple correlation coefficient of 0.822 and an R square coefficient of 0.676, with an adjusted R^2 of around 65%. These results conclude that that almost the 68% of the variation is explained by the set of independent variables chosen for the analysis.

The analysis of variance (ANOVA) from table 27 is defined with a ***null hypothesis*** for the case in which coefficients for independent variables are equal to zero and an ***alternative hypothesis*** that implicates the opposite. For the case in where F value is less than critical value F_0 for a determined confidence level, means that the null hypothesis could not be rejected. For this problem instance, F_0 is less than F value, which concludes that **there is not a statistical element to reject regression calculations.**

d) *Review of multiple regression assumptions.*

- *Linearity of the phenomenon measured*

In multiple regression, the use of ***partial regression plots*** expose the relationship of a single independent variable to the dependent variable. For the cargo attraction model, the results from partial regression plots is shown next, given satisfactory results for the regression model and assuming linear relationship between each independent variable with the dependent variable.

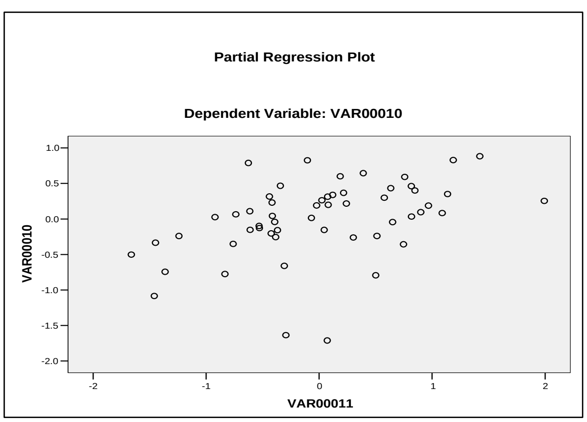


Fig 60: Graphical analysis of residuals between transformed A_j and X2

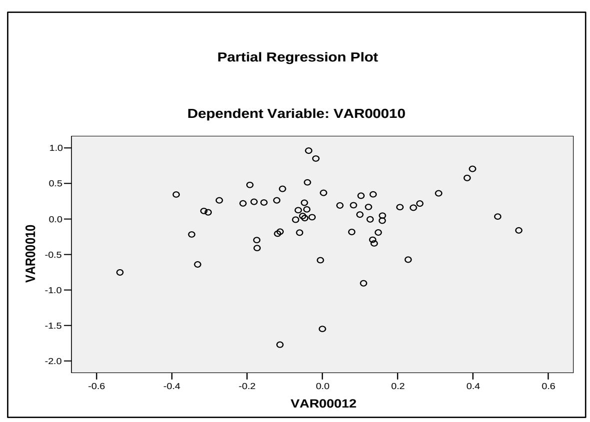
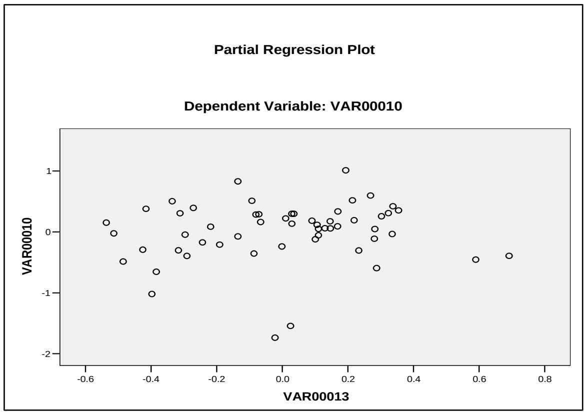


Fig 61: Graphical analysis of residuals between transformed A_j and X6



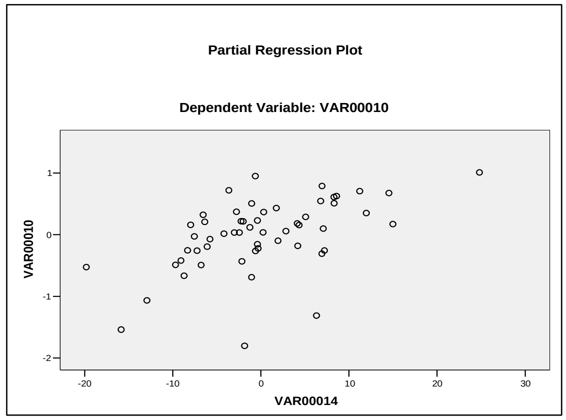


Fig 62: Graphical analysis of residuals between transformed A_j and X4

Fig 63: Graphical analysis of residuals between transformed A_j and X1

- *Constant variance on error terms*

To identify this pattern, residual plots are utilized. The graphical way to verify this assumption is to plot the residuals (studentized) against the predicted dependent values and compare with the desirable consistent pattern of variance called the ***null plot.*** For this problem instance there is a relative homogeneity in residuals but with some outliers that will be analyzed in order to find any influence in the model. According to the transformation realized to the original data, variance was stabilized.

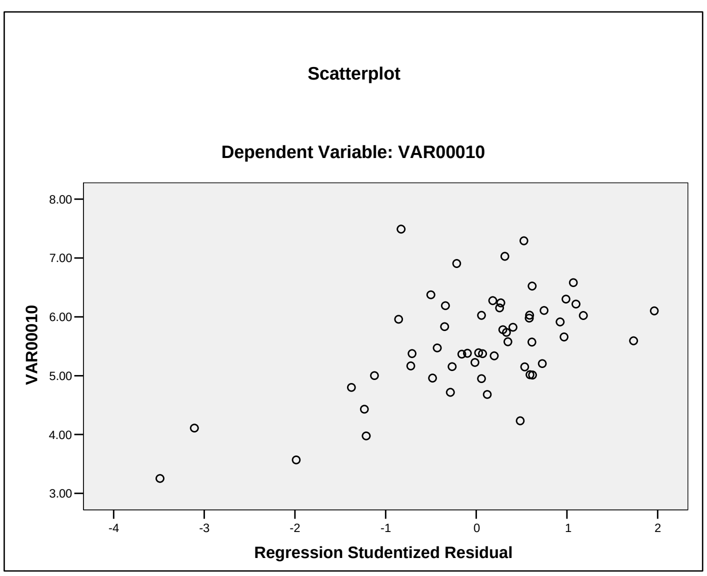


Figure 64: Graphical analysis of studentized residuals vs dependent variable A_j

- *Normality of the error term distribution*

For the normality of the error term distribution assumption, the ***histogram of residuals***, with a visual check for a distribution approximating to normal distribution will be developed. For this instance, standardized residuals are plotted, giving an asymmetric normal shape and identifying outliers that are reflected in this plot. Those outliers would be recognized as well as examining if these points should be out of the analysis.

