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ESTIMATING THE POTENTIAL DEMAND FOR AIRSHIP SERVICES: A METHODOLOGY

By

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Whenever we attempt to develop a formal model of a real situation, we are attempting to express a conviction as to which factors of the real situation are central and which are peripheral. These convictions may be contradicted by comparing their implications with actual observations or data, but can never be finally verified. It is worth noting, however, that even a contradiction or rejection must rest on some interpretation of our observations so that there must always be uncertainty in both directions.

— John P. Mayberry

What is true today may not necessarily be true tomorrow.

— Taoist saying

ABSTRACT

Although commercial airship operations ceased over 40 years ago, interest in resurrecting lighter-than-air vehicles has surfaced during the last decade on many fronts. One of the major problems confronting airship enthusiasts is the difficulty involved in evaluating the economic viability of this "new" transport mode. It was the objective of this study to formulate a methodology for determining the airship's potential in the commercial freight market.

In meeting the stated objective, two separate and distinct parts were involved. First, after briefly reviewing the literature pertinent to estimating the demand for transportation as well as the determinants of modal split, an abstract mode model was formulated which could be used to estimate the demand for airship services in a particular market. In addition, an extensive discussion of the theory upon which the abstract mode model is based was also presented.

The second part of formulating the methodology was initiated with an examination of some of the more substantial studies which have recently been carried out to ascertain plausible airship cost and service characteristics. Following this, a model for determining airship cost structure was presented. Finally, various crude estimates of airship rates were calculated employing differing assumptions regarding initial airship cost and performance characteristics.

Due to data limitations, no formal estimation of the demand for airship services was undertaken. However, a brief appraisal of airship costs and capabilities compared with rail, truck and airplane revealed that even at the lowest estimated rate, airships were currently still more expensive on a ton-mile basis than either rail or truck, but were less expensive than airplane. However, it was also found that while airships are somewhat slower than airplanes, they offer a faster delivery time than either road or rail freight movement by a fairly significant margin. Thus, while it is impossible to draw any definite conclusions regarding the "cost versus time" decisions which shippers will make, it does not seem unreasonable to say that the airship seems to offer a reasonable alternative to existing modes, especially in the movement of commodities where speed is an important factor.

It remains for a future study to combine the two parts of the methodology when the necessary data becomes available to formally determine the potential demand for airship services in the commercial freight market.

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I would like to thank all those who assisted in the completion of this study. First, and foremost, I would like to acknowledge the invaluable and timely suggestions and guidance provided by my major advisor, Dr. Edward W. Tyrchniewicz, Chairman, Department of Agricultural Economics.

Thanks is also due to the other members of the advisory committee: Dr. Martin H. Yeh, Department of Agricultural Economics and Dr. Greg Mason, Department of Economics, University of Manitoba, for their valuable suggestions and constructive criticisms.

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The typing of this study was done by Mrs. Gisele Perrault, and I would like to express my sincere appreciation for her excellent work.

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INTRODUCTION

While the crash of the German dirigible Hindenburg, in 1937, effectively put an end to commercial airship operation over forty years ago, it failed to extinguish the enthusiasm for airships which was felt by many. Apparently, this interest has managed to survive four decades of near inactivity and has surfaced during the last decade on many fronts.

In the forefront of the current attempt to resurrect lighter-than-air vehicles (LTA's) are engineers, economists, and businessmen whose various and varied studies started to appear with increasing regularity in both professional and popular publications. Although the reasons given to justify an airship resurgence have been many, they have tended to focus upon three factors. The first is the fact that the airship is an ecologically sound vehicle, both in terms of pollution and resource use.[1] The second factor is the more ready availability of helium at a reasonable price,[2] while the third involves the advances which have been made in structural engineering since the 1930's.[3] The latter reasons are important

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[1] R.D. Neuman and L.R. Hackney, "Airship Economics," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), p. 42.

[2] D. Howe, The Feasibility of the Large Freight Airship, Cranfield Report Aero No. 5 (Cranfield, U.K.: Cranfield Institute of Technology, 1971), p. 2.

[3] R.G. O'Lone, "Lighter-Than-Air Technology Broadens," Aviation Week and Space Technology, (Sept. 1974):42.

in dispelling the still commonly held belief that all airships are in imminent danger of either structural failure or bursting into flames, or both.

In addition to the variety of reasons given for a serious reappraisal of the airship's transport potential, enthusiastic proponents have also put forward a plethora of commercial and non-commercial applications for airships. The proposals, which are based primarily on LTA's unique ability to hover and float in the air, range from the movement of indivisible heavy loads[4] to the leisurely transportation of people to exotic places in what would in effect be a floating luxury hotel.[5]

However, no matter how good the uses of and reasons for a widespread reintroduction of airships may seem, the fundamental criterion for determining whether or not such a move is warranted at this time must be its economic feasibility. That is, is there sufficient demand to sustain the operation of a commercial airship service? It is this question which the present study was originally intended to address. Unfortunately, insurmountable problems in obtaining the necessary data have led to a shift in the focus, such that the fundamental objective of this study is to

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[4] P.O. Roberts, H.S. Marcus, and J.H. Pollock, "An Approach to Market Analysis for Lighter Than Air Transportation of Freight," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), p. 88.

[5] Jack R. Hunt, et al., "The Many Uses of the Dirigible," Astronautics and Aeronautics, (October 1973):60.

provide a methodology for assessing the potential economic viability of introducing airships into the commercial freight market.

Now, it seems reasonable to assume that the potential for successful market penetration by airships will be greater in some sectors of the transport market than in others. Unfortunately, no ready comparison of airship rates and service attributes with those of other transport modes is possible due to the fact that current airship information simply does not exist. While this is not surprising considering that there have been no commercial airship operations for forty years, it does present a problem. However, it is believed that reasonable rate estimates can be obtained by estimating airship operating and cost characteristics, given specific performance requirements. Once this has been done, the area of the transport market in which the airship would be best suited to compete can be selected.

In addition to the difficulty involved in intermodal comparisons, there are obvious problems associated with attempting to determine the specific level of demand for a non-existent transport mode. In order to make this determination, it is first necessary to identify those factors which strongly influence the modal choice decisions of shippers. Once these factors have been ascertained, they may be incorporated into an abstract mode model and an estimate of the demand for any transport mode can be obtained provided that the necessary data is available. As this latter requirement was not met, an explanation of the abstract mode approach to the demand for transport will be followed by the formulation of an abstract mode model; but no estimate of the demand for airship services will be attempted.

In essence, then, fulfilling the objective of this study, to provide a method of determining the economic feasibility of employing airships in freight transport, will entail two distinct steps. The first step will involve the explanation and formulation of an abstract mode model, while the second step will entail developing a costing methodology for airships in order to facilitate reasonable estimates of airship freight rates.

Now, before going on to formulate either the abstract mode or airship costing model, the second chapter will contain a review of the studies which have been done in the area of airship development and economics. Following this, the third chapter will include a review of the literature pertaining to demand and modal-split modelling for transportation.

The theory upon which abstract mode models rest as well as an actual model of this type will be presented in the fourth chapter, while the airship costing model, in theory and practice, will be the subject of chapter five. A discussion of the results which were obtained, the limitations of the study and any conclusions which can be drawn comprise the sixth and final chapter.

CHAPTER 2

AIRSHIPS DEMYTHOLOGIZED

2.1 Background to the Resurgence

Due to a series of spectacular disasters, one of which was alluded to earlier, the airship has been in a general state of disrepute for over four decades. However, in recent years, a number of individuals and organizations have attempted to revive interest in lighter than air vehicles (LTA's) and have to some extent succeeded. The question which arises, then, is why, after such a long period of obscurity, has interest in airships been renewed at this time? As was mentioned in the introduction, the answers given by most LTA enthusiasts most often pertain to improved aeronautical technology,[6] the increased availability of helium,[7] and a host of environmental considerations, such as waste and noise pollution, as well as the increasingly critical shortage of fossil fuels.[8]

The first two reasons cited, namely improved technology and ready helium availability, are critical to any LTA resurgence. This is because the disasters which led to the virtual disappearance of airships were due, for the most part, to either structural break-up under stress[9] or to the

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[6] O'Lone, "Transportation Broadens," p. 42.

[7] Howe, Feasibility, p. 2.

[8] Neuman and Hackney, "Airship Economics," p. 42.

[9] Howe, Feasibility, p. 1.

fact that hydrogen, an extremely flammable gas, was employed as the agent of buoyancy.[10]

There is, however, some concern about the validity of the claims which have been made. While helium may be more readily available, the critical matter of price remains unsettled, and even when considering the purchase of large quantities, the price may still prove to be prohibitive.[11] With regard to the improvement in aeronautical technology over the past forty years, very little disclaimer can be made. However, too often "...[t]he massive problems of the past are eliminated with the stroke of a pen and the all encompassing words 'New Technology'."[12] This is not to say that technological advance has not rendered the airship practicable, but rather, merely serves to point out that many of the claims made by airship proponents are thus far largely unsubstantiated.[13]

In meeting the concerns of environmentalists, however, LTA's are almost matchless in the transportation field. They are almost noiseless[14] and are far more efficient in their use of fuel and other resources than most other modes of transport.[15] In this latter regard, the fact that LTA's

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[10] M. Rynish, "Cargo Airships - A Plan for the Future," ICHCA. (Oct. 1971):15.

[11] Howe, Feasibility, p. 3.

[12] Neuman and Hackney, "Airship Economics," p. 42.

[13] O'Lone, "Technology Broadens," p. 42.

[14] F. Morse, "Cargo Airships: A Renaissance?" Handling and Shipping. (June 1972):45.

[15] J.G. Vaeth, "The Airship Can Meet the Energy Challenge," Astronautics and Aeronautics, (Feb. 1974):25.

are airborne eliminates the need for roadway facilities. In addition, since they are VTOL craft they do not require the expensive airport facilities which are needed by heavier-than-air craft.[16]

2.2 The Economics of Airship Viability

Even if the claims about the technical improvements in and environmental desirability of the airship are accepted as being true, they do not of themselves provide sufficient justification to undertake development of the airship at this time. The question which must be answered is whether or not there is a substantial market for the services which the airship can offer.[17]

In order to become an economically viable transport mode, airships must either generate an increased demand for transportation or else they must draw some users away from the modes which are presently in use. In order to achieve the former, LTA's would either have to offer services which were previously unavailable or they could extend the market areas for currently available products by means of absolute improvements in one or more service levels.[18]

To "steal" business away from already existing modes would require, perhaps, only relative improvements in some service characteristics.[19] In

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[16] Howe, Feasibility, p. 18.

[17] K.R. Stehling, "Vers Une Renaissance du Dirigible?" Interavia. (Sept. 1975):989.

[18] J.F. Vittek, Jr., "The Economic Realities of Air Transport," (M.I.T. Flight Transportation Laboratory, 1975), p. 1, (unpublished paper).

[19] Ibid.

effect, the first option would require an increase in the total amount of transportation consumed, while the second would involve a redistribution of the modal split. A third possibility might entail both an increase in total transport consumption as well as a change in the relative share of the transportation market captured by each mode.

Airship enthusiasts envisage many new roles for airships which will tend to increase the total consumption of transportation. Already mentioned in this list of innovative uses for LTA's is the conveyance of very heavy and/or indivisible loads, such as nuclear reactor parts, to presently inaccessible areas.[20] On the lighter side, it has been suggested that airships be used to transport natural gas from the arctic to more southern locations.[21] It has also been put forward that LTA's would make excellent floating hotels or luxury liners where people could relax and enjoy the passing scenery or travel in comfort to exotic places such as the south pole.[22] Other possible uses have included the fitting of airships as portable hospitals for use in emergencies arising from natural or man-made disasters,[23] as well as their employment as orbiting laboratories to carry out extensive biological and meteorological research.[24]

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[20] Roberts, Marcus and Pollock, "An Approach to Market Analysis," p. 88.

[21] N.P. Biederman, "Natural Gas by Airfreight," Pipeline and Gas Journal. (Oct. 1970):62-69.

[22] Hunt, et al., "Many Uses," p. 60.

[23] Stehling, "Vers," p. 989.

[24] Hunt, et al., "Many Uses," p. 61.

If we ignore its potential for carrying passengers, then it seems apparent that, with the exception of transporting heavy and/or indivisible loads and perhaps natural gas, the other uses put forward for LTA's are at best questionable insofar as their commercial viability in the private sector are concerned. Even the heavy-lift capability of the airship incurs problems in that the demand for this service would generally be limited to "one shot" moves.[25] Thus, a stable demand for its services, which is essential to the continuation of any transport mode, appears to be lacking in this case. Also, while it is apparently promising, further study will be required to determine the feasibility of moving natural gas by airship.

It has been suggested that airships can induce more transportation demand by extending the market areas of presently available products by offering faster or cheaper service than any other mode. Closer examination of this suggestion reveals that the former possibility can be eliminated (except for relatively short hauls, perhaps) due to the fact that the anticipated average block speed of the airship will be substantially lower than that of the airplane.[26] With regard to price, it seems unlikely that LTA's will be able to undercut the rates of all their competitors, even if the regulatory bodies allowed them to do so.[27]

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[25] Roberts, Marcus and Pollock, "An Approach to Market Analysis," p. 88.

[26] Most estimates of airship block speed are in the neighborhood of 100 MPH, well below present airplane speeds.

[27] Roberts, Marcus and Pollock, "An Approach to Market Analysis," p. 94.

