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AIR FREIGHT DEMAND MODELS:

AN OVERVIEW

by

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1. INTRODUCTION

The intent of this paper is to provide an overview of existing freight demand models, and to identify data sources available for conducting freight demand studies as an input to the more comprehensive analysis of technological change in the air freight industry. Air freight demand, as well as other freight mode choice, has long remained outside the mainstream of transportation planning and research. Researchers, analysts and planners have, however, begun to address themselves to these issues and their associated problems.

Early air freight studies were conducted for the benefit of carriers and other transportation firms who needed the information which was developed from them for marketing purposes. The work by Lewis and Culliton (12) at Harvard in 1956 and Gorham _et al_. (11) at the Stanford Research Institute in 1963 were both industry supported and reflected a strong marketing orientation. Yet a growing interest in a more quantitative treatment of freight demand in general, and of air freight demand in particular, has evolved for a number of reasons. Carriers have become aware of their need for more than a marketing technique -- they require analytic tools to aid in facility and operations planning as well as market analysis. Major investment decisions are based on these analyses, which must take into consideration both the carriers' fluctuations in market demand, and the reaction of the market to variations in the level of service provided by the carrier.

States concerned with transportation problems and economic development have become increasingly involved in "master planning" for various modes of transport. They must look for alternatives to a crowded air system, including reliever airports, capacity restrictions, and trade-offs between cargo and passenger uses of existing facilities. More information on the amount and importance of air cargo is needed for better planning and decision making. Proposals for all cargo airports seem to accentuate the need for good information on the demand for air cargo transportation. A comprehensive description of the different roles played by the states in freight planning is given in a recent report sponsored by the National Cooperative Highway Research Program (6).

The responsibilities of the U.S. Department of Transportation, within the context of the future of air freight systems, are similar to those of the States, but are more extensive. Federal policy is intended to achieve an efficient multi-modal transportation system for the nation. Since it can act responsibly only if it has an understanding of the dynamics of intermodal freight competition, the federal government has also shown increasing interest in intercity freight transportation from both system needs and energy-utilization perspectives.

Two primary areas of concern are addressed in this paper. These are the areas of freight demand modeling and of continuous time simulation of air transportation systems. The former area is the one in which most previous research has been undertaken. Several bibliographies and literature reviews have been prepared in this area (6, 17, 18). The most recent of these reviews explores a wide range of mathematical forms that have been used to describe freight mode choice and identifies the specific data requirements of these forms. The conclusions emphasize the inconclusiveness and lack of concensus regarding the results of these methods. (6). The use of continuous-time simulation in the assessment of the future of air transportation systems is a newer concept, for which few precedents can be found (9). The method provides an opportunity to explore the dynamics of the system in a continuously changing fashion, rather than in the usual static mode. Demand forecasts obtained by such models explicitly consider the interaction of supply and demand, and the response of the airline industry to changing shipper needs and preferences.

The following sections present a survey of some of the approaches which have been considered in freight demand estimation. They also review the few existing continuous-time computer simulations of aviation systems, with a view toward the assessment of this approach as a tool for structuring air freight studies and for relating the different components of the air freight system (8). The paper further reviews the variety of available data types and sources, without which the calibration, validation and the testing of both modal split and simulation models would be impossible.

2. FREIGHT DEMAND MODELS

2.1 Model Classification:

Models of freight demand vary in accordance with the extent of aggregation encountered in the model. The level of aggregation can be defined with respect to three basic dimensions: commodity specification, geographic specification, and mode specification.

Commodity specification classifies demand models by the extent to which they disaggregate commodities into their respective classes. Models dealing with the total volume of freight for example, would be at one extreme. Commodity detail can be increased by considering separate types of commodities such as produce or manufactured goods. Further disaggregations might result in volume estimates for commodity groups which are defined by the 2, 3, 4, or 5-digit-Standard Transportation Classification Code (STCC). One of the major problems with highly disaggregated commodity groupings, however, remains to be the absence of data which can be used in model development.

