A Preliminary Evaluation of Potential Cargo Demand for Very Light Jets

Yue Xu
Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University,
Blacksburg, VA, 24060

Antonio A. Trani
Department of Civil and Environmental Engineering
Virginia Polytechnic Institute and State University,
Blacksburg, VA, 24060

***Abstract*— this paper presents a research effort to study future air cargo demand using new generation Very Light Jets. Cargo demands are generated at county and airport level using T100D and Woods & Poole demographics data. At airport level, a growth factor based FRATAR model is applied to distribute air cargo demand among cargo airports up to year 2025. Historical trends of all-cargo carriers load factors are analyzed. An economics model is built to study Very Light Jet cargo transport cost. Cases studies are conducted to assess the competitiveness of the VLJ in terms of transport time and cost. Throughout our analysis, air cargo is further categorized into freight and air mail as they have different characteristics.**

Keywords-component *Very Light Jet, Air Cargo, Growth Factor, Demand Forecast*

I. Introduction

This paper is composed of two parts. Air cargo demand at airport and county levels is described in the first part. A Very Light Jet (VLJ) cargo transport cost model and case studies are presented in part two. The traditional four-step-model is applied and this paper addresses demand generation, distribution and mode split.

The first part uses Bureau of Transportation Statistics Air Carrier Statistics Domestic Market Database (T100D) as the primary data source. Air cargo demand is generated at around 900 cargo airports based on socio-economics. A growth factor based FRATAR model is applied to distribute predicted air cargo demand. In addition, demands at special transfer locations such as Memphis Airport (hub for FedEx) and Louisville Airport (hub for UPS) are redistributed.

In the second part of the paper, a cargo aircraft economics model is proposed to estimate cargo shipping cost using VLJ. The first Very Light Jet, Eclipse 500 from Eclipse Aviation is used as the prototype vehicle in the analysis. Various cost components including hourly variable cost, annual fixed cost, periodic cost, personnel cost, and facility costs are integrated in the model. The cost estimates are derived from estimates published by Business and Commercial Aviation and ARG/US Operations Planning Guide [1]. The model generates life cycle cost metrics including cost per hour, cost per mile, and cost per pound-mile, and a summary of annual cost components. Air cargo size and load factor are also analyzed.

II. Literature Review

Freight demand modeling has emerged as a major issue in the transportation industry. State and regional cargo demand modeling have received extensive attention in recent papers [2][3][4][5][6]. These models usually concentrate on rail and truck operations. State-of-the-Practice freight databases are well documented by A. Mani and J. Prozzi [7].

There are several nation-wide freight models in the U.S. and Europe. Freight Transportation Research Associates (FTRA) developed an input/ output model that forecasts freight demand in the U.S. The model collects data from 1965 through 2004 at 3-digit Standard Transportation Commodity Code (STCC) level and assigns shipments to rail, truck, pipeline and water [8]. Another national freight model, Global Insight's North American Trade and Transportation Data (TRANSEARCH INSIGHT) represents a more detailed multi-modal model. The model utilizes Global Insight's quantitative economics model to forecast freight volume up to 2030. It estimates inbound/outbound shipments at BEA (Bureau of Economic Analysis) and county level in terms of 4-digit STCC commodity [9].

In addition to proprietary databases, the Federal Highway Administration is developing a Freight Analysis Framework (FAF) that integrates data from various databases to estimate freight flow among states, regions, and major international gateways [10][11]. The first generation of FAF, FAF^1, is based on Bureau of Transportation Statistics (BTS) Commodity Flow Survey (CFS) 1997. CFS is one of the most commonly used freight flow databases in the literature. It collects sample data through survey forms from a universe of about 800,000 establishments [12]. However, CFS is estimated to cover about 70-80 percent of the U.S. cargo movement [13]. Therefore, the FAF model incorporates complimentary data sources to complete missing elements of CFS records. The first version, FAF^1 estimates shipment in 1997 and provides forecasts for 2010 and 2020. The new product, FAF^2, derives inputs primarily from CFS 2002 and predicts freight shipments through 2035 in 5 year increments [13]. It is comprised of three categories of data including CFS within-scope data, auxiliary data and CFS out-of-scope data. CFS within-scope data comes directly from CFS 2002. Auxiliary data represents complementary databases and is

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used in a log-linear model and iterative proportional fitting to estimate CFS out-of-scope data. The most detailed Origin-Destination (OD) table is a region to region OD table by mode by 2-digit SCTG code.