It seems most plausible that while not totally dismissing other potential income sources, the major portion of airship revenues will have to derive from business drawn away from other transport modes by the particular rate and service characteristics which the airship offers. The question which still remains is whether or not LTA's will be able to wrest enough traffic away from existing transport modes to make them economically viable in the highly competitive transport market. Perhaps an even more fitting question would be whether or not it is possible at this time to make the necessary determination. In this regard, a rather apt statement by Dr. R. Ausrotas may be of assistance:

> In the field of Lighter Than Air, there is a wealth of performance data and a dearth of economic data. Thus, it is not surprising that most discussions about the potential of LTA end in agreement that an airship of a given size could carry out a specific mission, but in disagreement as to how much it would cost. Since commercial airship operations have not been undertaken for almost forty years, this paucity of data is not surprising, and any new proposal for LTA--as far as its economic viability--runs into immediate suspicion...[28]

2.3 Recent Airship Cost Studies

While the lengthy quotation above sums up the general problem faced by those wishing to determine the economic feasibility of commercial airship operations, this is not to say that attempts have not been made to deal with the problem. A number of serious studies have been undertaken to examine the economic prospects for LTA's, and a discussion of some of these attempts follows.

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[28] Raymond A. Ausrotas, "Basic Relationships for LTA Economic Analysis," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), p. 1.

Now, if it is assumed that the airship's rate structure will be such as to provide a sufficient rate of return to make the supply of airship services economically viable, then it is first necessary to determine the cost structure upon which such rates will be based. As such, the development of a costing methodology for airships is a prerequisite to a detailed cost analysis. To this end, Hill devised a costing framework which made use of historical airship cost data updated to include "...the effects of new materials, propulsion techniques, and logistics concepts on costs and [the] adjustment of the dollar data to current price levels."[29] He suggests further, that the data base could be augmented by information derived from non-rigid airship operations which were just recently discontinued.[30]

The simplified flow chart presented in Table 1 below indicates the procedures which were followed in Hill's study. From the chart, it is evident that any cost analysis must be based on a comprehensive knowledge of vehicle characteristics and system requirements as developed by the designers, as well as any assumptions which may be involved. This is not to say that airship costs are necessarily highly sensitive to all design assumptions, but merely points out the need to test for such sensitivity.[31]

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[29] L.S. Hill, "An Integrated Approach to the Structuring of a Cost Model," paper presented at the 1st International Meeting of the Operations Research Society of America, Honolulu, Hawaii, Sept. 1964, p. 5.

[30] Ibid., p. 4.

[31] Ibid., p. 8.

Proceeding from the conceptual framework, Hill puts forward an aggregated general cost model for airships (Eq. 1).[32] That is, the model includes all elements of cost which should be considered during the entire life cycle of any airship project. This model

$$C = R + I + nU \tag{1}$$

where:

C = total program cost

R = research, development, test, and evaluation cost

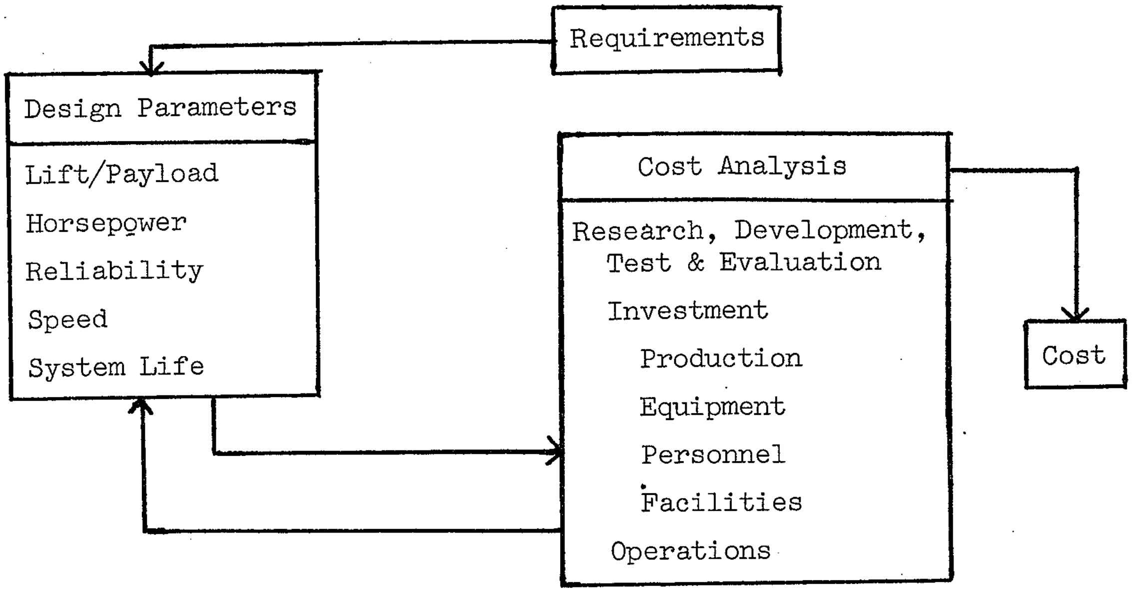
I = initial investment cost

n = number of operational years

U = annual operating costs

Table 1

Simplified Operation Flow Chart for Structuring an Airship Cost Model



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[32] Ibid., p. 10.

can be disaggregated into three separate but interrelated cost sub-models which are presented in equations (2), (3) and (4).[33] Of the three costs, research and development costs, (R) which are described in equation (2) are the most difficult to estimate due to the lack of a detailed data base.

$$R = D+T+T_s+\varepsilon_1 \tag{2}$$

where:

D = cost of design and development

T = cost of test vehicles and testing operations

T_s = cost of test support equipment

ε_1 = miscellaneous costs not included in the above

$$I = A+E+F+V+T+\varepsilon_2 \tag{3}$$

where:

A = cost of airships

E = cost of specialized equipment (mooring masts, ground handling equipment, helium purifiers, etc.)

F = cost of facilities

V = cost of personnel travel

T' = cost of personnel training

ε_2 = other costs not included above.

$$U = A_2+E_2+F_2+V_2P+T_2+L+M_A+M_E+M_F+\varepsilon_3 \tag{4}$$

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[33] Ibid., pp. 10-11.

where:

A_2 = cost of replacement airships

E_2 = cost of replacement of specialized equipment

F_2 = cost of replacement of facilities

V_2 = cost of annual personnel travel

P = cost of annual pay and allowances

T_2 = cost of replacement training

L = cost of fuel, lubricants, helium

M_A, M_E, M_F = cost of maintenance of airships, specialized equipment and equipment respectively

ε_3 = other operating expenses not included above.

Initial investment costs, (I), given in equation (3) may be viewed as "one-shot" expenditures necessary to introduce an airship operation after the required equipment has been developed and tested to the point where it is deemed to be at an acceptable level of reliability. Finally, the operating costs, (U), which are detailed in equation (4) pertain to those costs which are incurred in the operation and maintenance of airships after they have been introduced into service.[34]

It is unfortunate, but understandable in view of the high resource requirements, that Hill does not attempt to estimate the costs of an actual airship operation. However, his general cost model serves as a theoretical

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[34] Ibid., pp. 9-11.

framework to which actual cost analyses for airships can be compared. It should be noted, however, that due to the high costs and the uncertain nature of the results obtained, very few of the studies undertaken have attempted to estimate the costs of the total airship system. In most cases, the emphasis has been on ascertaining the operating costs with the attendant necessity of somehow allowing for initial investment costs since they will influence the costs of airship operation. Most studies defer from even mentioning research and development costs, and those that do generally introduce a figure without explaining how it was derived. These points should be kept in mind when considering the following studies.

In his attempt to determine airship operating costs Ausrotas states that the unit cost of an airship will be a function of: (a) the total development costs, (b) the anticipated airship production run, (c) the construction costs, and (d) the engine costs.[35] After making (hopefully) appropriate (but unfortunately unspecified) assumptions about the above four variables, Ausrotas proceeds to calculate the total operating costs for two airship proposals put forward by the Southern California Aviation Council. The projected operating costs for both airships, one with a payload capacity of 60 tons and the other with a payload capacity of 864 tons were based on the assumption that the airships would be utilized 4000 hours per year over a stage length not exceeding 2000 miles at an airborne cruise velocity of 100 MPH.[36]

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[35] Ausrotas, "Basic Relationships," p. 2.

[36] Ibid., p. 4.

Although the results which were obtained left something to be desired in terms of both the specified and unspecified assumptions employed to derive them, the estimated costs are interesting in that they clearly demonstrate that airship size will greatly affect economic viability. That is, Ausrotas found that both the direct and total operating costs of the smaller airship were more than three times the costs involved in operating the larger craft.

A seemingly more comprehensive cost analysis than that done by Ausrotas was performed by Goodyear Aerospace to determine the cost of transporting cargo over distances of 2,500 and 1,500 miles respectively. No new design innovations were considered for the 10×10^6 cubic foot displacement airship which was to cruise at an altitude of 5,000 feet, and only proven fabrication, dimensional and operational practices using currently available materials and engines were employed to calculate performance and cost characteristics.[37]

The costs were divided into investment and direct operating costs as shown in Table 2 below. The total operating costs, which consist of the totals of investment and direct costs per ton mile for 2,500 and 1,500 mile stage lengths appeared to indicate that the optimum cruising speed for the least cost per ton mile for a 10×10^6 cubic foot airship is in the vicinity of 90 MPH.[38] Of interest as well is that the estimated total

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[37] Robert T. Madden and Frederick Bloetscher, "Effect of Present Technology on Airship Capabilities," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), p. 36.

[38] Ibid.

costs per ton mile for the 1,500 mile stage length were approximately 13 percent lower than those estimated for the 2,500 mile stage length.[39]

The somewhat surprising result obtained in the Goodyear study, that airships achieve lower total operating costs over a 1,500 mile range than over a 2,500 mile range, receives support from a study done by Smith and Ardema.[40] It should be noted, however, that in describing the effect of range on total operating costs they start with a minimum range of 2,700 miles. Thus, looking at Figure 1 below, it does not seem unwarranted to say that perhaps total operating costs would continue to decline with decreasing flight range up to a certain point before it began to increase again, thus giving rise to a U-shaped cost curve.

Table 2

Preliminary Airship Transportation
Cost Model

Investment Costs

- Annual costs
  - Depreciation of Investment
  - Interest on Investment
  - Insurance
- Initial Investment Costs
  - Development Costs
  - Production Run

Direct Operating Costs

- Labour Costs/Flight Hour
  - Flight Crew
  - Maintenance Technicians
  - Ground Service Crew
- Material Costs/Flight Hour
  - Fuel and Oil
  - Helium
  - Spares/Equipment

Source: R.T. Madden and F. Bloetcher, "Effect of Present Technology on Airship Capabilities," p. 37.

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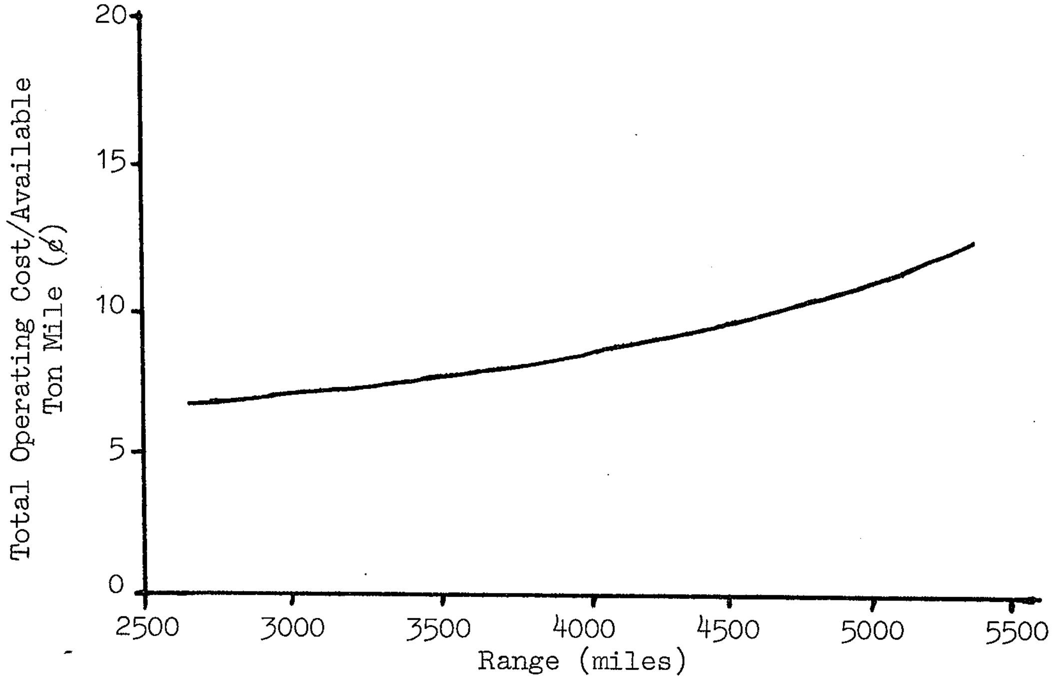
[39] Ibid., p. 38.

[40] C.L. Smith and M.D. Ardema, "Preliminary Estimates of Operating Costs for Lighter Than Air Transports," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), p. 7-20.

In arriving at their estimates, Smith and Ardema divided total operating costs into direct and indirect operating costs. The costing techniques employed were based on air transport experience. Thus, direct costs were computed using the Air Transport Association (ATA) cost equations, and indirect costs were derived using equations developed jointly by Boeing, Lockheed and Douglas (B-L-D) aircraft corporations.[41] A slight modification was made to these latter equations to include the replenishment of the lifting gas (helium) needed for airships.[42] Table 3 indicates the elements of direct and indirect costs included in the calculations.



Source: C.L. Smith and M.D. Ardema, "Preliminary Estimated of Operating Costs for Lighter Than Air Transports," p. 15.