Models can also reflect different levels of geographic detail. Starting at total domestic tonnage, increasing specificity (or disaggregation) includes inter-regional flows, inter-state flows, commodity flows between clusters of Standard Metropolitan Statistical Areas (SMSA's), and city-pair volumes. Local (intra-city) urban freight flows are even further along this dimension.

Mode specification refers to the extent to which detailed attention is paid to the particular mode in question. It is possible, for example, to estimate modal volumes (tonnages) by simple extrapolation, and without concern for such factors as changes in the relative level of service within and between modes. At the other extreme, a demand estimation effort may model the shippers' perceptions of the relative levels of service of two competing modes, or even two competing firms within the same mode.

2.2 Selected Model Descriptions:

This section briefly reviews six recent models which have been developed for estimating the demand for air freight. These models generally represent a relatively high level of disaggregation on at least one of the three dimensions described above. They are intended to provide a capsule of the state-of-the-art in air freight demand modeling.

McKinnel, Henry A., An Econometric Analysis of the U.S. Air Freight Market (15)

The author evaluates the air freight market, measuring factors that express both supply and demand considerations. He set out to develop two pairs of simultaneous supply and demand equations: one pair describes cargo carried by passenger air carriers while the second describes the characteristics of all-cargo operators.

Using two endogenous variables representing the quantity of air cargo and the air freight rate and eight exogenous variables, McKinnel developed a two-equation supply and demand model. In order to avoid the problems of multicollinearity, he used the two-stage least-squares method for parameter estimation. The resulting equations for the case where freight is carried in combined passenger-freight aircraft is:

$$Y_1=1.11x_1+0.95x_2+0.17x_3+0.71x_4+0.05x_5 +4.33x_6+2.06x_7+2.38x_8 \quad (1)$$

$$Y_2=0.73x_1+0.63x_2+0.11x_3+0.47x_4+0.03x_5 +0.92x_6-0.44x_7-0.50x_8 \quad (2)$$

where all the variables are defined as the natural logarithms of the following entities:

Y_1 = the quantity of air freight in revenue ton-miles

Y_2 = the rate charged to air freight in \$/ton-mile, using average revenue per revenue ton-mile as a surrogate,

x_1 = truck rates

x_2 = a measure of economic activity (GNP)

x_3 = airline promotional expenditures

x_4 = distribution costs

x_5 = defense spending

x_6 = cost of supplying capacity

x_7 = capacity available, and

x_8 = passenger rates

McKinnel did not succeed, however,in developing a similar model for all cargo operations, and thus concluded that the domestic market of all-cargo carriers (or, at least the reported data) was not stable enough to allow the construction of a meaningful model.

This work is an early attempt to describe air cargo volumes as a function of both socio-economic activity and air carrier characteristics. It doesn't, however, lend itself to forecasting, since predicting values of the independent variables used in this study would be at least as difficult as making a forecast directly. This model provides no commodity or geographic detail and minimal modal information; it represents an example of a highly aggregated demand estimation model.

Mathematica, Studies on the Demand for Freight Transportation, Vol. III (25)

Two models describing freight modal split were developed: one is an Inventory-Theoretic Model designed to minimize total logistic costs; the second is a probabilistic behavioral choice model of shippers' decisions. Models of both types were developed in commodity-specific and general commodity-abstract forms. Using 6400 pairwise modal split observations from the 1963 Census of Transportation, equation parameters were computed for each of 15 commodity groups, as well as for the aggregate of commodities by each method. Splits were between air/truck, air/rail and truck/rail in pairs. The general form of modal split function used is:

$$S^k_{mn} = \frac{1}{1+W} + \text{error} \quad (3)$$

where, S^k_{mn} is the probability of choosing mode m rather than n for commodity k,

W is a function which varies with the type of model.