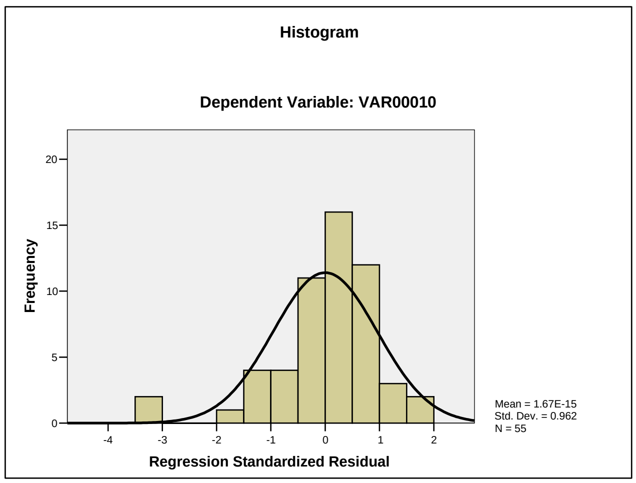


Figure 65: Histogram of standardized residuals

- *Independence of the error terms*

Final assumption is related to the independence of error terms. If there is a consistent pattern in the residuals, violation to this assumption will be incurred. For this purposes, residual analysis of dependent variable is compared with each independent variable and check if any pattern comes out from the analysis.

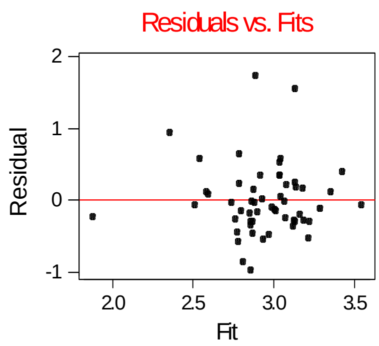


Fig 66: Standardized partial regression plot

Residuals vs X1

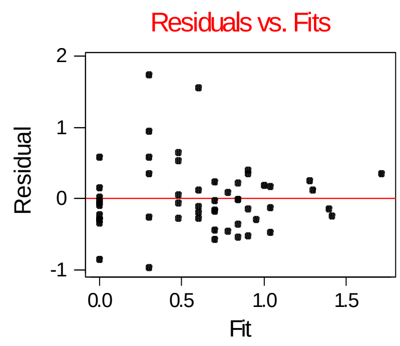


Fig 67: Standardized partial regression plot

Residuals vs X2

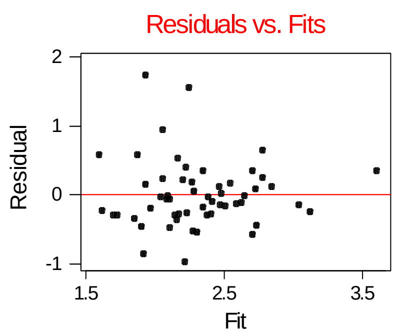


Fig 68: Standardized partial regression plot

Residuals vs X6

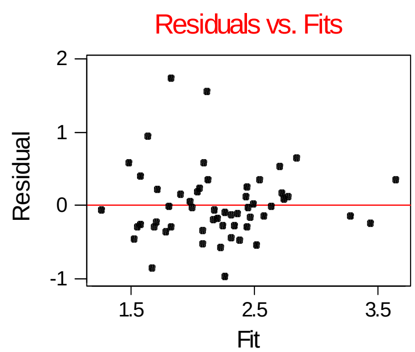


Fig 69: Standardized partial regression plot

Residuals vs X4

The additional analysis to be realized for this problem is the identification of any observations that are influential and/or with disproportionate impact on the regression analysis. The most basic diagnostic tool involves the residuals vs fits graph.

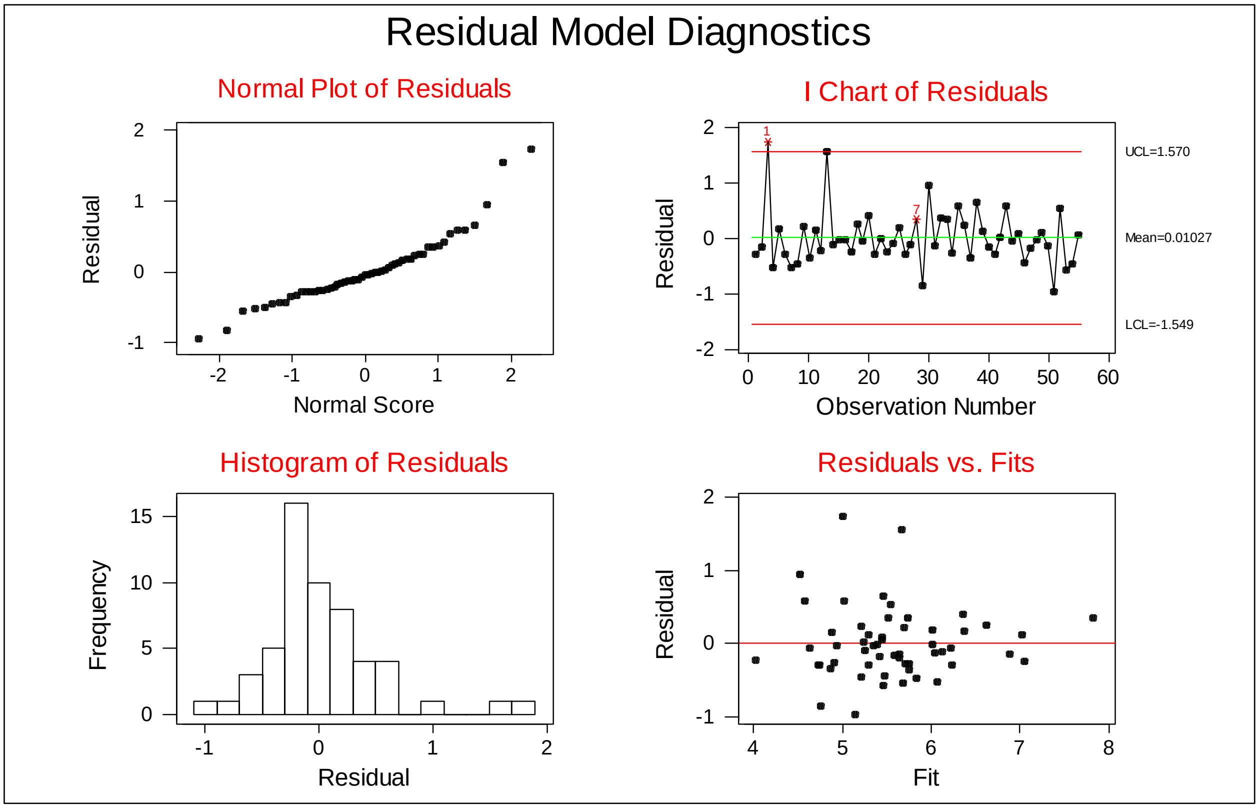


Figure 70: Plot of studentized residuals

From this plot is evident the existence of two outliers that are outside of the upper limits of the chart and almost outside the estimated limits established by Hair (1997). These outliers will be recognized in the validation process and according to the importance of the node could be taken out of the model and redefine the regression model.

e) Validation of results.