National freight movement modeling attracts extensive attention in Europe as well [14]. In Great Britain, a national multi-mode freight model, Great Britain Freight Model (GBFM), has been developed to predict freight demand and policy impacts [15]. The model estimates international cargo movements between counties within Great Britain and Europe as well as internal county to county and postcode to postcode cargo flows. Policy impacts can be evaluated via a set of operating cost models and transport route characteristics. A logit model is applied for mode and route choice. Meanwhile, there are several similar models such as Sweden SAMGODS [16][17], Norway NEMO [18], and Belgium WFTM [19]. All of them represent network models with cost functions and freight flows on modes and routes [20]. Besides network models, discrete models are widely used. Italy's SISD and the Netherlands's TEM models belong to this family [20]. In addition to TEM, the Netherlands has two other freight models that employ different philosophy [21]. The first one is SMILE, a model that introduces logistic segmentation and intermodal transport chains into a multimodal network [22]. The second model, MOBILEC, applies casual relationships between economy, mobility and dynamic growth [23]. France has two national freight models. Simulation techniques are used in the first model to forecast demand and assess policy impacts whereas the second model (named Transalpine) model is based on transport costs [20].

Apart from multi-mode cargo database, there are several dedicated air cargo databases. The Official Airline Guide (OAG) Cargo Database produces annual worldwide cargo schedules between origin and destination [24]. OAG Cargo covers cargo data from 138 carriers (as of Nov. 2006) who report their statistics to OAG. However, data from mainline cargo shippers such as FedEx, UPS and Airborne are not included. A more complete database, the FAA's Air Carrier Activity Information System (ACAIS) All-Cargo Activity Report covers 492 domestic carriers in 2007 [25]. It is designed for Federal funding allocation but not for direct cargo demand modeling because it only records the maximum possible cargo landing weight at airports, i.e. the maximum landing weight of scheduled cargo flights no matter how much payload is carried. Another public database, BTS Form 41 T100D Domestic Market database, comprises fewer carriers (64 all-cargo carriers in 2005) but includes mainline shippers and actual payload records. It consists of monthly data reported by certified U.S. air carriers on passengers, freight and mail transported [26]. Furthermore, it provides critical information on available capacity and seats, aircraft type, service class, aircraft hours, etc. Therefore, it is used as the main data source for airport-to-airport cargo flow estimation.

III. MODELING

In the beginning, multi-modal public databases such as FAF and CFS are explored to estimate air cargo share. However, due to the absence of detailed mode specific data, especially the air mode, it is difficult to quantify air cargo components using FAF and CFS. Consequently we turned to the air transportation oriented database T100D as our main data source. Figure 1 shows the flowchart for Very Light Jet cargo demand generation and distribution.