In the Inventory Theoretic Model, W was defined as:

$$W = \left(\frac{OAVC_m}{OAUC_n}\right)^b \quad (4)$$

Where OAVC is the "optimal average cost" which is given for each competing mode by an equation of the form:

$$OAVC = \text{rate} + a_1(\text{time})\ (v) + a_2 \left(V^k_{ij}\right)^{1/2} \quad (5)$$

Where, a's are regression constants,

V^k_{ij} is the total volume of commodity k transported between cities i and j,

v is the commodity value.

Each term represents a component of the logistic cost by the specified mode. The first term is the rate charged for the shipment. The second reflects in-transit carrying costs and the third approximates the inventory carrying costs. The coefficient a_2 was found to be statistically insignificant in almost all the equations developed. Further, the "rate" estimator for the air mode was not significant. The authors attribute this result to the low number of pairwise modal splits reflecting air activity (only 164 observations from the 6400 total).

In the Behavioral Model, W was defined as:

$$\left[\left(\frac{c_m}{c_n} \right)^{k_c} \left(\frac{t_m}{t_n} \right)^{k_t} \left(\frac{c_m^{\ln t_m}}{c_n^{\ln t_n}} \right)^{k} \right]^{u} \quad \ldots\ldots\ldots\ldots (6)$$

where c is cost, t is travel time, and k_c, k_t and k are regression constants. The "u" exponent is a function of commodity value and volume, but it was dropped from the series of equations which were developed since the equations were found to perform equally well without it. The functional form of this model is not as intuitively interpretable as that of the Inventory-theoretic model, but does reflect perceived relationships between characteristics (e.g., $\frac{cost_m}{cost_n}$ rather than a total cost for each mode.

As inputs to the model, the authors developed estimates of both travel times and freight rates. The 15 commodity groups used were generally STCC 2-digit groups, each consisting of a sample of 5-digit groups with the same 2-digit prefix.

Terziev, Marc N., Moshe Ben Akiva, Paul O. Roberts, Freight Demand Modeling: A Policy Sensitive Approach. (22) (Also subsequent reports (17, 21).

A methodology to predict the volume of any commodity transported by any mode between an origin-destination pair of cities is described in this report. The general relationship is expressed as:

$$V = f(T,C,M,R) \quad (7)$$

where, V = volume of freight

T = transport level of service attributes

C = commodity characteristics and special requirements

M = Market characteristics and attributes

R = Receiver attributes.

The analysis sequence is briefly summarized below. Prior to running the computerized model, economic data in the form of an input/output table for the receiving city and initial level of service information for the transport options between the origin and destination cities are developed. Twenty-one commodity groups, each consisting of one or more 2-digit STCC commodities, are identified. Firm size distribution and commodity input requirements are developed for each commodity group by drawing upon various published census and economic sources as well as the input/output model. Firms are then sampled from each commodity group, and a determination is made as to whether the purchases of each firm are made locally or are imported from outside the region. This is accomplished by evaluating alternative logistic strategies available to the firm, and by comparing local wholesale and retail prices with import prices. The sampling of firms is continued, and the results accumulated, until a predetermined stability criterion for the commodity group is met. Attention is then directed to local wholesalers, and their logistic strategies are similarly examined. The results of the group sample are finally expanded to the total market, and the process is repeated for each other commodity group. The whole process is computerized and represents a simulation of the purchasing and transportation decisions at the receiving city.

The series of reports which describe the different elements of this model represents a three year research period (1975-1977). Early reports in the series advance its theoretical foundations, while the following reports refine specific inputs such as truck and air freight rate models and travel time estimators.