Figure 1

Effect of Range on Total Operating Cost

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[41] Ibid., p. 11.

[42] Ibid.

The cruise speed selected by Smith and Ardema to maximize the productivity of their 16.7×10^6 cubic foot airship was 116 MPH.[43] The results which were obtained indicated that the crew and fuel costs made up nearly 60 percent of the direct operating costs for the 172.5 ton payload capacity airship, while maintenance costs accounted for nearly 25 percent.[44] It was also estimated that cargo traffic servicing would contribute 30 percent to indirect operating costs, while administrative overhead would require almost 20 percent of all indirect costs.[45]

Table 3

Operating Cost Elements

Direct Operating Costs (ATA Method)	Indirect Operating Costs (B-L-Q Method)
Crew	Maintenance of Ground Properties and Equipment
Fuel	Vehicle servicing
Insurance	Cargo traffic servicing
Maintenance	Reservations, Sales and advertising
Depreciation	General and administrative functions
	Gas replenishment

Source: C.L. Smith and M.D. Ardema, "Preliminary Estimates of Operating Costs for Lighter Than Air Transports," p. 12.

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[43] Ibid., p. 13.

[44] Ibid.

[45] Ibid.

In a study whose emphasis differed somewhat from that of the studies discussed previously, Beier and Hidalgo attempted to determine whether or not the airship can play a useful role in economic development.[46] As such, a major part of the study included an assessment of potential airship costs, and it is this aspect of the study which will be examined.

The airship envisaged by Beier and Hidalgo is similar in design to the Hindenberg. It is, however, 10 percent longer, giving it a gas volume of 9.39×10^6 cubic feet and a useful lift of 147 tons.[47] Based on the above assumptions, cost estimates were prepared. In addition, cost estimates for airships with useful lifts of 16.5 and 2.2 tons respectively were also prepared for purposes of comparison. The cost estimates which were obtained indicate that both the direct and total operating costs of the 16.5 ton capacity airship are nearly five times those of the 147 ton capacity LTA,[48] a result not unlike that obtained by Ausrotas in his study.[49]

Like Beier and Hidalgo, Coughlin also studied the feasibility of employing airships in underdeveloped areas.[50] In addition to attempting to

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[46] G.J. Beier and G.C. Hidalgo, "Roles for Airships in Economic Development," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), pp. 485-498.

[47] Ibid., p. 487.

[48] Ibid., p. 488.

[49] See pages 18-19.

[50] Stephen Coughlin, "The Application of the Airship to Regions Lacking in Transport Infrastructure," Proceedings of the Interagency Workshop on Lighter Than Air Vehicles, ed. J.F. Vittek, Jr. (Cambridge, Mass.: M.I.T. Flight Transportation Laboratory, 1975), pp. 499-508.

define the transportation needs of such areas, Coughlin also sets out to determine the operating costs of an airship with a payload capacity of 1000 tons. The cruise speed of the 83x10^{6} cubic foot mammoth is assumed to be 127 MPH, with the range of the ship being 1000 miles.[51]

One point of interest in Coughlin's study is the finding, illustrated in Figure 2, that increasing stage length will lead to decreasing operating cost/ton mile.[52] This is in direct contrast to the results reported by Madden and Bloetcher and Smith and Ardema.[53] It may be, however, that the

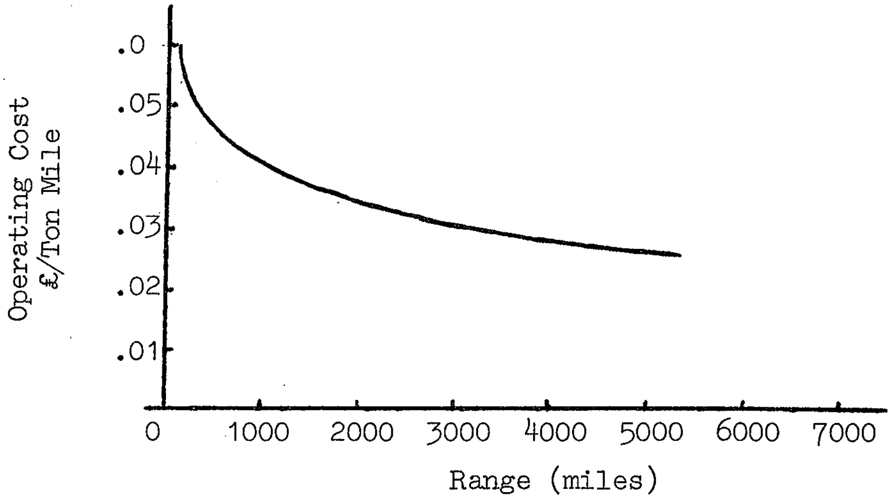

Figure 2

Variation of Operating Cost with Range

Source: S. Coughlin, "An Appraisal of the Rigid Airship in the U.K. Freight Market," p. 92.

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[51] Ibid., p. 505.

[52] Ibid., p. 507.

[53] See pages 21 and 22.

difference in opinion is due entirely to the fact that the sizes of the airships under consideration differed markedly.

In addition to his study of the applicability of the airship for use in underdeveloped areas, Coughlin has also done an extensive appraisal of the airship's potential to compete against existing transport modes in the British freight market.[54] Rather than the 1000 ton payload airship described previously, Coughlin examined the operating costs of a 314 ton capacity vehicle which had a gas volume of 25×10^6 cubic feet and had an anticipated cruise speed of 116 MPH.[55]

One of the more salient features of Coughlin's study was that he undertook a sensitivity analysis in an attempt to determine how much the assumptions used affected the estimated operating costs. The results of this analysis, which are given in Table 4, make it possible to discern the relative importance of each assumption, and to loosely group the assumptions according to their potential impact on operating costs, as was done in Table 5. It should be noted, however, that presenting the results in the fashion chosen can lead to some ambiguities. While using a ±50 percent variation seems to be a fair way of making a comparison without undue recourse to numerous value judgments, it may not necessarily reflect the true picture. This is because certain parameters can be defined more

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[54] Stephen Coughlin, An Appraisal of the Rigid Airship in the U.K. Freight Market, Cranfield CTS Report 3 (Cranfield, England: Cranfield Institute of Technology Center for Transportation Studies, 1973), pp. 1-102.

[55] Ibid., p. 87.

Table 4

Sensitivity Analysis of Initial Airship Technical and Cost Assumptions

Parameter	Initial Assumption	Percent Change in Operating Cost -50	 +50
Altitude	3000 feet	-4	+4
Length/Diameter	6	-22	+22
s.f.c.[a]	.47 lb/HP/hr.	-4	+7
s.w.[b]	.5 lb/HP	-1	0
min t_e[c]	.06 inches	-47	+70
F[d]	1.27	+108	
Transmission efficiency	.85	-10	+12
Max. speed/cruise speed	1.1	-5[e]	+27
Utilization	5000 hours	+55	-14
Interest on capital	10 percent	-15	+17
Vehicle life	10 years	+46	-14
Structure cost	20,000/ton	-40	+42
Gas cost	30/1000 ft.^{3}	-4	+3
Power plant cost	20/HP	-1/2	+1/2
Fuel cost	20/ton	-3	+5
Crew wages	140,000	-4	+4
Maintenance	4 percent initial cost	-9	+9
Insurance	1 percent initial cost	-3	+2

[a] specific fuel consumption of power plant.

[b] specific weight of power plant.

[c] minimum allowable shell thickness.

[d] structural efficiency.

[e] ratio taken as 1.

Source: S. Coughlin, An Appraisal of the Rigid Airship in the U.K. Freight Market, p. 23.

Table 5

Relative Importance of the Assumptions by Group Based Upon a ±50 Percent Variation

Critical	Relatively Important	Not Very Important
min t_e	length	design altitude
F	max. speed/cruise speed	s.f.c. & s.w.
structure cost	interest on capital	cost of power plant
vehicle life	transmission efficiency	cost of lifting gas
utilization		cost of fuel
		crew wages
		maintenance cost
		insurance cost

Source: S. Coughlin, An Appraisal of the Rigid Airship in the U.K. Freight Market, p. 24.

accurately than others. For example, looking at Table 5, the cost and weight of the power plant can be specified quite exactly, while the variation in the maintenance cost, which is included in the same group, may exceed even the ±50 percent variation evaluated. What clearly emerges from the sensitivity analysis, however, is that the critical area for determining operating costs "...is that of structural design, where a difficult interaction occurs between structural cost and structural efficiency."[56]

Like Coughlin, Howe also engaged in a detailed engineering study to arrive at the probable cost parameters for a 33.9×10^6 cubic foot airship with a gross lift of 1000 tons.[57] It is interesting to note that Howe prepared two sets of cost estimates employing varying assumptions regarding the airship's installed power and hence the assumed cruise speed. One set of estimates was based upon the assumption that hydrogen gas would be used along with helium as the agent of buoyancy and that some of the hydrogen would be burned as fuel to maintain neutral buoyancy as fossil fuel was expended. The other set of estimates was made with the assumption that a cryogenic system would be installed to liquify helium to maintain neutral buoyancy as fuel was burned.[58] In both cases Howe assumed that the indirect

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[56] Ibid., p. 25.

[57] Howe, Feasibility, p. 18.

[58] Ibid.

costs to be added to direct costs to obtain total operating costs would be in the neighborhood of 50 percent of direct costs.[59]

Having examined some of the more substantial efforts which have been made to estimate airship costs, it is unfortunate that no meaningful comparisons can be made between the results which were obtained due to the variations in time, space and costing techniques and assumptions among the studies. It is for this reason that none of the results were included and that only the occasional indirect comparison was attempted.

Of the variations among the studies mentioned, the most critical is that the cost estimates are based on a plethora of differing assumptions regarding airship size, load capacity, distances to be traversed, utilization rates, and just about every other factor critical to a cost calculation. In view of the fact that there does not seem to be a reliable way of determining which of the studies provides the best overall assumptions, it was decided that a costing model would be formulated employing assumptions regarding an airship of specific design and intended performance characteristics. This costing and performance model will be developed and presented in Chapter 5, following a review of the transport demand literature and the development of the abstract mode model which will take place in Chapters 3 and 4, respectively.

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[59] Ibid.

CHAPTER 3

THE CHARACTERISTICS OF THE DEMAND FOR TRANSPORT

3.1 Models of Demand and Modal-Split in Transportation

While a great deal of effort (on paper at least) has been put into the development of an airship which is capable of competing in present and future transportation markets, work has been continuously ongoing to determine the constituent factors of the demand for freight transportation. As well, the choice of transport mode has also come under serious scrutiny. It may be mentioned at this point that since only a small percentage of freight movement is by airplane, most researchers have tended to focus their attention on ground transport.

Many of the studies which have been performed, including those by Perle,[60] Benishay and Whitaker,[61] Sloss,[62] Fosbrooke and Hariton,[63] Morton,[64]

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[60] E.D. Perle, The Demand for Transportation, Research Paper No. 95 (Chicago: University of Chicago Press, 1964), pp. 1-96.

[61] Haskel Benishay and Gilbert R. Whitaker, Jr., "Demand and Supply in Freight Transportation," Journal of Indian Economics, 14 (1966): 243-261. -

[62] James Sloss, "The Demand for Intercity Motor Freight Transport: A Macroeconomic Analysis," Journal of Business, 44 (January 1971):62-68.

[63] R. Fosbrooke and G. Hariton, Transport Demand Elasticities, (Ottawa: Canadian Transport Commission, 1975), pp. 2-18.

[64] A.L. Morton, "A Statistical Sketch of Intercity Freight Demand," Highway Research Record, No. 296 (Washington, D.C.: Highway Research Board, 1969).

and Limmer,[65] made use of regression analysis to identify significant variables and/or to measure their influence on the demand for transportation. Research by Woods and Domenisch,[66] Escobosa,[67] and Stenger[68] was less rigorous methodologically than that cited previously due to the fact that these latter studies attempted to include quality of service[69] variables to explain the demand for transport, while the former did not. It should be mentioned, however, that no attempt was made to quantify the qualitative variables in a rigorous manner. Recently, however, efforts have been made

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[65] Ezekiel Limmer, "The Elasticity of Demand for Railroad Transportation of Florida Produce," Journal of Farm Economics, 37 (1955): 452-460.

[66] D.W. Woods and T.A. Domenisch, "Competition Between Rail and Truck in Intercity Freight Transportation," Proceedings of the 12th Annual Meeting of the Transportation Research Forum (Oxford, Indiana: The Richard B. Cross Company, 1971), pp. 263-276.

[67] Paul Escobosa, Some Aspects of Transportation of Fruits and Vegetables in the Western Part of the United States (Stanford, California: Stanford University Press, 1968), pp. 11-63 passim.

[68] Alan J. Stenger, "An Approach to Determining the Market Potential for Various Railroad Services," Proceedings of the 14th Annual Meeting of the Transportation Research Forum (Oxford, Indiana: The Richard B. Cross Company, 1973), pp. 409-422.

[69] Quality of service, as defined by Marc A. Johnson, may be taken as "...an aggregate term referring to the bundle of non-price characteristics of transportation inputs that influence their usefulness in the production process. Examples include transit speed, product safety, and service reliability..." Marc A. Johnson, "Estimating the Influence of Service Quality on Transportation Demand," American Journal of Agricultural Economics, 58 (August 1976):497.

by Johnson,[70] Allen,[71] and Kneafsey[72] to actually measure the effects of different aspects of service quality on transport demand.