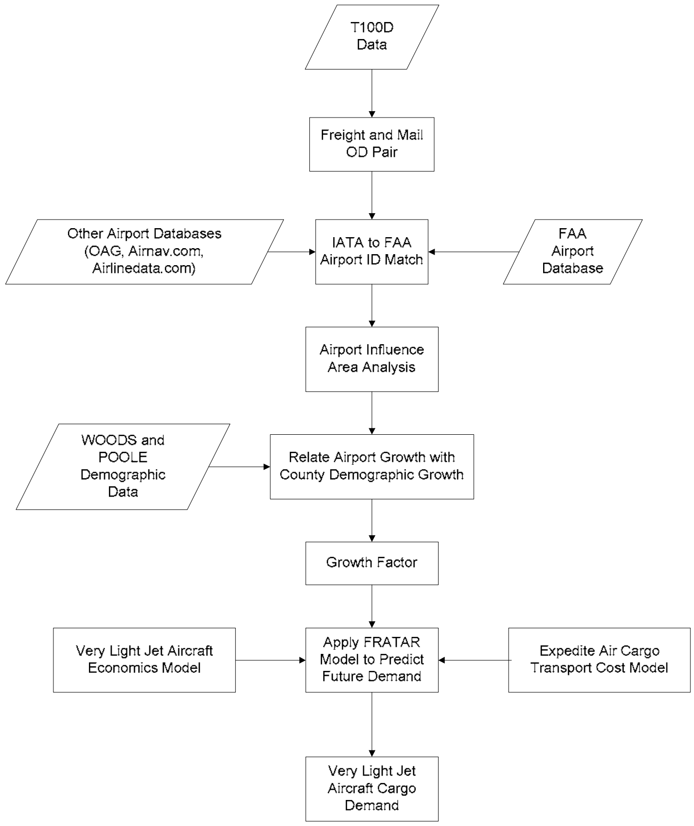

Figure 1: Very Light Jet Cargo Demand Generation and Distribution Flowchart.

T100D is used as the primary database and the baseline OD flows are derived for freight and mail. An airport influence area study is conducted to associate airport growth with neighboring county demographic growth. A growth factor based FRATAR model is used to distribute demand among OD pairs. The following sections will elaborate on each subject.

A. *AIRPORT TO AIRPORT CARGO DEMAND*

T100D consists of monthly data reported by certified U.S. and foreign air carriers on passengers, revenue freight and mail. Our analysis emphasizes on the cargo components of this database - revenue freight and mail. Conventional four-

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step model is applied to estimate VLJ cargo market share and demand. Domestic airport to airport cargo flows, including freight and mail, is extracted from origin and destination airports in the demand generation step. A demand prediction up to 2025 is obtained using growth factors. This paper covers demand generation, demand distribution and mode split.

Freight and mail demands are generated at airports using T100D database (year 2003). Different airport identifier naming conventions are discovered between T100D and FAA. An effort is made to convert T100D airport ID to FAA airport ID using auxiliary data source such as airnav.com and airliners.com in order to obtain necessary airport facility data offered by FAA Landing Facility Database.

1) *AIRPORT SERVICE RADIUS ANALYSIS*

VLJ is capable of operating at small to medium community airports to save transport time. To explore the potential cargo transport demand of the VLJ, it is necessary to redistribute the cargo demand at current cargo airports to surrounding counties and then re-evaluate the airport choice.

In order to relate airport with counties demographics, a service radius analysis is conducted. First, a population based county centroid is located at each county based on census track level population data. Then a correlation study is made using ArcGIS. Any county centroid within the service radius is assumed to be served by the airport. In our analysis, we assume T100D cargo airports are part of the hub-spoke system and are able to connect to other airports. Under this assumption, all T100D cargo airports could be candidate cargo airports for the county within their service radius. Three different scenarios are examined, i.e. 60 -120 miles, 70-120 miles and 90-150 miles. The radius varies proportionally to airport production and attraction demand. In the first scenario, one third of the cargo airports are unable to couple with any county. Therefore the lower bound of the radius is increased and the results are reexamined. By increasing the minima to 90 miles and the maxima 150 miles, all continental cargo airports can be coupled. However, there are counties cannot be coupled any neighborhood airports. In this case, the closest cargo airports are assigned to them. Similarly, if the airport cannot find a nearby county, the closest county is assigned. On average, around 20 counties can be served by one airport, implying a significant overlap in the service area considering a total of 3,000 counties in the continental U.S.

2) *REGRESSION ANALYSIS*

The outcome of service radius analysis is the association of airport and counties based on demand. Demographics of served counties can be explained as explanatory factors for future airport growth.

Various regression analyses are conducted to explain cargo demand versus socio-economic factors. County demographic data such as total employment and population are the initial trial parameters. As a result of the collinearity test, any pairs of the three parameters cannot be used simultaneously in the regression due to high collinearity. Linear regression produces satisfactory R-square value after removing several outliers which include large airports attracting and producing enormous cargo or hubs for major air cargo operators such as UPS and FedEx. Therefore, a single variable linear relationship is used. Transportation industry employment and earning are used as independent variables for freight and mail respectively.