The procedure was tested for two city-pairs: Houston-Chicago, which was considered to represent a medium-haul, non-air oriented market; and Los Angeles-Boston which was used to represent a long-haul, relatively air-oriented market pair (37). Results were mixed. In the Houston-Chicago market, the model overestimated the volume of air cargo by two orders of magnitude. In the Los Angeles-Boston corridor, the overestimation was only by a factor of two: markedly superior, but still of poor accuracy. The authors were aware of the problems involved in estimating low volumes which are introduced by their sampling technique. They were also aware of the "normative" tendency of their model to predict what shippers "should" be doing if they were minimizing total logistic costs (on an all-or-nothing modal choice basis), rather than what they would do in reality.

This series of reports reflects the most substantial effort to date to develop disaggregated modal freight forecasts. However, it suffers from two major deficiencies. The first is the decision-making rule by which freight is assigned to a mode between any city pair. The process by which total shipment cost is minimized requires that the shipper evaluate the total cost of transit offered by each mode and then select the cheapest. Hence, no receiver who orders by a less expensive mode on a regular basis and uses a faster, more expensive mode on occasion can be accounted for. Though attempting to be "explanatory" in its predictions, the model's predictive ability is weakened by this deficiency. A correlation approach to predicting demand, which searches for relationships in existing data, is not necessarily less useful than an explanatory model based on poor assumptions of shipper behavior, as the authors indicate.

A second problem with this work is that in approaching modal choice from the shipper's perspective, the model is weak in providing means by which the airline or any other transport industry might examine its internal dynamics and test the expected impacts of service changes. Though the model can be rerun to reflect lower transportation costs, increased reliability or other changes in the level of service, the model is simply not designed to address these issues adequately.

Transportation Systems Center, Forecasting Models for Air Freight Demand and Projection of Cargo Activity at U.S. Air Hubs. (32)

In a series of two reports bound together under this title, the Transportation Systems Center of the U.S. Department of Transportation developed a total domestic forecast of air freight demand and then forecasted the demand at 25 major domestic air hubs. The demand for air freight was assumed to be a function of: general economic activity (GNP), air freight rates, the quality of air freight service, and the price and quality of competing modes. However, since there is no direct measure of "quality," the model is based solely upon GNP and freight rates (approximated by the yield/revenue ton-miles).

After some modification due to intercorrelation between these two predicting variables, a least squares equation for domestic revenue ton-miles (RTM) was developed in both linear and log functional forms. The linear form is:

$$Y_t = a_o + a_1 DX_{1t} + a_2 X_{1t} + a_3 X_{2t} + a_4 X_{3t} + a_5 Y_{t-1}, \quad \ldots\ldots\ldots \quad (8)$$

where, Y_t = total domestic freight (in revenue ton-miles)

X_{1t} = Gross National Product in 1958 constant dollars,

X_{2t} = freight yield/revenue ton-mile

X_{3t} = a dummy variable to account for reporting changes

DX_{1t} = $X_{1t} - X_{1t-1}$

a_i's = constants of regression, and

t, $t-1$ = (subscripts) indicate the present and previous values of the same variable, respectively.

The log form is more concise:

$$\ln Y_t = a_o + a_1 \ln X_{1t} + a_2 \ln X_{2t} \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

Gross National Product forecasts from Wharton Economic Forecasting Associates, and three alternative assumptions for annual changes in freight revenue yields were used to develop three alternative forecasts. A recommended forecast is then selected judgementally from these three.

In the second phase of the study, the following four-step procedure was developed to allocate the national demand to individual hubs:

1. the allocation of a share of the total volume to each hub by that hub's share of domestic passenger enplanements.

2. the projection of passenger fleet lower hold cargo capacity by hub using markets identified as high cargo/passenger ratio or low cargo/passenger ratio markets, and average aircraft size and load factor estimates.

3. the allocation of projected hub cargo tonnage to passenger flight lower holds by market type until the capacity is exhausted. Any residual demand is assigned to all cargo (freighter) aircraft.

4. the conversion of residual cargo to the number of freighter departures.