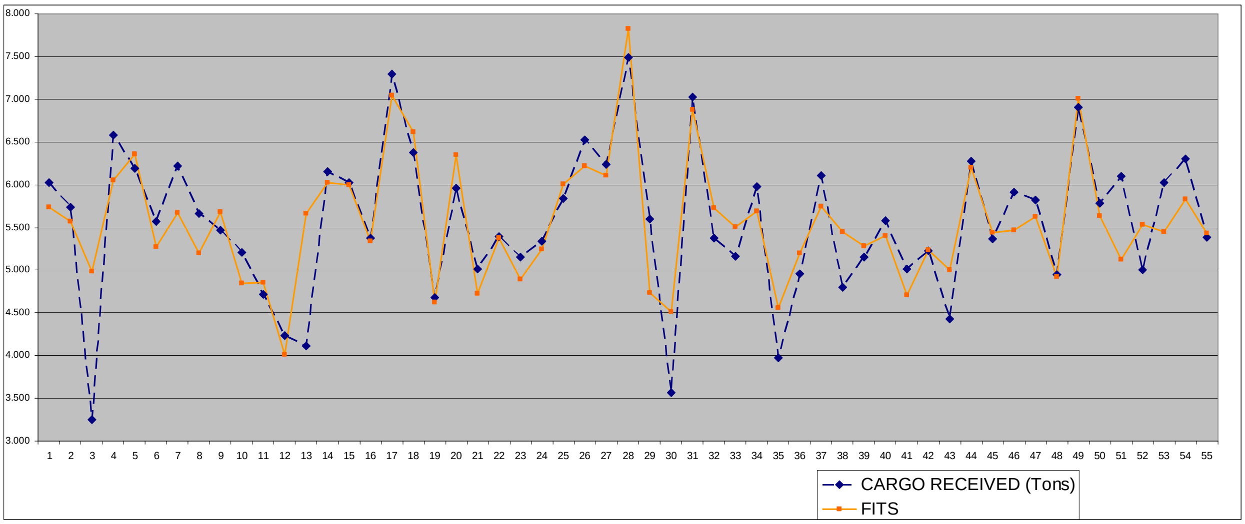


Figure 71: Validation of predicted values vs transformed Y1 results

To authenticate the results predicted by the regression model and to ensure that results could be generalized to the entire population, figure 71 reveal a comparison between the transformed Y1 values (dependent variable denominated cargo received by airport) and the predicted values resulted from the model.

From this plot it could be observed that regression model does not perform accurately comparing to the cargo generation model. This statement is supported by the results exposed by the regression analysis and with the appearance of outliers that has some influence in the statistical power of final results. Those outliers are cities that have some incongruence in cargo flows, either with the amount of cargo handled in relation to its industrial and/or airport development. Campeche, Cuernavaca, Monclova and Uruapan are identified as outliers and could be considered as atypical data inside the composition of the regression model and lie outside of general patterns with possible influence in regression results. Courses of action that could be taken to deal with outliers or influential points when the observation is correctly taken and has an unique combination of characteristics that makes it exceptional to the remaining observations are the deletion of those observations in case that they are not representative of the population, otherwise conceptual basis of the regression model should be modified and data retained.

The objective is to ensure the most representative model for the data that could reflect the behavior of the entire population. For this problem instance, the described cities that were identified as outliers do not participate strongly in the amount of cargo received by the entire Mexican airports system and according to their unusual behavior related to the facts described before; hence, the model will stand with current parameters.

To finish with this section, it is important to remark that the models exposed in this document have a descriptive attribute for actual interaction of cargo in air transportation industry in Mexico and also, the results that come from these models are directly affected by the current variables chosen to enter into the regression. Remarking the approach of this analysis based on a cross-sectional study, there is important probabilities to improve the possible "predictors" of the amount of cargo generated and/or received by the airports system as well as understand the movement behavior of the cargo in Mexico. Remaining the initial objective deployed at the beginning of this chapter focused on the construction of mathematical models that could describe the behavior of cargo flows inside the domestic air transportation system based on the information utilized in both analysis gives a good adjustment of the model to the entry data according to the ANOVA values exposed with a significance of 95% but having a moderate confidence for describing the flows that each terminal could achieve if the values of independent variables change, in agreement with the results taken from the R^2 and adjusted R^2 calculated by the model.

Constant augmentation of air cargo demand is motivated for different transportation users that visualize the air mode as an absolute competitive advantage for their particular businesses. For this reason, new logistics methods must be implemented by the involved enterprises in cargo activities in order to raise service levels, to remark the special attributes of this kind of service and obviously to increment profitability. This type of studies aid to provide more details about the general characteristics of air cargo industry in Mexico and also this information could be useful to air cargo enterprises for establish strategies for managing future growing of the business and in result, stimulate the economical development of the country and satisfy the mobility needed by the Mexican society.

6. OVERALL FINDINGS AND CONCLUSIONS

6.1 CONCLUSIONS RELATED TO AIR TRANSPORTATION INDUSTRY PERFORMANCE

Globalization and raise of trade agreements between countries, has extended the supply chain of the organizations as well as demand efficiency from their diverse logistics systems. In answer of this competitiveness environment, air transportation has come out as an essential service for worldwide companies. Availability of infrastructure for air transportation and high quality services in particular regions turns out to be a necessary requirement for world-class companies in their planning process for possible allocation of manufacturing, handling and distribution facilities or locations.

For Mexico, air cargo activities are rising significantly since the implementation of NAFTA in 1994, where trade between Canada and United States has grown considerably. In overall terms, Mexico has executed more free trade agreements with other countries than any other country in the world. It is clear that Mexico intends to be the pivot for trade throughout the world and those conditions should be taken for the encouragement of air transportation strategies in Mexico as well as future schemas would be required in order to continue to attract foreign investment and decrease the economic recession repercussions from previous governmental periods.

For the current operational activities realized in the air cargo industry, specifically from the amount of cargo carried in Mexico, more than the 75% were handled in 12 of the 85 airports that integrate the national airport system, where Mexico City handled almost 50% of the cargo movements registered by those 12 airports in recent years as well as being the most important origin or destination port of entry in Mexico in international air cargo terms. These unbalance flows between Mexico City and the other airports that compose the national airports system are mainly caused by the differences in economical activities between diverse regions, remarking Mexico City Metropolitan Area as the main point of consumption in the country; however, this situation makes cargo operations more difficult to handle; this type of centralized systems might not adequately serve the country as a whole and also do not encourage strategic development and regional economical growth across the country.

Some national airports incremented their participation in international cargo movements in recent years based on their connectivity with important US hubs like Memphis, Los Angeles, Miami and San Antonio where dedicated integrators for air cargo services have their multimodal terminals. However, current situation reflects that air cargo transportation in Mexico have incurred in low utilization, provoked by its current infrastructure, and must be improved to satisfy current worldwide development needs. This unbalanced behavior of current loads of cargo movement in some specific infrastructures attends at the continuous practice of centralization in Mexico, where most important infrastructure is built around Mexico City and surrounding areas, leaving some other regions in Mexico apart from possible development.

During the development of this study, two mathematical models of generation and attraction of cargo were built looking to replicate domestic cargo flows inside the air transportation system in Mexico. Both representations were calibrated using regression models techniques and it was required to realize a logarithmical transformation to the original data in order to achieve linearity and normality during statistical analysis. At the end, the results shown by those models were obtained, giving a moderate R square coefficient value relating the generation and attraction of cargo in each of the national terminals involved in the analysis with the population of the metropolitan area in where the airport is located, the manufacturing and transportation industries allocated in the area where airport is established and the average between origin-destination in each of the airports implicated in the analysis, even though the analysis of variance for both representations indicates that these models are valid for describing cargo flows as well as manage possible changes in dependent variable values, according to the variables already chosen during model creation process.