Turning now to the question of modal choice, a number of approaches have been taken to determine the allocation of traffic among the various modes in a particular transport market. Mikluis et al.[73] and Watson et al.,[74] made use of logit analysis in an attempt to predict modal choice from data on the performance attributes of each mode and shipment characteristics. As well, an attempt to extend modal split analysis to include the evaluation of not yet existing transport modes has been made by Quandt[75,76] and Quandt and Baumol,[77,78] by making use of what is referred

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[70] Ibid., pp. 497-500.

[71] W. Bruce Allen, "The Impact of Transport Loss and Damage on Transportation Demand," Proceedings of the 14th Annual Meeting of the Transportation Research Forum (Oxford, Indiana: The Richard B. Cross Company, 1973), pp. 605-615.

[72] James T. Kneafsey, Transportation Economic Analysis (Toronto: D.C. Heath and Company, 1975), pp. 57-292, passim.

[73] Walter Miklius, Kenneth L. Casavant and Peter V. Garrod, "Estimation of Demand for Transportation of Agricultural Commodities," American Journal of Agricultural Economics 59 (May 1976):217-222.

[74] Peter L. Watson, James C. Hartwig and William E. Linton, "Factors Influencing Shipping Mode Choice for Intercity Freight: A Disaggregate Approach," Proceedings of the 15th Annual Meeting of the Transportation Research Forum (Oxford, Indiana: The Richard B. Cross Company, 1974), pp. 139-144.

[75] Richard E. Quandt, "Introduction to the Analysis of Travel Demand," in The Demand for Travel: Theory and Measurement, ed. Richard E. Quandt (Lexington, Mass.: D.C. Heath and Company, 1970), pp. 1-6.

[76] Idem, "Estimation of Modal Splits," in The Demand for Travel: Theory and Measurement, ed. Richard E. Quandt (Lexington, Mass.: D.C. Heath and Company, 1970), pp. 160-161.

[77] Richard E. Quandt and William J. Baumol, "The Demand for Abstract Transport Modes: Theory and Measurement," Journal of Regional Science 6 (Winter 1966):13-26.

[78] Idem, "The Demand for Abstract Transport Modes: Some Hopes," Journal of Regional Science 9 (April 1969):159-161.

to as the abstract mode approach. Bayliss[79] makes reference to a study which attempted to make use of the abstract mode approach, but which was unsuccessful due to data limitations.

From the brief description of the research carried out in the past, as well as that currently ongoing, it can be seen that advances in understanding and predicting transport demand have been and are being made on many fronts. For the purposes of this study, however, it was decided that the abstract mode approach put forward by Quandt and Baumol offered the best prospect for estimating the potential demand for a "new" transport mode like the airship. As such, a more detailed description of this approach, as well as a discussion of the theory upon which it rests, are given below.

3.2 The Demand for Abstract Transport Modes

The abstract mode approach to evaluating the demand for transport put forward by Quandt and Baumol[80] is based on the conviction that modes can and should be defined in terms of their qualities or attributes rather than being delineated in the conventional manner of train, truck, bus, etc.[81] Instead of making use of a purely semantic differentiation with its implicit subjective evaluation of modal attributes, an abstract mode is characterized by an explicit vector of values for the relevant variables that affect the

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[79] B. Bayliss, Demand for Freight Transport, O.E.C.D. Round Table 20 (Paris: Economic Research Centre, 1973), pp. 35-48, passim.

[80] Quandt and Baumol, "Abstract Modes: Theory," p. 14.

[81] Ibid.

desirability of a mode to the individual for daily travel or to a shipper for determining the movement of his product to market.[82]

When modes are defined in abstract terms, then the decision to ship goods as well as the choice of mode is hypothesized to depend upon the best absolute performance of any mode in relation to each of the attributes specified as well as the relative performance of each mode in relation to the best.[83] Taking a very simple example, suppose that a product to be shipped degenerates rapidly, in say x days, to the point where it is no longer salable. In deciding whether or not to market this product in a particular location a shipper will need to know if the best absolute travel time by any mode from point of origin to destination is less than x days. If no mode can provide service in less than x days, then the decision will necessarily be not to ship. Suppose, however, that there were two modes, A and B, both of which provided service in less than x days. If more modal attributes, such as freight rate and reliability of service, are introduced, then the choice between mode A or mode B would depend on the best absolute performance for each characteristic, as well as on the relative performance level of each mode assuming that some minimum standard is met. This concept will be discussed more fully later in this chapter.

In essence, then, the abstract mode approach states that the demand for a particular transport mode is a function of its attributes, which are,

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[82] Ibid.

[83] Ruben Gronau and Roger E. Alcaly, "The Demand for Abstract Transport Modes: Some Misgivings," Journal of Regional Science 9 (April 1969):153.

hopefully, quantifiable. What differentiates this approach from others which specify the demand for transportation to be "...a function of a number of variables is that after all relevant variables have been held constant we consider the [mode] to be homogeneous: that is, if the observable attributes of one [mode] are precisely the same as those of another, then for our purposes, they are the same [mode]."[84] The advantage of this type of approach is that unlike traditional approaches, it allows for the introduction of new modes, such as the airship, simply by specifying such major characteristics as cost or travel time,[85] instead of requiring a total reconstruction of shippers' preference maps or an implicit characteristics appeal such as occurs when new products are stated to be "like" other products which are currently available.[86]

3.3 The Characteristics Theory of Demand

The crucial modification of conventional demand theory which allows the abstract mode approach to deal more effectively with the emergence of new transport modes is the premise that consumers are not interested in the institutional delineation of modes, but rather are interested in the characteristics or attributes which the various transport modes produce in differing amounts and proportions.[87]

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[84] Quandt and Baumol, "Some Hopes," p. 159.

[85] Richard E. Quandt, "Introduction," p. 6.

[86] Kelvin J. Lancaster, Consumer Demand: A New Approach, (New York: Columbia University Press, 1971), p. 116.

[87] Quandt, "Introduction," p. 5.

It appears, then, that the abstract mode approach to transport demand is "...similar to spirit..."[88] to Lancaster's characteristics approach to demand.[89] The fundamental proposition of Lancaster's demand theory is that all goods possess objectively measurable characteristics which are the pertinent factors in the selection of goods-collections which people make. Thus, the choice of a particular goods collection is a consequence of an individual's assessment of different characteristics, rather than his assessment of the characteristics content of a particular collection of goods.[90] It follows from this that the desire to acquire goods may be viewed as a derived demand for the goods "...in the sense that goods are required only in order to produce the characteristics."[91]

Now, suppose that an economy contains n goods with r characteristics from which utility is directly derived by consumers. If we define q_{ij} $(i = 1, ..., r; j = 1, ..., n)$ to represent the universally meaningful and objectively measurable quantity of the ith characteristic which one unit of the jth good possesses, and C_i and G_j to represent the quantity of the ith characteristic and jth good in a particular goods collection respectively,

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[88] Lancaster, <u>Consumer</u>, p. 117.

[89] Ibid.

[90] Idem, "A New Approach to Consumer Theory," in <u>The Demand for Travel: Theory and Measurement</u>, ed. Richard E. Quandt (Lexington, Mass.: D.C. Heath and Company, 1970), p. 20.

[91] Idem, <u>Consumer</u>, p. 7.

then it is essential for the viability of the Lancastrian model that two assumptions hold. The first is that:

$$C_i = q_{ij} G_j \qquad (1)$$

where C_i, q_{ij} and G_j are defined as above.

In essence this means that the quantity G_j, where $G > 0$, of the jth good possesses G times the amount of each characteristic in the goods collection as does a single unit of the jth good. The second assumption is that:

$$C_i = q_{ij} G_j + q_{ik} G_k, \qquad (2)$$

where C_i, q_{ij} and G_j are defined as above.

q_{ik} = the quantity of the ith characteristic which one unit of the kth good possesses

G_k = the quantity of the kth good in a particular goods collection.

Essentially this requires that the total amount of the ith characteristic possessed by a goods collection be the simple sum of the quantities of that characteristic possessed by each of the goods in the collection individually. One further assumption is that individuals possess ordinal utility functions on characteristics of the form U(c) and that they will tend to choose characterisitcs collections which maximize U(c).[92]

Returning to our economy of n goods and r characteristics, the total collection of characteristics possessed by the n goods may be stated as:

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[92] Idem, "A New Approach to Consumer Theory," Journal of Political Economy, 74 (April 1966):135.

$$C_i = \sum_{j=1}^{n} q_{ij} G_j \qquad i = 1, \ldots, r \tag{3}$$

Formulating this in matrix terms, (3) becomes:

$$C = QG \tag{4}$$

where:

$C = [C_i]$ is a vector of characteristics

$G = [G_j]$ is a vector of goods, and

$Q = [q_{ij}]$ is a matrix of coefficients relating goods and characteristics.[93]

Thus, since goods are productive of, but are not synonymous nor uniquely identified with characteristics, and characteristics cannot be purchased directly, it follows that there must be a link between goods and characteristics which facilitates the transformation of one into the other. To effect this transformation, Lancaster makes use of what he refers to as the consumption technology matrix, Q, as defined above, which has as many rows as there are characteristics and as many columns as there are goods.[94] For example, suppose there are three transportation modes, A, B, and D whose pertinent characteristics are load capacity, in tons, and frequency of service, given in terms of the number of trip originations per week. The consumption technology matrix, which is assumed to be objectively viewed

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[93] Idem, <u>Consumer</u>, p. 16.

[94] Quandt, "Introduction," p. 6.

as being the same by every individual in the economy,[95] for this particular collection of goods can be described as in Table 6. Each q_{ij} in Table 6 has an objectively quantifiable value which is determined by the intrinsic properties of the modes themselves. Through the use of this consumption technology matrix in the relationship C = QG, a linear transformation from "goods space" to "characteristics space" can be effected.[96]

Having established the relationship between goods and characteristics, let us now consider an actual mapping in characteristics space when the number of goods exceeds the number of characteristics.

Table 6

Consumption Technology Matrix
for Modes A, B, and D

j=n=3

i=r=2	A	B	D
load capacity (tons)	q_{11} (5)	q_{12} (4)	q_{13} (1)
frequency of service (origins per week)	q_{21} (1)	q_{22} (3)	q_{23} (4)

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[95] Lancaster, <u>Consumer</u>, p. 18.

[96] Ibid., p. 16.

In Figure 3, C_1 and C_2 represent objectively measurable and universally meaningful characteristics, while the points G_1, G_2, G_3, and G_4 represent the images of discrete quantities of goods G_1, G_2, G_3, and G_4 transposed into characteristics space. The slope of the rays from the origin to each of the points indicates the relative proportions of C_1 and C_2 produced by each of the goods. The length of a ray is determined by the price of the good in question, given that there is a budget constraint. Rays extend further from the origin in a north-east direction as the prices of goods fall or the budget constraint is eased.[97]

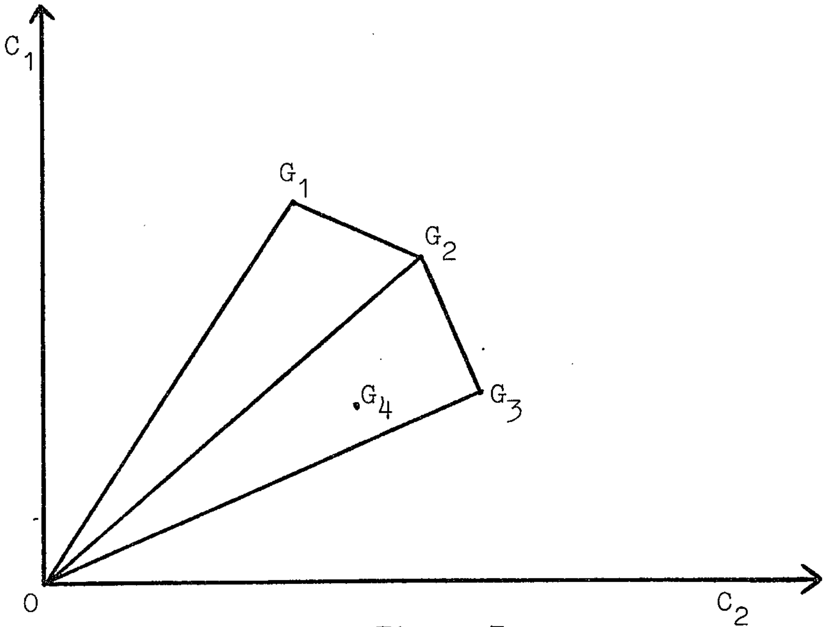

Figure 3

Characteristics Space When the Number Goods Exceeds the Number of Characteristics

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[97] Ibid., p. 54.

The points along the lines joining G_1, G_2, and G_3 form what Lancaster calls the efficiency frontier. This frontier represents collections of characteristics C_1 and C_2 which can be obtained and which would maximize a consumer's utility for a given budget constraint. This is true for any combination of G_1 and G_2, G_2 and G_3, or G_1, G_2, or G_3 consumed alone. The actual point chosen along the frontier will depend only on the consumer's preference for differing amounts of C_1 and C_2, not on his perception of the characteristics composition of the goods. Note that no rational consumer would choose G_4 since it is dominated by G_2. That is to say, he could obtain more of both C_1 and C_2 by choosing G_2 or some combination of G_2 and G_3.[98]

Suppose now, that new goods, represented by the points G_5, G_6, and G_7 in Figure 4 are introduced sequentially into the economy. All three goods also contain characteristics C_1 and C_2 but in different proportions to goods G_1-G_4. From Figure 4 it can be seen that with the appearance of G_5, the efficiency frontier would shift out somewhat, and would include vertices G_1, G_2, G_5, and G_3, as well as the points forming the lines or facets G_1 G_2, G_2 G_5, and G_5 G_3. No rational consumer would now purchase a combination of G_2 and G_3 since he could get more of at

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[98] Ibid., pp. 54-55.

least one characteristic and no less of the other by choosing a point on $G_2 G_5$ or $G_5 G_3$.