A 37% reduction in freighter activity was forecasted to occur between 1975 and 1987 with a 23% reduction occurring by 1977, which was the first year of the forecast. Despite this activity declines, enplaned tonnage decreased by only 4%. This was due to increases in both capacity and load factors. Only minor wide-body activity was projected for domestic service, and combined passenger/cargo carriers were expected to continue to dominate the cargo market with their primary emphasis being on passenger operations.

Research on specific commodity flows, modal split formulations and more precise modeling of price and service differentials between surface and air modes were identified as directions for further research. In its present form, the model provides no commodity detail, though it does reflect mode choice and geographic detail characteristics. Overall, the report reflects an innovative "top-down" approach to determining the future of the air cargo industry. But, as can be expected from the use of the ratio method of forecasting, it provides neither the detail nor the flexibility to evaluate the effects of changes in the aviation industry itself.

Watson, Peter L., James C. Hartwig, and William E. Linton, Factors Influencing Shipping Mode Choice for Intercity Freight: A Disaggregate Approach, (35).

This model is reviewed as an example of the many disaggregate models of modal choice, using a logit formulation which have been developed in recent years. The authors used a sample of waybills obtained from a shipper of large household appliances to test mode choice between full truckload and rail shipments, and then tested their results against a second sample. Cost, time, reliability, and the value of the commodity were the variables selected for analysis. Borrowing from other modal-split studies, the model had the following functional form:

$$P_t = \frac{e^u}{1 + e^u} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

where, P_t = the probability of choosing the train

$$u = a_0 + a_1 DT + a_2 DC + a_3 DR + a_4 V \quad \ldots\ldots\ldots \quad (11)$$

DT = the difference in travel time between the two competing modes.

DC = the difference in cost between the two modes.

DR = the difference in reliability between the two modes, and

V = the economic value of the commodity.

All coefficients, with the exception of that of DT, were found to be significant at the 99% level.

Conclusions indicated that the value of the commodity was the most significant influence on the choice of mode. This strongly suggests that some measure of commodity characteristics should be incorporated in any mode choice model formulation. The most significant carrier characteristic was found to be reliability. The magnitudes of the cost and reliability elasticities indicated that a potential exists for carriers to increase their relative share of a given market by both offering a more reliable service and charging a higher rate.

Though developed for train/truck competition, the study makes a strong case for including both modal characteristics and commodity attributes in any modal split evaluation. The need to consider reliability as a key "level of service" attribute is also underscored.

SRI International, Expanding Air Freight Horizons by Use of the Air Freight Profitability Factor, (13)

A highly disaggregated approach to mode choice was developed by SRI. Utilizing an Inventory-Theoretic analysis, the SRI approach does not make an all-or-nothing mode choice in determining the split. Instead, surface transportation is employed for the predictable portion of product demand, and air freight for the unpredictable. The model predicts the mode split within a given Shipper-Receiver pair that minimizes total distribution costs while maintaining a satisfactory (minimal) in-stock inventory.

To date the model has been used to resolve the distribution problems of SRI clients, but it has not been tested for any city pair to check its results against current practice. Since the model's emphasis is basically "normative" -- describing what shippers should do -- it remains to be seen how well it will replicate reality.

2.3 Conclusions:

Research into the issue of mode choice, and factors that influence it, has been moving toward increased disaggregation or specificity regarding modal characteristics, commodity detail and geographic or market detail. Yet, every study that has looked into the problem in detail, has looked at it from the shippers' or receivers' perspectives. While this is a sensible approach, its adoption requires the over simplification, or even exclusion, of other related issues, in order to keep the models manageable. Responses within the transportation sector to market conditions are usually omitted. As a result, the utility of these models as a tool for evaluating alternative technical and managerial options open to transportation firms is appreciably reduced. Models of the type reviewed in this section seem to have little sensitivity to the internal dynamics of the airline industry.