In conclusion with the results posted by both mathematical analyses, it is possible to define a descriptive study of current air cargo behavior that leads to portray the performance of cargo movement in Mexico, even though there is still a considerable opportunity to define better parameters that could define strongly how air cargo will behave according to selected data. In relation to the related studies mentioned on the last chapter, there are some similarities and differences in the proposed models obtained in this study. Comparing to the study deployed by Rico (2001), even though his results gave a significant value of R^2 (approaching to 80% -85%), with a pair of similar predictors that were used in this proposed model, there are not any statistical evidence that could support his results as well as did not provide any prove that could lead to the realization of a multiple regression analysis based on the variability of the nodes that composed the air transportation system in Mexico. On the other hand, comparing with the international flows analyses provided by the literature, the exclusion of other descriptive variables that could describe the social and economic environment in each region(for example the GDP by population, gross incomes per industry sector and so on) that may lead to reinforce the regression model and give better results for R^2.

Another important issue for the future development of national airport infrastructure is that the operative must be planned and programmed with modern logistics techniques and moreover the possibility to improve air transportation system program, with an emphasis to remark the importance of cargo movement as part of multimodal transportation, where airplanes do not deliver the cargo directly to their clients, and the freight must be moved from airports by a multimodal system that is generally complemented by other means of transportation that carry out the items from and to the airports. In the case of this proposed analysis, multimodal variables should be considered into the study, mainly because that they must be related on the capacity of freight movement by each airport in where efficient operation must be achieved between different transportation operators involved in a multimodal strategy.

With this type of mathematical analysis developed on Chapter 5 that could provide useful information in order to represent the amount of cargo operations in the air cargo environment, it is important to remark that the development of this type of analysis gives, initially, an important approach to understand general and particular characteristics of the event studied (cargo movement in national terminals), but also it could be an key tool that could be used by any decision entity to justify possible investments for a specific region, encouraging the development of cargo operations of Mexico. With this statement, this study tries to incorporate and strengthen that an analysis based on the utilization of mathematical techniques for decision process, which is not widely used by the decision players, could be an important factor that define if projected investments could be executed and allow to envisage growth tendencies of cargo movement in Mexico.

Supported on the complete operational analysis of cargo movement in Mexico, during the last decade, Mexican transportation structure has registered significant changes that encourage the participation of demoted transportation means in the past (air and rail transportation mostly) and motivate the existence of current exclusive cargo transportation companies, arise the investment of specialized cargo terminals and incite the growth of cargo demand national and internationally.

But even the explosion of air cargo activities not only in Mexico but worldwide, nowadays, Mexican air cargo industry has been incurred in under-utilization levels of air transportation infrastructure based on scarce activities in the majority of the airports and huge amounts of cargo managed in 5-8 airports nationally. This occurrence has been a factor of inadequate distribution of cargo constrained by the capacity of Mexican airports and leading to low levels of efficiency as well as higher costs and lower competitiveness levels for different productive sectors in Mexico.

In addition to this fact, there are limited aerospace regulations and government initiatives that incite in deficient planning for the construction of more infrastructure and inefficient programming for air cargo operations caused by the poor service level provided by governmental bureaus, basically related on poor information management and standardization as well as lack of experience on air cargo management and international requirements.

Therefore, air cargo transportation challenges in Mexico for the near future in cargo movement terms are closely related to encourage strategic development and economical growth for all the regions across the country, based on the utilization of this mode of transportation and remarking that the future development of national airport infrastructure is essential to satisfy the increasing needs of air transportation on future years.

6.2 ISSUES AND CHALLENGES IN MEXICAN AIR CARGO INDUSTRY

Multimodality enhances the economic performance of a transport chain by using modes in the most productive manner. Thus, line-haul economies may be exploited for long distances, with the efficiencies of trucks providing local pick up and delivery. The key is that the entire trip is seen as a complete system, rather than as a series of legs, each marked by an individual operation with separate sets of documentation and rates. The limits of multimodality are imposed by factors of space, time, form, pattern of the network, the number of nodes and linkages, and the type and characteristic of the vehicles and terminals. Multimodality can be conceived as the transition from one mode of transportation to another, and is organized around the followings concepts:

1. The nature and quantity of the transported commodities;
2. The modes of transportation being used;
3. The origins and destinations;
4. Transportation time and costs;
5. The value of the commodities and the frequencies of the shipments.

Currently, multimodal transportation services in Mexico evidence an incipient development (Secretariat of Communications and Transportation of Mexico, 2001). The main reason for that problem is because highways, rail, seaports and airports infrastructures were conceived in a separate manner. In consequence, transportation sector in Mexico is developed in a total fragmentation and inarticulate environment. These days, there are several organizations that are offering integrated services for safety and efficient movement of cargo as well as infrastructure capacity is being built for freight movement; however, connections between rail, highways and port infrastructures and feeding nodes must be improved in order to increase multimodal terminals across the country. Deficient planning of national governments and lack of multimodal services based on inadequate infrastructure for its expansion, could lead Mexico to reach a remarkable drawback where in globalize economy, transportation services provides high-strategic value.

A competitive strength for a multimodal infrastructure from the international transportation point of view (imports and exports) is the availability of custom services with help to diminished in a big sense possible bottlenecks coming from international trade procedures that must be developed and also, this would aid to raise in-transit movement of cargo, incrementing transportation utilization. From the value-added services viewpoint, multimodal terminals should foresee this need that is an actual requirement from all transportation users. Those value-added services are basically the possibility to do consolidation in the same terminal and allow a decreasing of transportation cost for modest exporters. This issues should be take in consideration by the government and private investors for the augmentation of competitiveness either for Mexican products that comes from international markets as well as inciting foreigner investors to realize more trade in Mexico.

At the same time as manufacturers are spreading their production facilities and assembly plants around the globe to take advantage of local factors of production, transportation becomes an even more important issue. The integrated transport chain is itself being integrated into the production and distribution processes. The choice of transportation means can no longer be considered as a separate service that is required only as a response to supply and demand conditions.

It has to be built into like an entire supply chain system, from multi-source procurement, to processing, assembly and final distribution. An almost unique form of multimodal unit that has been developed until these days is the rail-truck multimodal industry. It would be interesting to develop this kind of industry integrating air transportation with other transportation services, offering standard rates to customers by integrating air transportation services, picking and delivery in a local and regional basis, producing important competitive advantages for national multimodal transportation.

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APPENDIX A: PRINCIPLES FOR ALLOCATION OF AIR CARGO TERMINALS FOR MULTIMODAL INFRASTRUCTURE

Efficient transportation infrastructures supports in a decisive manner to the national integration, stimulating commerce between main centers of manufacture and consume as well as allows synchronization between production chains and industrial corridors allocated on different geographical points in order to stronger industrial productivity and foment competitiveness in national economy.

Contribution from transportation is vital to national economy activities, mainly because it is an important factor to consider in production and distribution costs in addition to be the way to move cargo across geographical regions. Nowadays, the vision for the future development of national economy ought to be based on the continuous growth of national transportation systems, but specifically multimodal transportation should be the strategic element to impulse in order to achieve major levels of competitiveness in globalization environment. Multimodal transportation must promote and consolidate safety, efficient and competitive services, based on strategically allocation of terminals and logistic chains for transportation, which could link diverse transportation infrastructures, replying to increasing demand for those kinds of services.

Conventionally, the competition between the modes has tended to produce a transport system that is segmented and non-integrated. Each mode has sought to exploit its own advantages in terms of cost, service, reliability and safety. Carriers tried to retain business by maximizing the line-haul under their control. Major efforts have been made to integrate separate transport systems through multimodalism. This involves the use of at least two different modes in a trip from origin to destination through a multimodal transport chain.