With the introduction of G_6, it can be seen that G_3 becomes an inefficient choice, since it is dominated by G_6. The efficiency frontier would now consist of vertices G_1, G_2, G_5, and G_6 and the lines joining them.

Finally, when G_7 comes onto the market, all other goods become inefficient, and all rational consumers would spend their entire budgets on G_7 since they could obtain more of both C_1 and C_2 than by the purchase of any combination of goods. In this case, the efficiency frontier would simply consist of the one point, G_7. It should be noted that in this

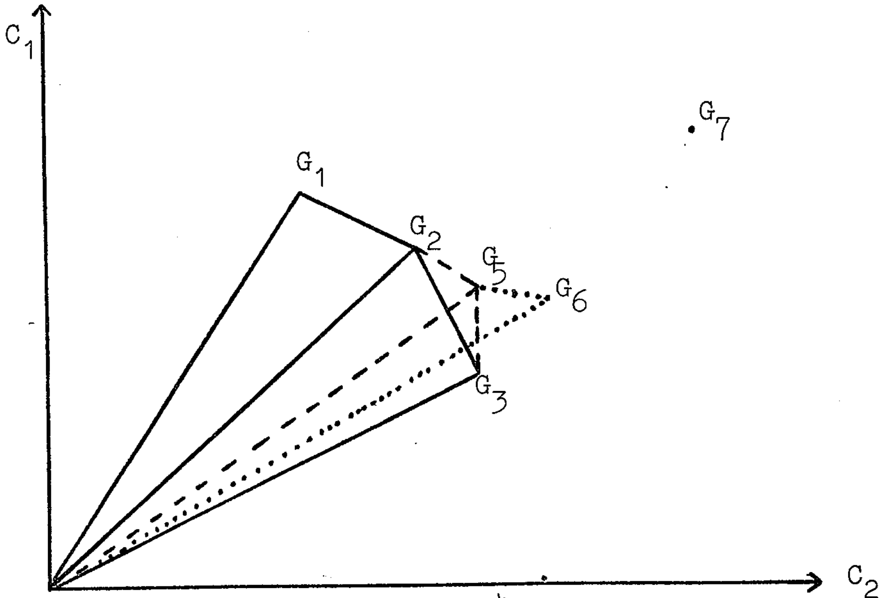

Figure 4

The Effect of the Introduction of New Goods into the Economy last, rather extreme case, it is required that a good like G_7 possesses something of all relevant characteristics.[99]

It seems then, that the shape of the efficiency frontier depends on the relative prices of the goods being considered. Changes in the shape of the frontier can come about through the introduction of new goods, as was illustrated above, or by changes in the relative prices of the goods already in the economy. It is important to remember that the position of a new good in the system depends more on its price than on the proportions of characteristics it contains.

Turning now to the case where the number of characteristics exceeds the number of goods, the shape of the efficiency frontier also changes with relative prices. If we consider the simple situation where there are two goods and three characteristics, as illustrated in Figure 5, an edge like VZ may form the frontier if both of the goods are efficient, or the frontier may consist of simple points like x or y if either G_1 or G_2, respectively, were dominant.[100]

From the preceding discussion it is apparent that regardless of the makeup of characteristics space, both the shape and composition of the efficiency frontier change as the relative prices of goods change. This change in the shape and/or composition is due to what Lancaster refers to as the efficiency substitution effect,[101] where one good is substituted

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[99] Ibid., pp. 55-56.

[100] Ibid., p. 57.

[101] Ibid.

for a combination of other goods, or conversely, a combination of goods replaces one good. In either case, this substitution effect is universal and objective because efficiency is the only criterion on which it is based. It is in no way dependent upon individual preferences.

However, in addition to the efficiency substitution effect, there is a private substitution effect which is dependent upon the individual's preference function. Also, since knowledge of individual preference is necessary for determining the actual choice of particular characteristics collections, it might be useful at this point to look at a particular preference model.

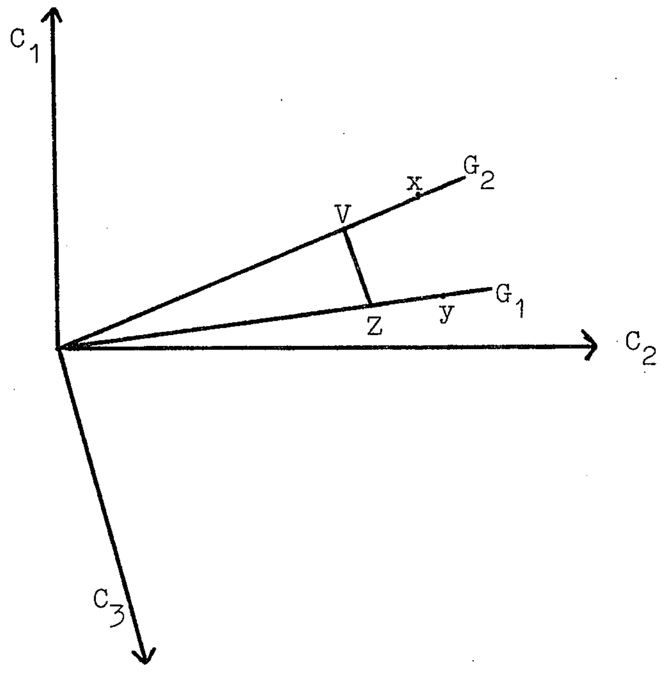

Figure 5

Characteristics Space When the Number of Characteristics Exceeds the Number of Goods

In developing his theory, Lancaster makes use of "...a simple preference model...based on Cobb-Douglas preference functions,[102] with each indifference curve[103] having the form (for r characteristics)

$$\prod_{i=1}^{r} C_i^{\alpha_i} = A$$

where A is a constant and $\Sigma\ \alpha_i = 1$."[104] This means that an individual preference function is defined by the choice of the indices. That is, different choices of the α_i's correspond to different preferences. It follows then, that the distribution of the α_i's over an entire population describes the preferences of that population.[105]

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[102] As Lancaster indicates in Consumer Demand (p. 73), there are two points which inhibit the use of the Cobb-Douglas preference function in a traditional model of the representative consumer. First, its homogeneity gives rise to unit income elasticities for both goods, and second, it has unit elasticity of substitution, so that the proportion of total income spent on each good depends only on the value of α and does not change with changes in either relative price or income. Lancaster justifies the use of the Cobb-Douglas preference function by calling attention to the fact that the drawbacks mentioned are less important in the case of an individual since the properties of aggregate demand are determined by the distribution of the preference parameter as well as the individual functions. What is really implied by the Cobb-Douglas form is that a given consumer's preferences fit this general form at each utility level. It is not necessary that a particular individual have the same preference parameter at different utility or income levels.

[103] Indifference curves in characteristics space are assumed to have the properties of monotonicity, non-intersection, and convexity to the origin, just like indifference curves in conventional goods space.

[104] Lancaster, Consumer, p. 72.

[105] Ibid., p. 73.

In the simplest formulation of the model, only two characteristics are considered. In this case, indifference curves for any individual would be described by

$$C_1^{\alpha} \; C_2^{1-\alpha} = A$$

where A = constant, $0 \leq \alpha \leq 1$. Since a variation in α defines an individual's preference variation, there is only one parameter, α, whose distribution need be considered. For the preference function above, a consumer for whom $\alpha = 0$ would be interested in only characteristic C_2, while a consumer for whom $\alpha = 1$ would only desire characteristic C_1.

Now, given an individual with the preference function detailed above, and a characteristics frontier with slope -m, as shown in Figure 6 below, then this individual will choose a point on the

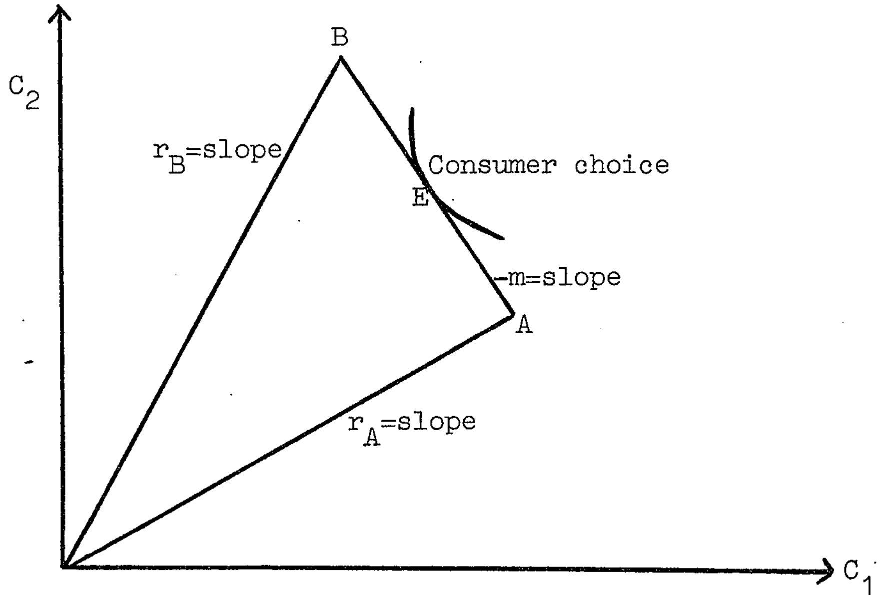

Figure 6 .

Consumer Choice for a Consumer with Preference Function $C_1^{\alpha} \, C_2^{1-\alpha}$ = A Given Characteristics Frontier BA characteristics frontier at which:

$$\frac{dC_2}{dC_1} = -m$$

where $\frac{dC_2}{dC_1}$ is taken along an indifference curve. Since

$$\frac{dC_2}{dC_1} = \frac{-\alpha}{1-\alpha} \; \frac{C_2}{C_1}$$

the consumer will select a facet point, say E, for which

$$\frac{C_2}{C_1} = \frac{1-\alpha}{\alpha} m$$

assuming such a point exists.

Point E will exist on facet AB for a consumer whose preferences are defined by a particular α value only if the ratio $\frac{C_2}{C_1}$ at E, where the indifference curve has slope $-m$, lies between the ratios r_A and r_B, where r_A and r_B are the slopes of rays from the origin to the vertex points A and B, respectively. As such, E will be a point on AB iff

$$r_B \geq \frac{1-\alpha}{\alpha} m \geq r_A$$

or

$$\frac{m}{m+r_B} \leq \alpha \leq \frac{m}{m+r_A}$$[106]

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[106] Ibid., p. 77.

If we consider an efficiency frontier such as that illustrated in Figure 7, an individual would choose a point, say F, which is a vertex at the conjunction of facets BF and FA, where the slope of a ray through the origin to point F is r, iff

$$\frac{m_A}{m_A+r} \geq \alpha \geq \frac{m_B}{m_B+r}$$

For this same individual to choose an upper end vertex such as B in Figure 7, the requirement would be that:

$$\frac{m_B}{m_B+r} \geq \alpha \geq 0$$

while for a lower end vertex, such as point A in Figure 7, to be chosen it would be necessary that:

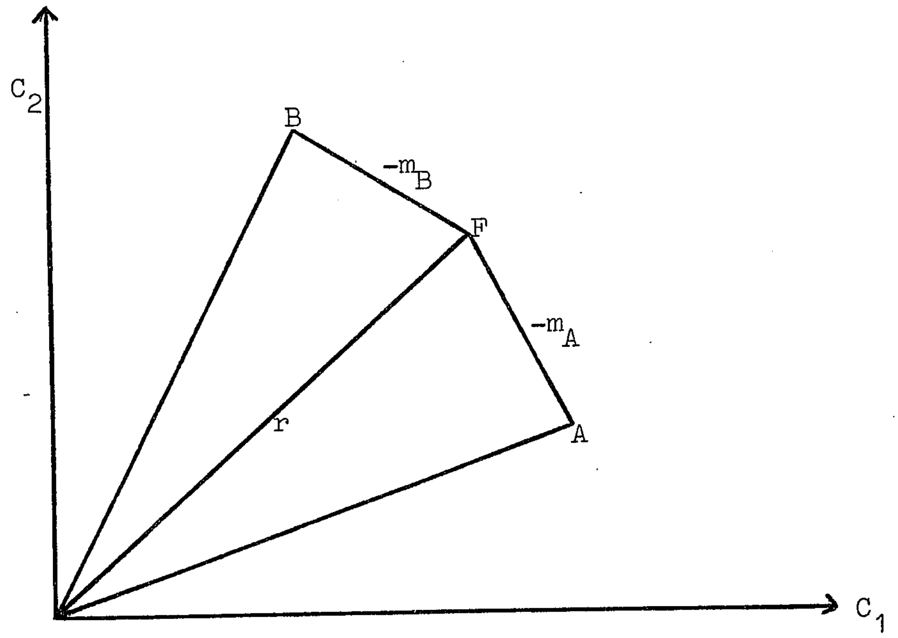

Figure 7

Consumers May Choose Points on Facets BF or FA, or on Vertices B, F, or A

$$1 \geq \alpha \geq \frac{m_A}{m_A+r}$$ [107]

Having set out the parameter limits for an individual to actually choose a collection of characteristics on a particular facet or characteristics frontier, it is now possible to examine the preference distribution over that characteristics frontier. If we let F (α) be the cumulative distribution function, then F (α) will designate the number of individuals whose preference parameters lie between 0 and α. The density function of F (α) is:

$$f(\alpha) = F'(\alpha)$$

so that

$$dF = f(\alpha)\, d\alpha$$

will indicate the number of individuals whose preference parameters lie between α and $\alpha + d\alpha$. "Then the total number of consumers who will choose a particular vertex, or a point on a particular facet is given by:

(a) For a facet:

$$\int_{\frac{m}{m+r_B}}^{\frac{m}{m+r_A}} f(\alpha)\, d\alpha$$

(b) For a vertex:

$$\int_{\frac{m_B}{m_B+r}}^{\frac{m_A}{m_A+r}} f(\alpha)\, d\alpha$$

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[107] Ibid.