3. CONTINUOUS-TIME SIMULATION

3.1 Selected Model Descriptions:

Empirical formulations of modal choice models are but one aspect of the complex interactions which characterize the components of an air transportation system. Computer simulations can be developed which allow the researcher to establish links and connections within a dynamic system resulting in a model of overall system behavior. Such simulations will allow the researcher to observe and evaluate the expected behavior of the shipper/freight-operator system over time. Several continuous-time aviation-related simulations exhibiting these attributes have been developed. Three such simulations are described below. It should be noted that only the second of these three models includes an air freight component. The other two deal with passenger carriers and general aviation. They do, nevertheless, provide some insights into the potential of dynamic simulation as a tool for demand estimation.

Technische Universitat, Berlin, Possibilities and Limits of Simulation with the Help of System Dynamics...of a Typical Transport System of Air and Space Travel, (24).

This report attempts to develop a dynamic simulation of the effect of introducing new aircraft into Lufthansa's fleet. The model was developed to aid in the airline's decision-making process. The simulation's goal was to determine what combination of aircraft and operational alternatives are most profitable. Specifically, it attempts to predict when it would be appropriate to introduce a new aircraft into the fleet and at what frequency it should be operated, in order to minimize total fleet costs.

The major elements of the simulation include:

-Specification of aircraft size
(capacity, speed, operating costs, utilization measures, quality of transportation)

-Demand specification
(number of passengers, mean trip length, potential revenues)

-Operating specification
(ticket costs, break-even costs, desired and actual load factors, departure times, on-board service and its quality)

-Supply specification
(number of seats available per month, route network, length of routes, monthly frequency of flights on a route).

The study focuses on the interaction between fleet characteristics, costs and profits, and the degree of corporate goal achievement. To achieve the results sought, details of the internal financial and investment patterns of the firm were simulated.

Three models were developed -- each reflecting a different assumption about operating frequency: the single factor identified as a key constraint within the European aviation system. The first allowed frequency to vary freely, the second held frequency constant (at its 1973 level), while the third allowed frequency to vary within predetermined bounds. In each of the models, various strategies of new aircraft introduction were undertaken. The aircraft which were included in the analysis were the A-300 Airbus, B-727-200, B-737-200 and the B-727 advanced. The simulation was run for a ten year time span.

It appears that the models suffered from over-aggregation. All routes were assumed to be 975 Km long and the fleet was measured by characteristics of a "typical" aircraft, rather than a mix. The creation of three separate models characterized by distinct frequency (scheduling) alternatives was felt to be unrealistic since a real system would incorporate all three. Variations amongst alternatives would occur between routes. The assumption that network growth was equally distributed among routes and occured at a fixed rate of 4% per year was acknowledged as another shortcoming of the model. This is especially true since capacity grows by step-like additions as new aircraft are added. Despite these methodological difficulties, this model is indicative of the range of issues and relationships that can be explored using simulation techniques. Unfortunately, while the simulation was developed to assist corporate analysis, the report provides no indication of the model's actual utilization by Lufthansa's management.

Futures Group for the Federal Aviation Administration, <u>Alternative Future Scenarios for the National Aviation System</u>, (10)

A look at potential future environments and their relationship with the National Aviation System was undertaken. The Futures Group chose five alternative scenarios that were judged to represent a range of likely events from the present to the year 2000. The scenarios included:

> -Expansive Growth. Unprecedented prosperity marked by high population and GNP growth is achieved through a return to the free enterprise system.
>
> -Individual Affluence. Prosperity with high GNP growth, a low population and strong Federal regulations.
>
> -Resource Allocation. Lower GNP growth than in the preceeding scenarios, though one remaining at moderate levels. Low population growth. A stable environment in which technological solutions are found for (currently) pressing problems.

-Limited Growth. Low population and GNP growth rates both reflect a federally adopted limited growth policy.

-Muddling through. Low GNP, high population and continual recession, inflation and general uncertainties.

A core set of socioeconomic variables was forecasted and scenarios were developed using mutually consistant groups of forecasts supplemented by narrative descriptions.