3) *GROWTH FACTOR*

The Woods and Poole Complete Economic and Demographic Data Source provides county demographics data and forecast from 1970 to 2025 for a total of 3,091 counties [28]. Based on county-airport association and W&P demographic prediction, a two-by-two growth factor matrix is developed for each cargo airport by airport type (as origin (production) or destination (attraction) airport) and cargo type (freight or mail).

For outliers such as Memphis and Louisville airport, FAA Terminal Area Forecast (TAF) demand forecast is used. TAF includes forecasts for active airports in the National Plan of Integrated Airport System (NPIAS). It should be noticed that growth factors of these hub airports are smaller than the growth factors of small to medium airports obtained from demographics growth. This can be explained by terminal congestion levels and the potential to use small to medium airports to detour demand of those hub airports. By this procedure, a complete growth factor matrix is built (See Figure 2).

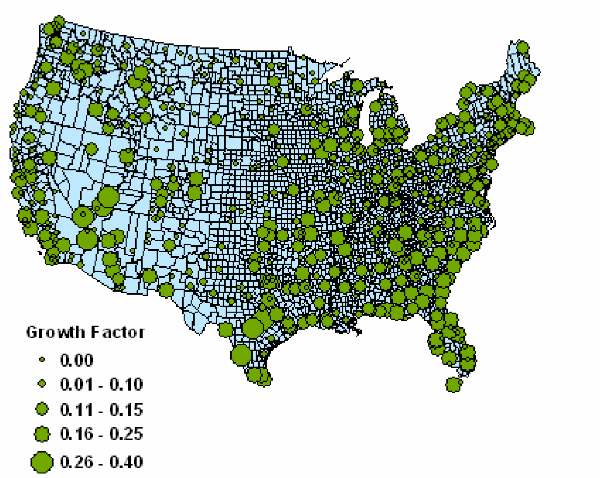

Figure 2: Mail Attraction Growth Factor in Year 2010.

4) *FRATAR MODEL*

FRATAR model is a growth factor based demand distribution model. Given both origin and destination growth factors, demand distribution prediction can be obtained using following equation.

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$$T_{ij} = T_i \frac{t_{ij} G_j}{t_{ix} G_x} \quad \text{Equation 1}$$

Where T_{ij} = number of trips estimated from zone *i* to zone *j*

T_i = future trip generation in zone *i*

t_i = present trip generation in zone *i*

$G_{j,x}$ = growth factor

t_{ij} = present trips between zone *i* and *j*

t_{ix} = number of trips between zone *i* and other zone *x*

Both of the origin and destination growth factors have been derived from correlated county demographics. FRATAR model is then applied at airport level to predict future cargo origin and destination flow up to year 2025 (

Figure 3). The model converges quickly after a few iterations.

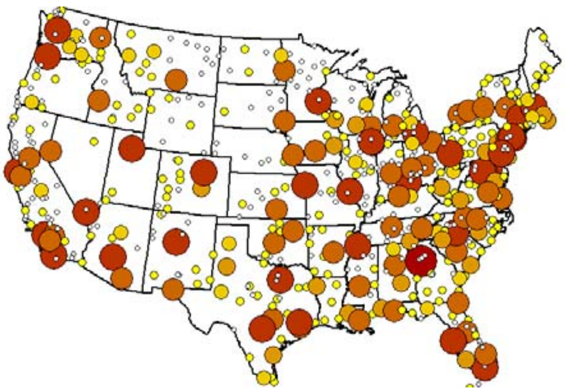

Figure 3: Mail Attraction at County Level in Year 2010.

B. COUNTY DEMAND ASSIGNMENT

Initially, cargo demand at airports is assigned to neighboring counties within service radius based on regression analysis. Initially, cargo demand is distributed to counties proportionally to their share to the total demographics served by the associated airports. Then demand is summed up if one county has multiple service airports.