There are several characteristics that are important to the success of multimodal freight terminals. According to Foster (2005), some of the most successful cargo terminals have some important characteristics that include proximity to large population centers, availability of land for further development, capable runways and facilities, onsite customs (for international cargo), foreign trade zone location, and possible delays due to weather factors.

Proximity to large population centers as well as its closure to consume points is potentially some of the most important characteristics to achieve by a cargo terminal. For air cargo case, the closer a gateway airport is to the people who are buying the goods, the more sense it makes for a cargo plane full of retail goods to land there (Foster, 2005).

The availability of land for further development is also a very important characteristic. This factor will seriously hinder the future growth for airports that are currently handling the great majority of air cargo. The best-known case is Mexico City Airport, which will not be able to expand their cargo operations as the air cargo business expands in the next two decades, because it simply do not have room to grow.

If an airport attempts to be successful as an air cargo terminal it must have long runways that are capable of handling international landings, since most of the growth of cargo transportation is focused on international movement, most of the new opportunities in this market will require capabilities for international cargo. Other capabilities are also required for a further development of an air cargo terminal. Customs services that are onsite of cargo terminals allows a much quicker international cargo turnaround time. In addition, close proximity to highways that offer access to desired highway systems are extremely important, because the preferred transfer for time-sensitive cargo is from air to truck. Quick access to rail or water ports can also be strong advantages, but are not as critical for the time-sensitive goods that generally fly by plane. Also, sufficient cargo space is important for preventing congestion and allowing for growth in business. Another factor to be considered for multimodal infrastructure planning is to provide advantages that serve to avoid empty returns from any kind of transportation that is going to be developed in a multimodal structure. One way to facilitate that goal is promoting reduced tariffs and discounts that may lead to decrease the growth of empty containers.

A competitive strength for a multimodal infrastructure from the international transportation point of view (imports and exports) is the availability of custom services with help to diminished in a big sense possible bottlenecks coming from international trade procedures that must be developed and also, this would aid to raise in-transit movement of cargo, incrementing transportation utilization.

From the value-added services viewpoint, multimodal terminals should foresee this need that is an actual requirement from all transportation users. Those value-added services are basically the possibility to do consolidation in the same terminal and allow a decreasing of transportation cost for modest exporters. In addition, special infrastructure for specific products, i.e. acclimatized-warehouses for perishable products, will growth competitiveness either for Mexican products that comes from international markets as well as inciting foreigner investors to realize more trade in Mexico.

Facilities that have cargo as their main priority are bound to capture a great deal of the market in following years. Based on the current development and growth of air cargo transportation, it might be worth to establish a formal structure of air cargo terminals oriented to multimodal transportation that could achieve the best conditions to impulse, increment and develop Mexican air cargo transportation and national economy. In addition to those described principles written in this section, an important academic background linked to air cargo that have received considerable attention is service fragmentation strategies, which are mostly based on hub-and-spoke (HS) structures, where systems employ centrally located hub facilities to transship flows between the nodes. HS structures have become popular with successful applications in ground and air transportation, communication networks, retailing and other logistic systems.

This type of network organization allows the system to take advantage of the economies of scale and centralization of operations at hubs. The idea in hub location models is to provide the correct parameters for consolidation from different origins and send it directly or via another hub to different destinations (nodes that are not destined as hubs are referred to as spokes), thus achieving economy of scale on hub-to-hub links. To date, the design or redesign of large-scale distribution networks has been one of the most important activities assigned to the logistics function. Hence, given the intensive competition in global markets, the performance of distribution logistics in the supply chain is considered a strategic issue in achieving and maintaining competitiveness seeking to achieve the goal of making the distribution channel more flexible and responsive to customer needs (Abdinnour-Helm, 1999).

APPENDIX B: ALLOCATION OF AIR CARGO TERMINALS IN COMPETITIVE ENVIRONMENTS: ANALYTICAL REVIEW OF HUB-AND-SPOKE FORMULATIONS FOR DISTRIBUTION NETWORKS ON AIR TRANSPORTATION INDUSTRY.

B.1 INTRODUCTION TO HUB AND SPOKE DISTRIBUTION NETWORK STRATEGIES

Given the intensive competition in global markets, logistics supply chain performance is considered a strategic issue in achieving and maintaining competitive advantage. To date, the design or redesign of large-scale distribution networks has been one of the most important activities assigned to the logistics function (Lumsden, et al., 1999).

The most immediate way to connect a number of points located in different geographical positions (production factories, distribution centers, warehouses, transit points, etc.) is through a direct connection system. This system corresponds to a ``point-to-point" network, where each pair of nodes is joined by a specific link from the departure node to the arrival node.
A further evolution of the ``point-to-point" network is the multiple terminal system. In this case, goods are transferred from their origins to one or more terminals where they are unloaded, then possibly stored for a short time and then loaded with other goods with a common final destination. In this case, since terminals are generally lower than the number of departure/arrival nodes, the number of connections required in a two terminal system is less than the classical “point-to-point configuration”.

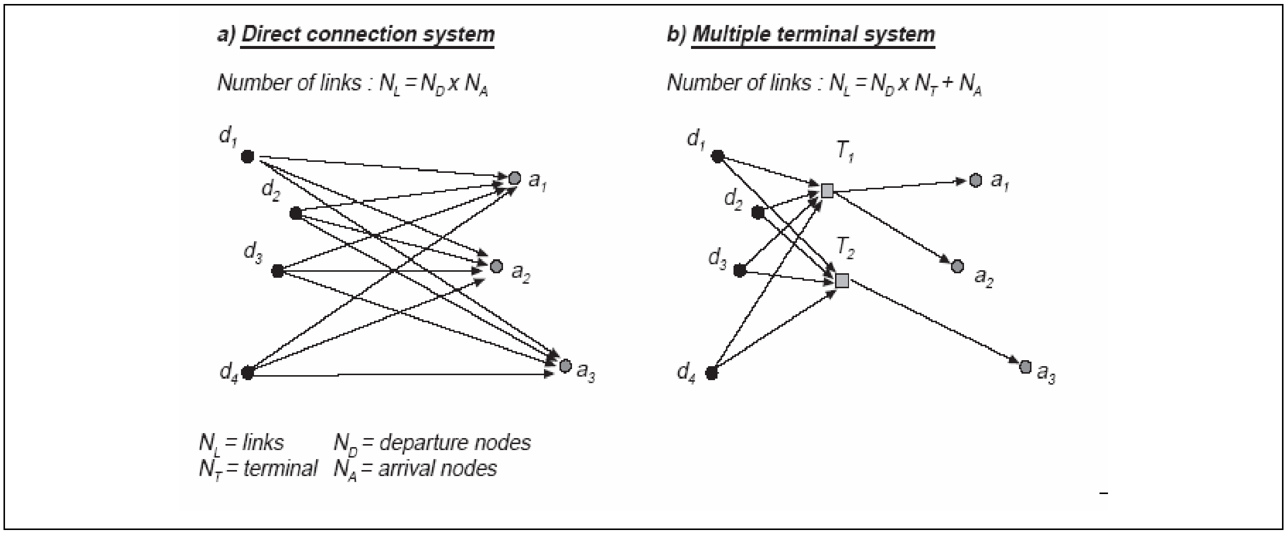

Figure B1: Point-to-point distribution networks.