The study focused on a number of FAA concerns (e.g., airspace and airport capacity, safety, energy consumption and noise) and upon relevant aspects of the aviation industry (revenue, passenger miles, enplanements, cargo revenue ton-miles and GA and commercial aircraft activity). The scenarios were not intended as forecasts, but were rather developed to provide a logical framework for policy analysis and synthesis. Sample results for the future of air freight and aircraft technology are given in Table 1.

TABLE 1

EXAMPLES OF ALTERNATIVE AVIATION FUTURES

Scenario	Air Freight	Aircraft Technology
Limited Growth	growth 3%	minor changes in existing aircraft
Muddling Through	grow 2% later, declining	minor changes in existing aircraft
Resource Allocation	4% growth	advances in fuel efficiency and noise reduction
Individual Affluence	9% growth, increase	improved technology reflecting environmental concerns, some new aircraft.
Expansive Growth	12% growth, all-cargo airports	new aircraft, including SST's and Super Large Jets

The study was reported to have achieved the FAA's desire to develop a context within which to conduct their planning function in light of rapidly changing socioeconomic and technological conditions (14). The scenario approach provides a basis for the development of a robust planning methodology that will be capable of responding to a variety of future conditions.

Battelle Columbus Laboratories, General Aviation Dynamics (33)

This Battelle model was developed for three purposes: (i) to forecast general aviation activity; (ii) to aid in the evaluation of alternative policies; and (iii) to permit the performance of sensitivity analyses within the realm of the general aviation system. This particular model was expected to overcome the shortcomings identified in previous studies and is characterized as a "bottom-up" projection, in contrast to the commonly-used "top-down" forecasting procedures.

The model's structure and the rationale behind it are documented in this report. The general aviation system was divided into three sectors: pilot supply, aircraft utilization, and aircraft demand (the last two being very closely linked). The first sector uses the system dynamics technique to good advantage: each class of pilots is represented as a level (State variable) and the relationships describing the flow of persons through the various classes of licensees (from student to instrument) are developed. Pilot supply, as determined by socioeconomic variables, influences aircraft utilization factors, which in turn influence aircraft demand. The aircraft demand sector is disaggregated for various user/aircraft categories (e.g., corporate/turbojet or personal/single-engine piston).

A baseline run was made resulting in a forecast of increasing aircraft activity and decreasing student pilots over the next ten years. Two comparison cases were run reflecting changes in the social env[illegible]onment. Extensive tabulations of annual results from the three cases by type of aircraft, primary use, utilization, pilots, fuel consumption and federal tax revenues were prepared. This report represents an easy to follow example of how continuous-time simulation utilizing empirically-derived econometric relationships can be used in forecasting and policy anlaysis.

3.2 Conclusions:

The complexity of the systems involved suggests that simulation may be the only analytical approach which is capable of capturing the interactions among the different actors influencing the demand for air freight services. To keep such simulations manageable, however, and to provide the desired flexibility, a judicious simplification of reality is required. Variables and parameters must be selected to reflect the issues being explored. They must also be at an appropriate level of specificity or aggregation. The distinction between the Lufthansa and the FAA/Futures Group simulations illustrates this point. In the former, the internal response of the firm is explained in detail, while other socioeconomic factors are exogenously determined. In the FAA/Futures Group simulation, the opposite perspective is adopted; the focus is upon the socio-economic changes and an aggregated decision making rule is used to provide the industry's response.

Procedures for testing and validating simulations are available, though only the Battelle/FAA model described any of them. Just as tests of correlation and significance are expected for econometric relationships, tests of structure, behavior and policy implications should be conducted for system dynamic models. These have been extensively discussed elsewhere

(39). Tests to build confidence in the model are necessary if the model's results are to be accepted by its user. Continuous time simulation provides a useful tool for exploring and experimenting with complex issues and relationships. The examples provided indicate the types of experiments conducted to date. Air freight is touched upon only briefly by these works and remains to be an area in which much can yet be accomplished.