Two largo cargo centers exist in the country, Memphis International Airport (MEM) and Louisville International Airport (SDF), hubs of FedEx and UPS, respectively, function as sink nodes in the initial distribution. These nodes do not represent the true cargo destination and thus warrant a secondary redistribution step. This step treats MEM and SDF as transfer nodes. A simple transfer rate is assumed: 90% of freight and 85% of mail demand reached MEM is redistributed and at SDF, 90% and 75%. This rule assures a symmetric cargo flow arriving and leaving MEM and SDF.

After the two-step distribution, the county demand OD matrix was collected by rows and columns to obtain county level demand generation.

Figure 4 shows air mail demand attraction at county level.

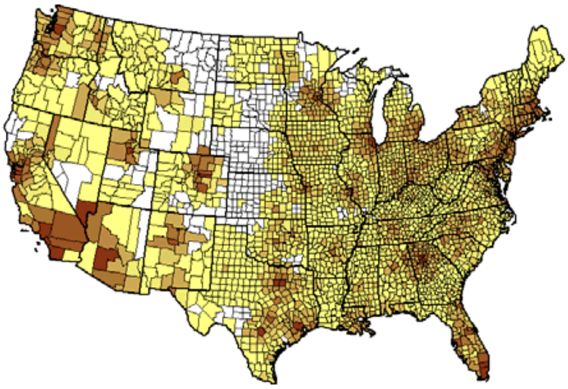

Figure 4: Mail Attraction at County Level.

C. AIR CARGO WEIGHT STUDY

Upon completion of cargo demand generation and distribution, total air cargo demand and OD flows are projected at county level. However, VLJ is not capable of accommodating all the demand due to capacity and weight balancing constraints. Practically VLJs are unable to transport shipments beyond 1,000 lbs. Therefore it is necessary to study air cargo size distribution to estimate VLJ compatible cargo demand.

Air cargo weight distribution can be derived from the Commodity Flow Survey (CFS) from the four regions reported. Study shows that there is no significant difference in the four regions for shipment less than 1,000 lbs. This result justifies a national cargo weight analysis concentrating on shipments less than 1,000 lbs. It shows approximately 40% of current air cargo is compatible with VLJ aircraft.

D. CARGO AIRCRAFT ECONOMICS MODEL

VLJ aircraft economics models are developed using STELLA Research 7.0. Various cost components including hourly variable cost, annual fixed cost, periodic cost, personnel cost, and facility costs are integrated in the model.

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The model allows users to modify parameters such as jet fuel cost, load factor, number of pilots, flight hours per year, percent resale value, profit margin, mission stage length, annual pilot salary, and percent repositioning flights. The model provides Life Cycle Cost Metrics, including cost per hour, cost per mile and cost per pound-mile, and a summary of annual cost components.

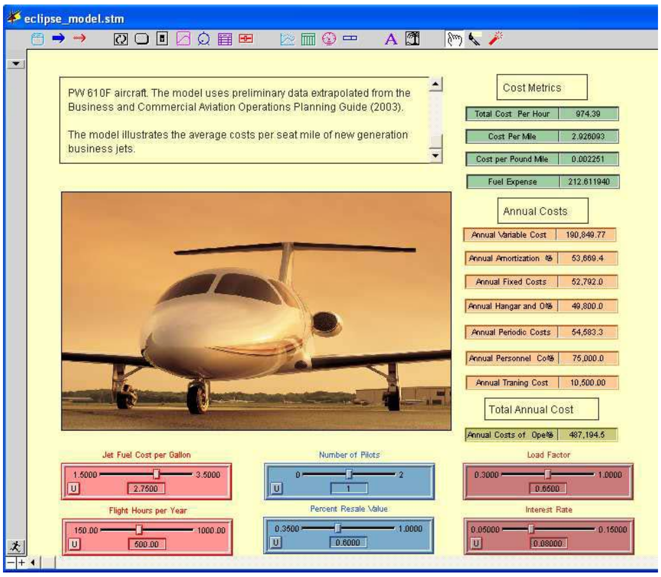

Figure 5: Eclipse 500 Economics Model.