(c) For an end vertex: $$\int_{0}^{\frac{m_B}{m_B+r}} f(\alpha)\, d\alpha \text{ or } \int_{\frac{m_A}{m_A+r}}^{1} f(\alpha)\, d\alpha$$ [108]

Now, since every facet is terminated either by its intersection with another facet or an end vertex, while every vertex is either an end vertex or the intersection of two facets, it follows that the total number of individuals on the characteristics frontier can be stated as:

$$\int_{0}^{\frac{m_A}{m_A+r}} f(\alpha)\, d\alpha + \int_{\frac{m_B}{m_A+r}}^{\frac{m_A}{m_B+r}} f(\alpha)\, d\alpha + \int_{\frac{m_A}{m_B+r}}^{\frac{m_B}{m_B+r}} f(\alpha)\, d\alpha +$$

$$\int_{\frac{m_B}{m_B+r}}^{1} f(\alpha)\, d\alpha = f(1)$$ [109]

In constructing a simple preference distribution model, if we assume both a uniform distribution of income so that average income is constant over the α's, and a rectangular distribution of preferences with constant density (which can be taken to be unity, so that $f(\alpha) = 1$, then the number of consumers on a facet like AB in Figure 6 will be given by:

$$\frac{\bar{m}}{m+r_A} - \frac{m}{m+r_B} \text{ or } \frac{m(r_A-r_B)}{(m+r_A)(m+r_B)}$$

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[108] Ibid., p. 78.

[109] Ibid.

By the same token, the number of consumers on a vertex at the intersection of two facets, such as point F in Figure 7, will be equal to:

$$\frac{m_A}{m_A+r} - \frac{m_B}{m_B+r} \text{ or } \frac{r(m_A-m_B)}{(m_A+r)(m_B+r)}$$ [110]

Before going on to an example to calculate the distribution of consumers along a particular characteristics frontier given a specific consumption technology and prices, it is important to note two important propositions which follow from the assumption of a rectangular preference distribution. The first result is that the distribution of consumers along any facet is uniform, in the sense that the line density along the facet is constant.[111] The second proposition, which assumes a uniform income distribution in addition to the rectangular preference distribution, states that the aggregate expenditure over all consumers on any facet will be equally divided between the two goods which correspond to the vertices terminating the facet.[112]

Now suppose we have the consumption technology for three goods and two characteristics given earlier in Table 1. That is:

$$Q = \begin{bmatrix} 5 & 4 & 1 \\ 1 & 3 & 4 \end{bmatrix}$$

For facility of calculation let the price of each good be fixed at unity. Then, the price vector associated with goods A, B, and D will be:

$$p = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}$$

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[110] Ibid., p. 79.

[111] Ibid.

[112] Ibid., p. 80.

Figure 8 illustrates the geometry of the efficiency frontier generated by the given consumption technology and prices. If it is assumed that the distribution of Cobb-Douglas preferences is rectangular with density 100 and uniform income distribution with unit average income, then the computation of aggregate demand will depend on the various ratios of the form m/m+r. The relevant ratios in absolute terms are:

$$R_1 = \frac{m_A}{m_A+r_A} = \frac{2}{2+.2} = .91$$

$$R_2 = \frac{m_A}{m_A+r_B} = \frac{2}{2+.75} = .73$$

$$R_3 = \frac{m_A}{m_A+r_B} = \frac{.33}{.33+.75} = .31$$

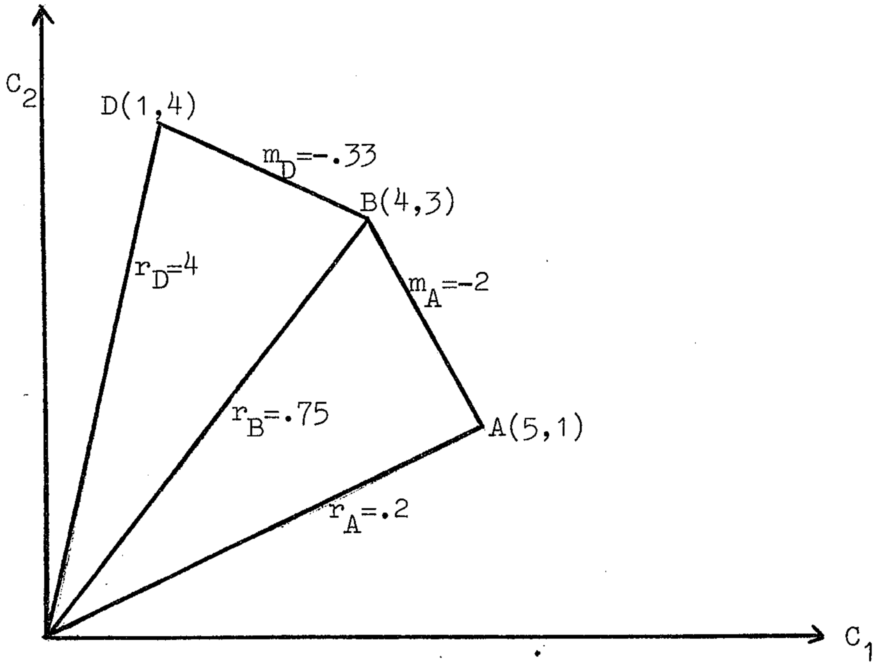

Figure 8

The Geometry of the Efficiency Frontier

$$R_4 = \frac{m_D}{m_D+r_D} = \frac{.33}{.33+4} = .08$$ [113]

The distribution of individuals over the characteristics or efficiency frontier is then given by:[114]

$$\text{Facet AB} = 100\ [R_1-R_2] = 18$$

$$\text{Facet BD} = 100\ [R_3-R_4] = 23$$

$$\text{Vertex A} = 100\ [1-R_1] = 9$$

$$\text{Vertex B} = 100\ [R_2-R_3] = 42$$

$$\text{Vertex D} = 100\ [R_4-0] = \underline{8}$$

$$\phantom{\text{Vertex D} = 100\ [R_4-0] =\ } 100$$

The relative sharpness of the angle at vertex B is the reason for the large number of consumers who select that characteristics collection. Because all individuals are assumed to have unit income, and because purchases by facet consumers are evenly divided between the goods corresponding to the vertices of the facet, the distribution of expenditure on the three goods can be calculated as follows:[115]

Good A (Vertex A + 1/2 Facet AB)	= 18.0
Good B (Vertex B + 1/2 Facet AB + 1/2 Facet BD)	= 62.5
Good C (Vertex D + 1/2 Facet BD)	= 19.5
	100.0

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[113] Ibid., p. 62.

[114] Ibid., p. 63.

[115] Ibid.

Finally, before turning to a closer examination of Quandt and Baumol's abstract mode formulation, it would be useful to look at how a change in the price of one good will affect the distribution of expenditure on all goods. Suppose, then, that the price of good B increases from 1 to $1 + \delta_{P_B}$ (where δ_{P_B} is very small). It follows that the amount of good B that can be purchased with unit income will decrease from 1 to $1 - \delta_{P_B}$ (neglecting second order terms).[116] The coordinates of vertex B' will change, as shown in Figure 9, from (4,3) to $4(1 - \delta_{P_B}), 3(1 - \delta_{P_B})$. This results in a change in the facet slopes m_A and m_D, and therefore, a change in the distribution of individuals over all three vertices as well

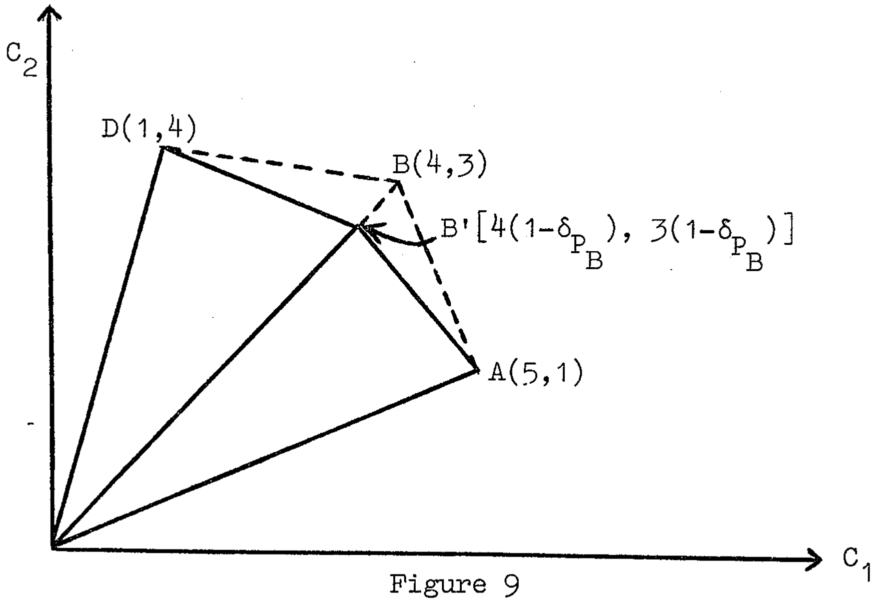

Figure 9

The Effect of a Price Change on the
Distribution of Expenditure

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[116] Ibid., p. 84.

as both facets. Using standard approximation methods it is possible to calculate the new slopes of m_A and m_B. The changes in the "R-ratios" can then be computed, and from these the changes in the number of individuals on each vertex or facet are obtainable. Intuitively, an increase in the price of good B should lead to a decrease in the number of consumers on vertex B and an increase in the number of consumers on the facets AB and BD as well as on the vertices A and D. This is in fact the case, according to Lancaster.[117]

It is the change in slope of the two facets which is responsible for this movement of some individuals from vertex B onto facets AB and BD, and of some individuals from the facets onto the end vertices A and D. It should be noted, however, that the expenditure on good B decreases by an amount that is less than the decrease in the number of consumers on B. This is due to the fact that there is a concurrent increase in the number of facet consumers, half of whose expenditure will be on good B. At the same time though, the decrease in the actual quantity of good B consumed will be greater than the decrease in expenditure as a result of the fact that the price of good B has increased.[118]

Having given a short explanation of the characteristics theory of demand, it remains to consider the relationship between the theory and the abstract mode concept developed by Quandt and Baumol. It is to this task, as well as a more detailed discussion of abstract mode models, that the next chapter is devoted.

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[117] Ibid.

[118] Ibid., p. 85.

CHAPTER 4

ABSTRACT MODE MODELS: PAST AND PRESENT

4.1 The Quandt and Baumol Model

The brief description of Lancaster's theory of demand which was furnished in the last chapter has application when considering Quandt and Baumol's abstract mode approach to transport demand, which was introduced earlier. Quandt and Baumol make use of the characteristics concept of demand in order to estimate the market potential for new or not yet existing transport modes. One of the problem areas which still remains is that, while a characteristics theory provides useful insights and justifies intuition in many cases, it "...does not provide a direct avenue to the mathematical form of the demand function."[119]

In actually formulating a model for passenger travel demand which can be tested, Quandt and Baumol suggest using an expanded gravity model of the form:

$$T_{kij} = \alpha_o P_i^{\alpha_1} P_j^{\alpha_2} Y_i^{\alpha_3} Y_j^{\alpha_4} M_i^{\alpha_5} M_j^{\alpha_6} N_{ij}^{\alpha_7} f_1(H) f_2(C) f_3(D) + \varepsilon \quad (1)$$[120]

where:

T_{kij} = number of trips along arc ij by mode k

P_i = population of node i

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[119] Quandt, "Introduction," p. 6.

[120] Quandt and Baumol, "Abstract Modes: Theory," p. 23.

P_j = population of node j

Y_i = mean income at node i

Y_j = mean income at node j

M_i = institutional (industrial) character index of node i

M_j = institutional (industrial) character index of node j

N_{ij} = the number of modes serving the area ij

$$f_1(H) = (H_{ij}^{b})^{\beta_0} (H_{kij}^{r})^{\beta_1}$$

$$f_2(C) = (C_{ij}^{b})^{\gamma_0} (C_{kij}^{r})^{\gamma_1}$$

$$f_3(D) = (D_{ij}^{b})^{\delta_0} (D_{kij}^{r})^{\delta_1}$$

where:

H_{ij}^{b} = the least required travel time between i and j

H_{kij}^{r} = the relative travel time between i and j by the kth mode

C_{ij}^{b} = the least cost of travel between i and j

C_{kij}^{r} = the relative cost of travel between i and j by the kth mode

D_{ij}^{b} = the best departure frequency between i and j

D_{kij}^{r} = the relative departure frequency between i and j by the kth mode.