Source: Lumsden,, et al. (1999) "Improving the efficiency of the Hub-and-Spoke system for the SKF European distribution network"

The Hub and Spoke system (HS) is derived from the multiple terminal systems and could be used in those logistics systems having few main routes but a consistent flow in both directions. Although the number of relations in a HS system is the same as in a single terminal network, the two-way flow in each link means there are twice as many connections. A typical HS system configuration, largely employed by express couriers, is the multiple terminal networks based on multiple hubs at the same hierarchical level (O'Kelly, 1998). This means that goods coming from/going to any satellite points require one or more handling operation before reaching the final destination.

There are two basic types of hub-and-spoke networks, differing in how non-hub cities are connected to the hubs. In the single assignment model each city is connected to a single hub. There is no sorting at the origin because all flow must travel to the same hub. The multiple assignment models allow each city to be connected to more than one hub. Sorting must occur at each origin that interacts with more than one hub.

This model increases the number of links in the network but at the same time decreases individual travel times (O´Kelly et al., 1996).

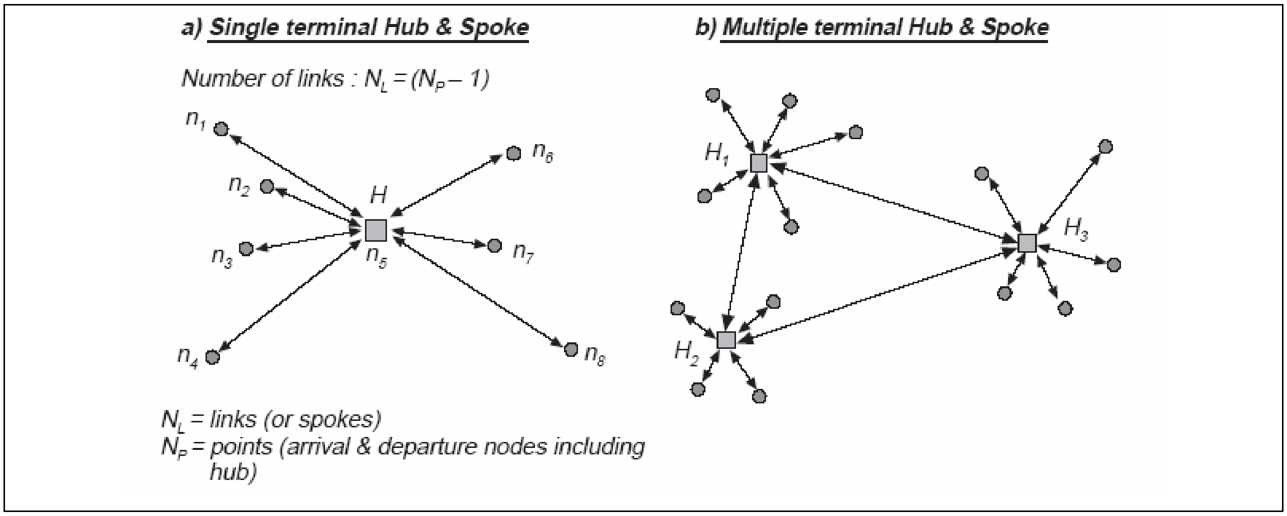

Figure B2: Hub-and-spoke distribution networks.

Source: Lumsden,, et al. (1999) "Improving the efficiency of the Hub-and-Spoke system for the SKF European distribution network"

The basic hub-and-spoke network design problem could be described as a network of nodes where each pair has a given path, and its objective is to determine which nodes are set as hubs so that every flow is first routed through one or two hubs before being disseminated to its destination, differing from a completely- interconnected network, where its flow travels directly from the originating city to the destination with no intermediate stops.

Compared to the single terminal network, the multiple terminal configuration results, on average, in reduced distances traveled, but less efficient of transportation resources, from the utilization point of view. In a hub-and-spoke network the reduction in the number of links is made possible by the establishment of hubs or transshipment points.

A characteristic feature of HS networks is the collection of flows on the inter-hub links. By bundling flows, carriers can use larger aircraft and thus reduce item-mile costs. Hubbing results in lower total network costs but it increases individual travel miles because most routes are no longer direct flights and instead are one- or two-stop routes (Elhedhli, et al., 2005).

As affirmed before, HS networks could provide important benefits (Lumsden, et al., 1999):

- Fewer links are required to connect the same number of points;

- Higher carrier filling rates, because the transportation flow is concentrated in fewer links;
- Possibility of higher travel frequencies between nodes (i.e. approach for JIT production);
- Service coverage maintained to many outlying origins/destinations and along low-traffic routes;

However, the system causes some drawbacks (Lumsden, et al., 1999):

- Increased average lead times;
- Increased mean distances between each pair of nodes (especially if nodes are quite close);

HS problems focused on the hub location problem and the development of models to represent it is very broad. The scope of this recompilation is to briefly discuss some heuristics and formulations for this specific assignment problem provided by the literature. Hub location problems are concerned with locating hubs and assigning spoke nodes to the hubs to meet a predefined objective. Finally, a summary of the current state of hub location models will be deployed.

B.2 HUB LOCATION PROBLEMS

Hub location problems deal with a network of interacting nodes, for which the distance and the flow between each pair of nodes is given. Such a network could represent airline passenger flows, communication traffic, express package delivery, data transactions, etc. The idea is to design a network structure where a subset of the nodes in the network (discrete) or points in the plane (continuous) act as hubs. Each of the other remaining nodes in the network is assigned to a single hub, and is referred to as a spoke.

The result is a pure hub-and-spoke network, in which flow between any pair of nodes can only take place through the hubs. A major incentive for this type of system is to consolidate traffic through the hub to hub links, and hence achieve economies of scale by allowing lower unit costs on those links.

Campbell (1994) defines four fundamental types of discrete facility hub location problems: the *p-median* problem, the *uncapacitated facility location problem*, the *p-center* problem and *covering* problems. Hub location problems could be classified also by the way in which demand points are assigned, or allocated, to hubs. One possibility is single allocation, in which each demand point is allocated to a single hub, i.e. each demand point can send and receive via only a single hub (O'Kelly et al, 1996, 1998, 2002; Jaillet, et al., 1999). A second possibility is multiple allocation, in which a demand point may send and receive via more than one hub (Campbell, 1994, 1996; Abdinnour-Helm, 1999; Mayer, et al., 2002; Elhedhli, S, et al., 2005).

Hub location problems belong to the NP-hard problems (Abdinnour-Helm, et al., 1998). They are different from other standard facility location problems in that the flow between the hubs depends on the choice of the hubs. The key difficulty in hub location problems is that even when the hubs are given, the allocation of each of the remaining nodes to a single hub is an NP-hard quadratic assignment problem. Hub location problem formulation started in 1987, when O'Kelly formulated a quadratic integer program for a p-Hub Median Problem and showed that it was NP-hard. This type of problems tries to find p hubs in a network of interacting nodes to minimize the overall transportation cost. The formulation implies that all non-hub nodes have single assignment whereas the hubs have multiple assignments. In addition, all inter-hub links are completely interconnected. Another assumption is that the hubs have unlimited capacity.

The Quadratic Single Assignment Model

(1) $$\text{Min} \sum_i \sum_j W_{ij} \left(\sum_k Z_{ik} C_{ik} + \sum_m Z_{jm} C_{jm} + \alpha \sum_k \sum_m Z_{ik} Z_{jm} C_{km} \right)$$

s.t.