4. DATA SOURCES

4.1 Freight Data Sources:

Development and calibration of an air cargo simulation requires characteristics of commodity flows, commodity attributes, economic conditions and airline decision making. Since the proposed simulation evaluates the aviation industry in competition with the trucking industry, information on that industry will also be necessary. Some utilizable sources are described below.

The 1972 Census of Transportation (29) is the single most useful source of commodity flow data available. The Commodity Transportation Survey portion of the Census contains a wealth of information on the volume of freight transported by commodity, by mode, by origin, by destination, and by length of haul. In its published form, these factors are not tabulated simultaneously. That is, when origin-destination data is printed in its most disaggregate form, it does not include disaggregate modal-split information, and vice-versa.

Commodity classification is presented at the 2-, 3-, 4- and 5- digit (Standard Transportation Commodity Code) levels. At times, however, 3-digit data is omitted and frequently 4- and 5-digit information is not presented. Recommendations have been recently made to improve this data base, although these recommendations have yet to be implemented (38).

Commodity characteristics are available from several sources. A Commodity Attribute File (19) has been prepared by researchers at the Center for Transportation Studies at the Massachusetts Institute of Technology. This listing provides seven characteristics for almost 1200 commodities (coded at the 5-digit level) and includes: the STCC code number; commodity name; value per pound; density; shelf life in weeks;

state (e.g., solid, liquid, particle); and special conditions (e.g., freezing temperature).

Another extensive listing of densities (by 4-digit code) is found in West Coast Ocean on-Dock Density by Commodity prepared by the Boeing Aircraft Company (5). Additional data on value per ton has been calculated by the Transportation System Center, based primarily on the wholesale price data available from the Bureau of Labor Statistics, as well as a variety of other sources (34).

A number of other reports that provide useful approximation procedures for a variety of transportation system variables have also been prepared at MIT. These include Models of Travel Time and Reliability in Freight Transportation (23), Models of Freight Loss and Damage (36), Modeling the Freight Rate Structure (20), and Policy Analysis and Forecasting Models for U.S. Domestic Air Cargo Movements (37).

Depending on the calibration needs of the modal split function, the Census of Manufacturers (28), and the Census of Business (27) provide useful information. The former includes statistics of the manufacturing industry such as total employment, wages, cost of material, values of shipments, inventories and capital expenditures. The latter reports value of product, employment size and sales data. County Business Patterns (30) provides information on payroll and number of employees by employment size class and industry classification. The Bureau of Economic Analysis of the Department of Commerce has published a series of volumes known as the Obers Projections (31), which contain forecasts to the year 2020 of employment and earnings by industry in each of 173 areas, in constant 1967 dollars.

Civil Aeronautics Board publications provide data on the air cargo industry. The publications briefly described below provide some basic sources of information for modeling activities. Airport Activity Statistics (1) presents air-freight volume (tons) for major domestic air traffic routes, as well as data on passenger, express and mail volumes which are tabulated by both airport and carrier. The Handbook of Airline Statistics (2) contains information by carrier for the last ten years, on such as operating revenues, expenses and profits, investments, rates of return and net income. Operating Results of Scheduled All Cargo Service (3) makes public the revenues, expenses, yields, unit costs, investment and traffic data for scheduled all-cargo service. Trends in Scheduled All-Cargo Service (4) is a collection of trends in finances, traffic and operations, unit costs, and scheduled service.

A general source for the trucking industry's data is the annual TRINC's Blue Book of the Trucking Industry (26). This publication provides a variety of information on Class I, II, and III carriers, including fleet size, investments and operating expenses. An overview of the trucking industry in its entirety is difficult to obtain since much of its activity is unregulated. Edward Moritz puts such published freight data sources as TRINC's in perspective in his recent paper entitled "Cost/Benefit Analysis: The Effective Measurement of Carrier Operations" (16).

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