ε = error term

Once an equation has been estimated on the basis of statistical information covering a sufficient number of nodal pairs, then the volume of shipments via the kth mode can be predicted for a particular arc by using the information available about the characteristics of the modes serving that arc. Suppose that the information from Table 6, which gave the absolute performance levels of modes A, B, and D, is used to construct Table 7, which indicates the relative performance characteristics of the modes. Suppose also that, for facility of calculation, instead of estimating a logarithmic function the rather simplistic hypothetical equation which has been estimated is:

$$T_k = -200 + 40\ C_b + 15\ S_b + 100\ C_{rk} + 300\ S_{rk} - 20N \qquad (2)$$

where the subscripts b and r refer to the best and relative performance levels for each characteristic respectively. If the predicted volume of shipments by the kth mode is denoted by M_k, then for the modes which are described in Table 1 and 2, the following volumes would result:

$$M_A = 175$$

$$M_B = 305$$

$$M_D = \underline{320}$$

$$800$$

Table 7

The Relative Performance Levels of
Three Transportation Modes

	Mode			Mode		
	A	B	D	A	B	D
Load Capacity (C)	5	4	1	1	.8	.2
Service Frequency (S)	1	3	4	.25	.75	1

Now, if a fourth mode, say E, with load capacity 4.5 and frequency of service equal to 6 is introduced, the values of C_b and C_r remain unchanged, but the value of S_b as well as the S_r values for all modes will change. Substituting these new values into equation (2), the results are as follows:

$M_A = 146$

$M_B = 240$

$M_D = 230$

$M_E = \underline{380}$

$\quad\;\; 996$

Two things are apparent from these results. The first is that the introduction of mode E led to an increase in the total traffic generated. The second result is that mode E has caused a redistribution of traffic among the existing modes. Thus, mode E seems to have captured a share of the traffic which was formerly accommodated by modes A, B, and D.

The preceding example was strictly hypothetical and was intended merely to demonstrate the methodology by which predictions can be made concerning new transportation modes.[121] The methodology described, which was first put forward by Quandt and Baumol, has a number of advantages. It enables one to predict the effect of the introduction of a new transport mode on every other mode. Furthermore, it allows for the introduction of

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[121] Ibid., pp. 17-18.

a new mode simply by specifying its relevant characteristics. Finally, the forecast of total transport demand is treated as a function of the transport alternatives available.[122]

However, problems still remain in any attempt to actually make use of the models put forward. The following comments which Lancaster makes about operationalizing his model of consumer demand apply with equal force to abstract mode models:

> Operational use of the model requires identification of the relevant characteristics and data on the consumption technology. Neither of these requirements is yet easily met, partly because of the conceptual problems of identifying relevant characteristics and partly because the appropriate data have not hitherto been available.[123]

4.2. The Netherlands Institute of Transport Model

A group at the Institute of Transport in the Netherlands discovered first hand how true Lancaster's statements were. They formulated an abstract mode model which was primarily intended to determine modal split in freight transport. The model was almost identical in form as well as variables to the model formulated by Quandt and Baumol presented earlier:

$$T_{kij} = \alpha_0 P_i^{\alpha_1} P_j^{\alpha_2} Y_i^{\alpha_3} Y_j^{\alpha_4} M_i^{\alpha_5} M_j^{\alpha_6} N_{ij}^{\alpha_7} f_1(H) f_2(C) + \varepsilon \qquad (3)$$

where:

Y_i = the gross regional product of node i

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[122] Ibid., p. 19.

[123] Lancaster, Consumer, p. 113.

Y_j = the gross regional product of mode j

and all other variables are defined as they were in equation (2). Unfortunately, when an empirical test of the model was attempted, data limitations required the form of the model to be changed such that the parameters became mode specific and the abstract mode property of the original model was lost.[124]

4.3 A Simplified Model Explained and Specified

Originally, the present study was intended to pick up where previous abstract mode studies left off in the sense that it aimed at an empirical assessment of the feasibility of introducing a new transport mode, airships, into the freight market. Unfortunately, the data which was required was not available. However, it might be illustrative to consider the intended study as an example of what would have been done had the necessary information been accessible. As such, recalling the characteristics approach to demand, it was assumed that LTA's fit into the group of goods, called transportation modes, which is defined by a number of relevant attributes, and that this group can be treated as being separate from the remainder of the consumption economy. It was also assumed that the consumption sub-technology for transportation modes is linear and additive. It followed, then, that the demand for the LTA mode would depend on its position with regard to the efficiency frontier for transportation modes, as well as on the distribution of shippers' preferences and transportation budgets.

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[124] Bayliss, Demand, p. 65.

In considering the shipment of freight by airships, say fresh produce from the United States to Canada, Figure 10 may help to illuminate the situation. Essentially, there are three technically feasible modes at present for continental transport (excluding water movement as well as mixed-modes such as piggy-back service), and these are labelled P, R, and T, corresponding to airplane, rail and truck, respectively. It is assumed, for ease of presentation, that there are only two attributes, C_1 and C_2, which are relevant for determining shipper's modal choices. It is known that no shipments of fresh fruit and vegetables from the United States to Canada are presently being made by airplane,[125] and it is assumed that this is because the rate charged

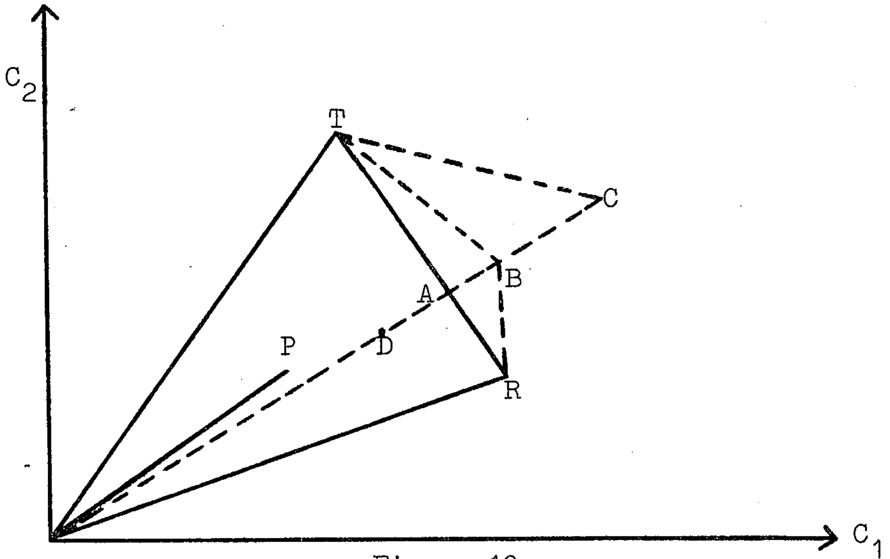

Figure 10

Transport Modes in Characteristics Space

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[125] Canada, Department of Agriculture, Production and Marketing Branch, Annual Unload Report, Fresh Fruits and Vegetables on Twelve Canadian Markets (Ottawa: Queen's Printer, 1953-1974).

by this mode is too high. Therefore, point P has been drawn as an inefficient point and for this reason does not appear as part of the efficiency frontier.

Now, suppose that the LTA mode possesses characteristics C_1 and C_2 in such proportions that its image points in characteristics space will be along the broken ray, OC, in Figure 10. The exact location of the point along OC will be determined by the price charged by the new mode. If the price is too high, then point D will result, and the airship will be an inefficient choice, and most likely will not be used. The highest price at which the LTA mode will be employed, even marginally (assuming that the prices of P, R, and T remain constant) would be that which just puts it on the efficiency frontier; that is, at point A in Figure 10. If the price for airships were lower, then point B might result, and shippers would be faced with choosing points on facets TB or BR or else choosing the vertex points T, B, or R. Finally, if the new mode had a price low enough such that point C were its image in characteristics space, the rail mode would suddenly be inefficient and rational shippers would choose points on facet TC or else vertex points T or C.

If a determination of the cost of freight transport by airship is neglected for the moment, then perhaps the most important task now is the selection of the modal attributes which are particularly pertinent to modal choice. In this regard, Bayliss puts forward a list of variables which have been ranked by European shippers according to their importance in modal selection, while Wood provides a similar ranking by North American shippers. Included among the variables mentioned by Bayliss, presented in the order of their importance to shippers are: certainty of delivery time, charge, speed and safety.[126] Wood indicates that service variables like travel time, time reliability and the probability of loss and damage seem to be the factors uppermost in the minds of North American shippers when considering choice of mode.[127]

Of the variables mentioned above, it would appear that freight charge and speed or travel time are the most easily measurable. Although the remaining variables are theoretically measurable, they require the kind of cooperation from shippers or transport firms which has to date not been forthcoming.

Now, the demand for freight transport between two locations as well as the demand for a particular mode will depend on the characteristics of the mode, such as those described above, and also on a number of variables which can be considered to be exogenous except over very long time periods. These exogenous variables may be socio-economic, geographic or demographic characteristics of the locations in question.[128] In considering this type of variable it was felt that those which have an important bearing on the demand for transport, as well as on modal split, include the population of the destination node, the per capita income in this node, and the distance between the origin and destination nodes.

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[126] Bayliss, Demand, p. 48.

[127] Woods and Domenisch, "Competition," pp. 268-269.

[128] Quandt and Baumol, "Abstract Modes: Theory," p. 16.

Even if all the variables which have been put forward, both those considered to be endogenous and those considered exogenous, are accepted as being relevant to the demand for transportation, a problem still remains. Since, as was mentioned earlier, Lancaster's theory does not furnish a direct articulation of the mathematical form for the demand function,[129] it is necessary to decide on the functional form which best expresses the relationship between the variables deemed relevant to and the demand for transportation. Following the lead of Quandt and Baumol, it is first assumed "...that the logarithm of the demand is linear in the logarithms of the variables."[130] The assumption is that the variables enter the equation multiplicatively rather than additively, and this seems to be a reasonable first approximation to more complex forms.[131] It should be pointed out, however, that it may be necessary to assume other forms which may better approximate the relationship which exists between the variables.

In natural numbers, then, the demand for transportation takes the form:

$$T_{kij} = \alpha_0 P_j^{\alpha_1} Y_j^{\alpha_2} D_{ij}^{\alpha_3} f_1(C) f_2(S) f_3(I) + \varepsilon \tag{4}$$

where:

T_{kij} = the demand for freight transport between nodes i and j by node k

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[129] Quandt, "Introduction," p. 6.

[130] Quandt and Baumol, "Abstract Modes: Theory," p. 16.

[131] G.C. Archibald and Richard G. Lipsey, An Introduction to a Mathematical Treatment of Economics (London: Weidenfeld and Nicolson, 1973), p. 61.

P_j = the population of destination node j

Y_j = the per capita income in destination node j

D_{ij} = the distance between nodes i and j

$$f_1(C) = (C_{ij}^{b})^{\beta_0} (C_{kij}^{r})^{\beta_1}$$

$$f_2(S) = (S_{ij}^{b})^{\gamma_0} (S_{kij}^{r})^{\gamma_1}$$

$$f_3(I) = (I_{ij}^{b})^{\delta_0} (I_{ij}^{r})^{\delta_1}$$

where:

C_{ij}^{b} = the shipping charge between i and j by the cheapest mode

C_{kij}^{r} = the charge for shipping between i and j by the kth mode relative to the cheapest

S_{ij}^{b} = the fastest transit time between i and j

S_{kij}^{r} = the transit time by the kth mode between i and j relative to the fastest

I_{ij}^{b} = the insurance charge between i and j for the mode with the lowest charge per dollar of shipment value

I_{kij}^{r} = the insurance charge between i and j by the kth mode relative to the lowest charge.

ε = error term

The important characteristic of a log-linear demand function is that it has a constant elasticity throughout its entire range, which is equal to the exponent α_i's.[132] If a logarithmic transformation is performed, equation (4) becomes:

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[132] Ibid., p. 137.

$$\log T_{kij} = \log \alpha_0 + \alpha_1 \log P_j + \alpha_2 \log Y_j + \alpha_3 \log D_{ij} + \beta_0 \log C_{ij}^{\,b} + \beta_1 \log C_{kij}^{\,r} + \gamma_0 \log S_{ij}^{\,b} + \gamma_1 \log S_{kij}^{\,r} + \delta_0 \log I_{ij}^{\,b} + \delta_1 \log I_{kij}^{\,r} \tag{5}$$

One of the important features of equation (5) is that the parameters, the α_i's, now represent demand elasticities. This is a very convenient result, because it is often useful to consider the relationship between the demand for transportation and one particular variable *ceteris paribus*. While transportation demand is assumed to be a function of a number of variables, it is of interest to isolate the effect of one variable alone.[133]

In addition, the fact that this demand function is linear in its logarithmic form makes it amenable to estimation by the relatively uncomplicated and inexpensive procedure of ordinary least squares (OLS). In estimating the parameters of the demand model, the form of the equation will be transmuted from the deterministic form presented in equations (4) and (5) to the stochastic or probablistic form of equation (6):

$$\log T_{kij} = \log \alpha_0 + \ldots, + \delta_1 \log S_{kij}^{\,r} + \mu \tag{6}$$

where:

μ = the error term,[134] and all other variables have the same meaning as in equation (5)

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[133] J.S. Cramer, *Empirical Econometrics* (New York: American Elswier Pubishing Company Inc., 1971), p. 77.

[134] The error term is assumed to be a random variable with the following properties:

(footnote 134 continued on p. 65)

If the estimating equation satisfies the requirements of the Gauss-Markov least-squares theorem,[135] then the distribution of the OLS estimate of any of the parameters in equation (6) will be centred around the true parameter value; that is, all the estimates are unbiased.[136] Furthermore, the OLS estimates are the least variance estimates compared with any other linear unbiased estimate obtained by other econometric methods.[137] Now, an estimate which is unbiased and has minimum variance of all linear unbiased estimates is referred to as the Best Linear Unbiased Estimator (BLUE).[138] It must be stressed, however, that while the OLS estimates are BLUE, there might be nonlinear or biased estimators from other econometric methods which have a smaller variance.[139] However, "...we restrict ourselves to linear estimates because they are easy to analyse and understand..."[140]

(footnote 134 continued)

$$E(\mu_j) = 0 \qquad j = 1, \ldots, n \qquad (1)$$

$$E(\mu_j^2) = \sigma^2 < \infty \qquad (2)$$

$$E(\mu_i \mu_j) = 0 \qquad i \neq j \qquad (3)$$

$$E(X_{jy} \mu_j) = 0 \qquad (4)$$

A. Koutsoyiannis, Theory of Econometrics (London: The Macmillan Press Ltd., 1973), p. 113.

[135] In addition to the assumptions already stated about the error term in note 134 the Gauss-Markov theorem requires that all explanatory variables be measured without error and that they be truly independent.