(2) $$(n - p + 1) Z_{kk} - \sum_i Z_{ik} \geq 0 \qquad \forall k$$

(3) $$\sum_k Z_{ik} = 1 \qquad \forall i$$

(4) $$\sum_k Z_{kk} = p$$

$$Z_{ik} \in \{0,1\} \qquad \forall i, k$$

Where:

n = the number of nodes in a network

p = the number of hubs to be located

a = the interhub discount factor 0 £ a £ 1

Wij = the amount of flow traveling between i and j

Cik = the per unit cost of traveling between i and k

Zik = 1 if node i is allocated to hub k, 0 otherwise

Figure B3: Quadratic Single Assignment Model realized by O´Kelly, 1987.

Source: Modified from O´Kelly, M. "A geographer's analysis of Hub-and-Spoke networks", 1998.

From this formulation provided by O´Kelly, objective function (1) minimizes total network cost. Constraint (2) requires a hub to be open before a node is assigned to it. Constraint (3) constrains each node to be assigned to a single hub. Constraint (4) requires that *p* hubs be open.

This formulation is very similar to the *p*-median problem with the exception of the quadratic term in the objective function. In the *p*-median, once facility locations are determined the remaining nodes are simply assigned to the nearest facility which minimizes total network cost. Travel costs then consist of a single component: the cost of traveling from the origin to the facility. However, in the hub location model nearest-center assignment is not guaranteed to be optimal.

Also, O´Kelly proposed two enumeration-based heuristics to solve this problem. Both heuristics considered all possible *p*-hub combinations. In the first one, the allocation was made to the nearest hub, whereas in the second one, the allocation was made to the first or second nearest hub. The second heuristic gave a tighter upper bound on the objective function than the first one, and therefore, it was closest to optimality.

Several researchers continue to develop several heuristics for this problem, including Campbell (1994, 1996), who initially developed a p-hub median problem analogous to a p-median problem formulated by Hakimi (1964, 1965). Abdinnour-Helm and Venkataramanan (1998) develop an approach based on simulated annealing, trying to find good solutions to the single assignment hub location problem. An exchange method is described, looking to determine both good hub locations and allocations for the simulated annealing heuristic; Aykin (1994) formulated a branch-and-bound algorithm and a heuristic procedure based on Lagrangian Relaxation, partitioning the set of solutions on the basis of hub locations, reducing into a smaller routing problem. Ernst and Krishnamoorthy (1996) formulated another simulated annealing heuristic improved on the bounds obtained by Abdinnour-Helm and Venkataramanan. One of the best results obtained for this problem and related in almost all literature is the one developed by Skorin-Kapov and Skorin-Kapov (1994) with tabu search. Time lower bounds were found making lower bounds tighter and closer to the true optimal solution.

The development of a linearized version of the quadratic model was a great advance in hub research. This was initially accomplished by Campbell (1994). This development allows the use of linear programming to find optimal solutions. To get this linearization, Campbell defines first the p-hub median problem as follows:

$$\text{Minimize} \quad \sum_{i}\sum_{j}\sum_{k}\sum_{m} W_{ij} X_{ijkm} C_{ijkm}$$

$$\text{subject to} \quad \sum_{k} Y_k = p, \qquad (1)$$

$$0 \le Y_k \le 1 \text{ and integer for all } k, \qquad (2)$$

$$0 \le X_{ijkm} \le 1 \text{ for all } i,j,k,m, \qquad (3)$$

$$\sum_{k}\sum_{m} X_{ijkm} = 1 \quad \text{for all } i,j, \qquad (4)$$

$$X_{ijkm} \le Y_k \quad \text{for all } i,j,k,m, \qquad (5)$$

$$X_{ijkm} \le Y_m \quad \text{for all } i,j,k,m. \qquad (6)$$

Figure B4: P-Hub Median model defined by Campbell, 1994.

Source: Modified from Campbell, J. "Integer programming formulations of discrete hub location problems", 1994.

Where the objective function is the minimization of the transportation cost over all origin-destination pairs; constraint (1) establishes exactly p hubs; constraint (2) restricts Y_k to be zero or one; constraint (3) limits the range of X_{ijkm}; constraint (4) assures that the flow for every origin-destination pair is routed via some hub pair. Constraints (5) and (6) assure that flows are routed via locations that are hubs.

Campbell remarks some differences between P-median formulations compared to the P-Hub median problem deployed in his research. Those differences are mainly based in the conception of p-median formulations, where each demand point is optimally allocated to a single facility, which is also the nearest (least cost) facility, differing from the hub location problems where there are specified origin to destination flows and the inter-hub transportation rate is generally discounted. Minimizing travel distance does not generally minimize transportation cost, because of the different transportation rates.

Another motivation for the linearization model provided by Campbell is because he had the intention to find integer solutions, where in the case of the hub location problem, the locations of the hubs must be integer, as the size of the problem restricts the use of integer programming to very small networks; linearization resulted to be the way to solve the need for exact solutions to small problem instances.

The linearization model proposed by Campbell leads to formulate the multiple assignment model, which allows spoke nodes to interact with more than one hub. Given the hub locations, every interacting pair selects the path that minimizes their own total travel costs. Formulation for this specific is exposed next:

The Linearized Multiple Assignment Model

(5) $$\text{Min} \sum_i \sum_j \sum_k \sum_m W_{ij} \left(C_{ik} + \alpha C_{km} + C_{mj} \right) X_{ijkm}$$

s.t.

(6) $$\sum_k Z_k = p$$

(7) $$\sum_k \sum_m X_{ijkm} = 1 \qquad \forall i, j$$

(8) $$\sum_m X_{ijkm} - Z_k \leq 0 \qquad \forall i, j, k$$

(9) $$\sum_k X_{ijkm} - Z_m \leq 0 \qquad \forall i, j, m$$

Figure B5: Linearized Multiple Assignment model defined by Campbell, 1994.

Source: Modified from Campbell, J. "Integer programming formulations of discrete hub location problems", 1994.

Where: *Xijkm* = the fraction of flow from origin *i* to destination *j* that is routed via hubs *k* and *m* in that order.

Zk = 1 if *k* is a hub and 0 otherwise.

The objective function minimizes total network. Constraint (6) requires that p hubs be open. Constraint (7) ensures every interacting pair (i,j) is allocated to a path via hubs k and m. Taken together, constraints (8) and (9) guarantee that the O–D flow will not be routed via k and m unless both k and m are in fact hubs.

However, Campbell's model resulted in fractional solutions for the problems tested in his research. O'Kelly, et al. (1996) obtained a tight linearized version of the hub location problem. A tight linearization resulted in integer solutions for the hub locations without forcing integrality through the use of integer programming, finding exact solution values small problem instances. Once a linearization was found resulting on exact solutions to small problems, some researchers began focusing on different linearizations of the problem. Ernst and Krishnamoorthy (1996) realized a linearized variation of O'Kelly (1987) original quadratic model. The immediate result was to reduce the number of variables and computation time, even though integer programming must be used to obtain optimal solutions so this model did not result in an increase in the size of the problem that could be solved to optimality.