Life-cycle costs of similar small cargo aircraft, Cessna Caravan and Falcon 20F, are also modeled for comparative purposes. The cost estimations are derived from data published by Business and Commercial Aviation and ARG/US in the Year 2004 Operations Planning Guide. Average load factor is obtained from BTS Air Carrier Summary Data T2 as the quotient of revenue ton-miles over available ton-miles. From the historical trend revealed by T2, average load factor is assumed to be 0.65. Life-Cycle cost estimates for the three aircraft are shown in

Table 1.

Table 1: Small Cargo Aircraft Economics Model Output.

Aircraft	Total Cost per Hour (Dollars)	Cost per Pound Mile (cents / lb-mile)
Eclipse 500	974	0.25
Cessna Caravan	1,112	0.50
Falcon 20F	2,258	0.63

E. CASE STUDIES

Case studies are conducted to assess the competitiveness of VLJ cargo operations. Commercial cargo service providers such as UPS and FedEx are modeled as the primary competitor. Both FedEx and UPS offer same day and second day expedite service. In our case studies, UPS Ground and UPS Sonic-Air express service are modeled as the primary commercial service competing against the on-demand cargo service using VLJ.

It is assumed that the VLJ aircraft operates either as a dedicated on-demand service or with a load factor of 0.65. The former means the VLJ aircraft will be used solely for the requested package whereas the latter combines the package with other payloads. Two package sizes, i.e. 100 lbs and 200 lbs, and ten distance categories (100 – 1000 miles) are evaluated. Estimation of VLJ travel time is based on assumption that 3,000+ airports available for VLJ cargo operation [29]. The closest airport to the origin and destination zip code is chosen as origin and destination airport. The result (for 200lbs) indicates that VLJ aircraft require the least transport time thanks to its point-to-point operation concept. In the cost competition, the position of cargo VLJ operation greatly depends on load factor. A load factor of 0.65 is sufficient for the first place in the competition. However, schedule delays may be added for transport time. If the operation is completely dedicated to this package, cargo VLJ will be most expensive one among the three methods.

IV. Results and Conclusions

This paper presents demand generation, distribution and partial mode choice of the four-step model to study VLJ cargo transport capability. Air cargo demand is generated and distributed at 900 cargo airports and 3,091 counties for the entire US. A strong linear correlation is found between cargo demand and demographics. Transportation / Communication / Public Service employment and earnings are found to be the best explanatory variables for freight and mail demand respectively.

It is observed that cargo demand concentrates at highly populated area. As a result of cargo airport service area analysis, more than 200 counties cannot locate a cargo airport within 60-120 mile radius. And it is under the assumption that all airports appearing in T100D are reliable enough to offer regular air cargo service. More counties will be isolated if only airports with regular cargo service are to be considered.

Growth factor analysis indicates that the potential growth tends to concentrate at high density where congestion could constrain projected growth in the future. By operating from point-to-point and reduce ground time at under-utilized rural airports, VLJ offers an attractive alternative mode for highly time sensitive shipment. Case studies suggest that VLJ provides substantial travel time savings compared to expedited commercial service currently available. VLJ offers competitive prices if moderate to high load factors are achieved.

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V. Model Limitation and Recommendations

In the distribution analysis, a static airport network has been applied. Emergence of new cargo OD pairs is not considered in the model. Furthermore, the demand distribution is limited by T100D OD pair network. Intermodal operations that reflect the true origin and destination are approximated by service area. Small to medium hubs' sorting and redistribution function is not considered in this analysis. A dynamic air cargo operator behavior model and the inclusion of small to medium hub redistribution step will enhance our distribution model and in turn improve mode choice. Further validation is needed.

Our primary data source, T100D, does not provide information on small cargo carrier operations such as air taxi. A database collection analysis should be undertaken to understand this market segment.

A complete mode choice module needs to be built to estimate VLJ market. Several parameters need to be addressed, including percentage of highly time sensitive cargo, percent repositioning flights, commodity value of time, commercial cargo transporter expedite service cost structure, and reliability of VLJ operations.

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