As mentioned before at the beginning of this review, Campbell (1994) classified different types of discrete facility hub location problems as well as formulated those ones in an integer manner; for those defined problems, objective function is not necessary the minimization of total network. One of them was the uncapacitated hub problem where initially, the numbers of hubs are not predetermined; therefore, a fixed cost for establishing a hub is included in the formulation. The integer formulation developed by Campbell is shown next:

$$
\begin{aligned}
\text{Minimize} \quad & \sum_i \sum_j \sum_k \sum_m W_{ij} X_{ijkm} C_{ijkm} + \sum_k F_k Y_k \\
\text{subject to} \quad & 0 \le Y_k \le 1 \text{ and integer for all } k, \\
& 0 \le X_{ijkm} \le 1 \quad \text{for all } i,j,k,m, \\
& \sum_k \sum_m X_{ijkm} = 1 \quad \text{for all } i,j, \\
& X_{ijkm} \le Y_k \quad \text{for all } i,j,k,m, \\
& X_{ijkm} \le Y_m \quad \text{for all } i,j,k,m,
\end{aligned}
$$

Figure B6: Uncapacitated hub location problem formulation defined by Campbell, 1994.

Source: Modified from Campbell, J. "Integer programming formulations of discrete hub location problems", 1994.

From this formulation, the main difference with the p-hub median problem is the variable F_k added to objective function which establishes a fixed cost of establishing a facility at location k. The constraints are identical to those of the p-hub median problem, except that the number of hubs is not given. O'Kelly (1998), Aykin (1994), Abdinnour-Helm and Venkataramanan (1998) developed heuristics to solve this problem instances, using mainly Genetic Algorithms.

For hub center problems mentioned by Campbell, the objective is to minimize the maximum distance traveled by any interacting pair of nodes (either for the entire route or for individual links). Campbell defines that this type of network would be appropriate when the maximum travel time needs to be as small as possible. He defines the hub center problems as analogous to the p-center problem. Integer formulation for this specific problem as well as their conception is developed in his research. The constraints are almost identical to those of the p-hub median problem, defining X_{ijkm} as an integer.

$$
\begin{aligned}
\text{Minimize} \quad & \underset{i,j,k,m}{\text{Maximum}} \{X_{ijkm} C_{ijkm}\} \\
\text{subject to} \quad & \sum_k Y_k = p, \\
& 0 \le Y_k \le 1 \ \text{ and integer for all } k, \\
& \sum_k \sum_m X_{ijkm} = 1 \quad \text{for all } i,j, \\
& X_{ijkm} \le Y_k \quad \text{for all } i,j,k,m, \\
& X_{ijkm} \le Y_m \quad \text{for all } i,j,k,m, \\
& 0 \le X_{ijkm} \le 1 \quad \text{and integer for all } i,j,k,m.
\end{aligned}
$$

Figure B7: Hub center problem formulation defined by Campbell, 1994.

Source: Modified from Campbell, J. "Integer programming formulations of discrete hub location problems", 1994.

Hub-covering problems were also considered by Campbell, describing that they mainly locate hubs to cover all demand such that the cost for the hubs is minimized. A node is considered covered by a hub if the cost of the node's path via that hub is less than a specified amount or alternatively, if the flow between an origin and destination can travel the path via the assigned hub within a specified period of time.

F_k is the fixed cost to establish a hub at location k. If all F_k are identical, then the objective is equivalent to minimizing the number of hubs.

$$
\begin{aligned}
\text{Minimize} \quad & \sum_k F_k Y_k \\
\text{subject to} \quad & 0 \le Y_k \le 1 \ \text{ and integer for all } k, \\
& X_{ijkm} \le Y_k \quad \text{for all } i,j,k,m, \\
& X_{ijkm} \le Y_m \quad \text{for all } i,j,k,m, \\
& \sum_k \sum_m V_{ijkm} X_{ijkm} \ge 1 \quad \text{for all } i,j,
\end{aligned}
$$

Figure B8: Hub covering problem formulation defined by Campbell, 1994.

Source: Modified from Campbell, J. "Integer programming formulations of discrete hub location problems", 1994.

Some researchers have focused their attention to incorporating more realistic characteristics of hub networks into the model. Due to the complexity that those assumptions add to the diverse formulations given in literature, the model proposed is often simplified by assuming fixed hub locations before extensions are introduced. Daskin and Panayotopoulos (1989) addressed the problem of assigning aircraft to routes with the objective of maximizing profits. They implemented a heuristic based on Lagrangian relaxation and found an upper bound on the profits. In this model each route originates at a single hub, visits one or more other cities, and then returns to the hub. Elhedhli and Xiaolong Hu, (2005) analyzed the relationship between hub-and-spoke networks and congestion, or schedule delay. In this analysis they assumed a single assignment hub-and-spoke network with fixed hub locations. Simulation of daily operations showed that the amount of the locally originating demand is a crucial determinant of schedule delay. As local demand increases, both the required total number of connections and the potential for schedule delay decreases. O´Kelly et al. (1998) and Cheung et al. (2001) addressed some variations on the pure hub-and-spoke network based in particular characteristics. They worked in problem instances applied to express package delivery systems which practices guarantee delivery within a narrow time window—generally one or two days. Time limits place a constraint on the distance traveled by each package and this fact should be factored into network design.

Another approach to the hub location problem has been realized by Aykin (1994) considered the design of a hub-and-spoke network that allows spoke to spoke connections as well as one- and two-stop routes. Aykin included a factor for the spokes to reflect the economies of scale earned on those links but not for direct non-hub to non-hub routes. A heuristic based on Lagrangian relaxation was developed to solve this model. Jaillet, et al. (1996) makes an extension of Aykin´s research, designing a network in which no a priori hub-and-spoke structure is assumed. Calculations of total cost developed by the algorithm proposed in this research will return the “strong connecting cities” based on the efficiency of cost achieved by the algorithm.

A remarkable difference in this research is that most studies require a hub to serve as a transshipment point and only allow hubs to serve in this capacity, but in their formulation did not place this restriction on their model. Rather 'hubs' are defined as any city that receives a large amount of flow. Any city in the network is allowed to serve as a transshipment point, even if it is not designated as a hub.

In these extended models the objective remains the minimization of total network cost. However, other goals are also important in network design. Some of them were briefly included in the last paragraph and are related to consider different congestion-based objectives for network design that measure hub usage (Marianov et al., 1999 and Cheung et al., 2001); they basically found that by minimizing variability of hub usage the resultant design provides an equitable allocation of nodes to hubs. When the objective is the minimization of total hub usage, demand tends to be concentrated quite heavily in one central facility.

In summary, since the hub location model was first formulated in 1987 a great deal of research has been conducted on this interesting problem, and many advances have been made. Researchers now have a tight linearization to solve small-size problem instances and reliable heuristics have been performance to solve much larger, realistically-sized problems. Several extensions to the basic model have also been formulated. The purpose of these extensions is to improve modeling capabilities by incorporating important characteristics of actual networks into models. The main idea of this recompilation is basically to create knowledge based on the research that has been developed during recent years but the most important issue is to identify different research opportunities that exist nowadays in this particular problems. Even though the literature has presented a large number of strong analyses of different models, looking for a more robust application of these models to real network systems, more research is needed. Certainly to get to more realistic applications, it is necessary to consider multiple objectives, as well as stochastic changes in flows, making sure to design and build networks that do not lock in on flows which will inevitably change over time. Hence, this type of research could provide a helpful aid to several companies that are emerged into the logistic world, using this type of models and solution techniques from the literature to improve the design of the distribution function in their supply chain.