[136] P. Rao and R. Miller, Applied Econometrics (Belmont, California: Woodsworth Publishing Co., 1971), p. 28.

[137] Koutsayiannis, Theory of Econometrics, p. 106.

[138] Ronald J. Wonnacott and Thomas H. Wonnacott, Econometrics (New York: John Wiley & Sons, Inc., 1970), p. 21.

[139] Koutsayiannis, Theory of Econometrics, p. 106.

[140] Wonnacott and Wonnacott, Econometrics, p. 21.

While the model which has been put forward may be a reasonable compromise between reality and necessity, the variables which are included in any formulation will be dependent on the nature of the commodity to be shipped as well as on the availability of data. It is somewhat discouraging that even employing what may be considered to be the simplest form of the model, the information necessary to test the model was unobtainable. It is felt, however, that the model will be operational in the future as information in the required form becomes more readily available. In the meantime, an attempt will be made in the next chapter to establish a method for estimating airship cost and performance features in anticipation of the day that the abstract mode model can be employed to determine the potential demand for airship services.

CHAPTER 5

AIRSHIPS AT WHAT COST

5.1 Coughlin's Airship: Design, Engineering and Cost

Determining the cost of operating a modern-day airship entails more than simply calculating the direct cost of inflight operation. One must also take into consideration the initial start up costs as well as the costs associated with ground support functions. Of equal, if not more, importance in any cost model are the assumptions which are made regarding airship design and performance requirements. Since the studies examined in Chapter 2 offered no ready concensus regarding airship performance and technical relationships, it was decided to make use of many of the assumptions employed by Coughlin in this regard to determine airship costs.[141]

In his examination of the feasibility of introducing airships into the British freight market, Coughlin emphasized the importance of integrating performance criteria into any design.[142] He developed two criteria for such integration, one based on maximizing work capacity and the other based on cost effectiveness. After considering maximizing work capacity, Coughlin concluded that his approach gave rise to inefficiency due to the airship's relatively poor aerodynamic design.[143] Thus, Coughlin decided

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[141] Coughlin, Appraisal, p. 71.

[142] Ibid., p. 5.

[143] Ibid., p. 9.

that cost effectiveness would be the more appropriate design criterion.

In assessing airship design in terms of performance, Coughlin made use of the concept of net present value such that:

$$NPV = C_f \frac{1-(1+r)^{-n}}{r} - C_0 \qquad (1)$$ [144]

where:

C_f = cash flow/year

C_0 = airship initial cost

r = interest payable on capital

n = airship life in years.

Substituting $C_f = C_R - C_C$ and $C_R = (F)(T)$

where:

C_R = cash revenue/year

C_C = cash cost/year

F = break even freight charge/unit

T = number of units carried/year

into equation (1) gives:

$$NPV = (FT-C_C)\left(\frac{1-(1+r)^{-n}}{r}\right) - C_0 \qquad (2)$$ [145]

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[144] Ibid., p. 10.

[145] Ibid., p. 79.

If the relationship expressed in equation (2) is viewed in cost terms only, the theoretical optimum could be expressed as:

$$NPC = 0 = (FT-C_C)\,\frac{1-(1+r)^{-n}}{r} - C_0 \quad ^{146} \qquad (3)$$

Using simple algebraic manipulation equation (3) can be transformed to yield:

$$F = \frac{1}{T}\,\frac{\dfrac{C_0}{\;}}{\dfrac{1-(1+r)^{-n}}{r}} + C_C \quad ^{147} \qquad (4)$$

Thus, Coughlin has managed to provide a basis for airship freight charges in terms of airship initial cost, operating cost, and the volume of freight moved per year.

In pursuing initial cost, Coughlin divides the cost associated with building an airship into three parts: shell cost, gas cost, and power plant cost. He maintains that these costs may be described as follows:

$$\text{Shell cost} = C_S = (W_C)\,(\tfrac{u}{10})\,(2240) \qquad (5)$$

where:

W_C = empty weight - power plant weight in tons

u = cruise speed in MPH

$$\text{Gas cost} = C_G = V_G(C_H) \qquad (6)$$

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[146] Ibid.

[147] Ibid., p. 11.

where:

V_G = gas volume in ft.^{3}

C_H = cost of helium

Power plant cost = $C_P = P(20)$ [148] (7)

where:

P = installed power

Breaking the shell cost down further, W_C may be expressed as:

$$W_C = W_{ST}+W_{PR}+W_F+W_{FT}+W_{FW}+W_H \tag{8}$$

where:

W_{ST} = weight of hull structure

W_{PR} = propellor weight

W_F = fuel weight

W_{FT} = fuel tank weight

W_{FW} = fixed weight (i.e., controls, instruments, cabin, etc.)

W_H = weight of cargo handling equipment

A more detailed examination of the variables contained in equation (8) gives rise to the following:

$$W_{ST} = S_{WET}(t_e)(W_M) \text{ [149]} \tag{9}$$

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[148] Ibid., p. 80.

[149] Coughlin neglects to include density of the hull material in equation (9).

where:

S_{WET} = wetted surface area

t_e = shell thickness of the airship

$[W_M$ = density of the hull material$]$

$$W_{PR} = (.24)(P) \tag{10}$$

where:

P = installed power

$$W_F = \frac{(P)(R)(sfc)}{u} \tag{11}$$

where:

P = installed power in bhp

R = refuelling range

sfc = specific fuel consumption in lbs./HP/hour

u = flight speed in miles/hr.

$$W_{FT} = .0024\ W_F \tag{12}$$

$$W_{FW} = \text{assumed to be 10 tons} \tag{13}$$

$$W_H = .02xW_{DISP} \tag{14}$$

where:

W_{DISP} = wt. of payload + weight of fuel

Substituting back into equation (5) yields:

$$C_S = 224\ u\ [(S_{WET})(t_e\ W_M)+(.24PSW) + \frac{PRsfc}{u} + .0024\ \frac{PRsfc}{u} + .02\ W_{DISP} + 10] \tag{15}$$

Turning now to the cost of gas, $C_G = V_G\ C_H$, V may be expressed as:

$$V_G = \frac{W}{.0628} \tag{16}$$

where:

$$W = \text{the total displacement weight of the airship} = W_C + W_{PP} \tag{17}$$

where:

$$W_{PP} = \text{power plant weight} = PxSW \tag{18}$$

where:

P = installed power

SW = specific weight in lbs./hp.

W_C = defined as in equation (5)

Substituting back into equation (16) gives:

$$C_G = \left[\frac{S_{WET}t_eW_m + .24\ PSW + 1.0024\ \frac{PRsfc}{u} + .02\ W_{DISP} + 10 + PSW}{.0628}\right] .C_H \tag{19}$$

Finally, assuming that the installed power required will be only that necessary to overcome aerodynamic drag, power plant cost, $C_P = Px20$ can be expressed as:

$$C_{P-} = (D)(u)(20) \tag{20}$$

where:

$$D = \text{drag} = 1/2\ \rho\ u^2\ S_{WET}xC_D \tag{21}$$

where:

ρ = air density

u = cruise velocity

S_{WET} = wetted surface area

C_D = drag coefficient

Now, the wetted surface area, S_{WET}, is the total external area of the airship which is exposed to airflow, and may be expressed as:

$$S_{WET} = [3.73\ R^{1/3}+.8]V^{2/3} \qquad (22)$$

where:

R = the length to diameter ratio of the airship

V = hull volume = $V_G\left[\frac{1}{1-\frac{.026}{10^3} \times \text{altitude}}\right]$

The drag coefficient, C_D, was assumed by Coughlin to have a value of .0025 for all R values.

Thus, substituting back into equation (7),

$$C_P = 1/2\ P\ u^3\ [3.73R^{1/3}+.8]V^{2/3} \times .0025 \times 20 \qquad (23)$$

While further substitution could be made into equations (15) and (19), it was decided that this operation would not be performed later, if at all. First, annual operating cost, C_R, will be examined.[150]

Coughlin's estimation of annual operating costs may be stated as follows:

$$C_C = C_F+C_W+C_M+C_I\ ^{151} \qquad (24)$$

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[150] Coughlin, Appraisal, pp. 60-65.

[151] Ibid., p. 80.

where:

C_C = total operating cost/year

C_F = cost of fuel/year

C_W = crew wages/year

C_M = maintenance costs/year

C_I = insurance cost/year

Fuel cost per year may be expressed as:

$$C_F = (P)(sfc)(O_h)(P_F) \qquad (25)$$

where:

P = power

sfc = specific fuel consumption

O_h = operational hours

P_F = price of fuel

Coughlin arbitrarily states both maintenance and insurance costs as a function of the initial cost of constructing an airship, with the former cost being 4 percent and the latter 1 percent of the initial airship cost. Crew wages are also determined in an arbitrary but unspecified way.

To obtain a value for airship freight charges, all that is required is to determine the volume of freight which airships could carry in a year. Coughlin states that the payload carried per year, T, can be calculated as follows:

$$T = \frac{(P_y)(u)(O_h)}{S_L} \qquad (27)$$[152]

where:

P_y = payload

S_L = stage length

5.2 Coughlin's Airship Relationships Modified

A comparison of Coughlin's cost model with that proposed by Hill reveals that the former does not consider all the elements contained in the latter. Of special interest in Hill's model is the inclusion of research and development costs, as well as greater emphasis on airship support systems. Thus, while Coughlin's work provides the best procedure for estimating airship freight charges based primarily on the cost of constructing an airship, it seems that a more complete picture of airship costs, and hence required charges, could be obtained by extending Coughlin's model to include more of the direct and indirect costs associated with airship operation. As such, a model which retains Coughlin's basic relationships but expands upon them appears below:

$$F = \frac{1}{T}\left[\left(\frac{R_o/A+C_o+C_E+C_{FA}}{\frac{1-(1+r)^{-n}}{r}}\right) + C_C + C_{HR}\right] \qquad (28)$$

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[152] Ibid., p. 82.

where:

F = freight charges

T = freight carried/year in tons

R_O = research and development costs

A = the number of airships in the production run

C_O = the initial cost of constructing an airship as defined above

C_E = the cost of specialized equipment such as mooring masts, ground handling equipment, etc.

C_{FA} = cost of facilities

C_C = annual airship operating costs

C_{HR} = cost of helium replacement/year.

In addition, a number of changes were made in calculating the costs of constructing and operating an airship. With regard to the former, the shell cost, C_S, was calculated as:

$$C_S = W_S \times \$140{,}000/\text{ton} \qquad (29)$$

The structure cost of $140,000/ton was conceived to be a compromise between the empty weight cost of a commercial airplane, $260,000/ton for the Boeing 727,[153] and the cost of an aluminum glider, $40,000/ton.[154] It was felt that, if anything, this figure used to compute airship

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[153] Personal communication, Greg Nordal, marketing analyst, Boeing of Canada Ltd.

[154] Personal communication, Dr. J. Tinkler, Department of Mechanical Engineering, University of Manitoba.

structure cost is on the high side, since the low velocity airship will have to endure stresses and loads which more closely resemble those encountered by gliders than those faced by high velocity jet aircraft. As well, the cost of the power plant was determined by fitting a particular engine to the needs of the airship and obtaining the cost of this engine.[155]

With regard to airship operating costs, crew wages were determined as:

$$C_W = C_{FC} + C_{GH} x H_{GH} \tag{30}$$

where:

C_W = crew wages/year

C_{FC} = annual salary of flight crew (pilots and co-pilots)

C_{GH} = average wage rate of ground crew (maintenance and cargo)

H_{GH} = number of hours ground crew work

Before any calculation of the actual freight rate is attempted, the assumptions which have been made regarding airship size, design and performance features will be specified. It should be noted that many of the assumptions which appear below in Table 8, especially those pertaining to the technical engineering relationships, are drawn mainly from Coughlin's study directly or represent modifications or updates thereof. However, in addition to design and performance assumptions, such things

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[155] Personal communication, Mr. Dave Maxfield, Standard Aero Ltd.

Table 8

Airship Design, Operating and Cost Assumptions

Parameter	Assumption
Research and development cost (R_o)	various
Cruise speed (u)	various
Gross lift	1000 tons
Normal lift	900 tons
Disposable load	515 tons
Payload	various
Load factor	75 percent
Fuel weight (includes 33 percent reserve)	various
Range	2000 miles
Altitude	3000 feet
Length	1263 feet
L/D	6
s.f.c.	.502 lb./HP/hour
s.w.	.38 lb./HP
Min. t_e (shell thickness)	.06 inches
F (structural efficiency)	1.26
Tr (transmission efficiency)	.85
K (max. speed/cruise speed)	1.1
Utilization	5000 hours/year
Interest on capital	13 percent
Vehicle life	10 years
Structure cost	$140,000/ton
Fuel cost	$180/ton (67.78¢/ Imp. gal.)
Gas volume	31,847,134 cubic feet
Gas cost	7¢/cubic foot
Crew wages (3 crews, 3 man crew)	$497,333/year
Maintenance cost	4% of initial cost
Insurance cost	10% of initial cost

as research and development costs as well as the cost of support and replacement systems must also be taken into account. With regard to the former, there did not seem to be any clear cut criteria upon which to base cost estimates, and thus a number of avenues were explored.

The most promising attempt to obtain factual research and development costs involved contacting Aerospace Development Corporation, a British firm which had contracted to deliver 22 small to medium size airships to Venezuela. Unfortunately, repeated promises by a company representative to send all pertinent research and development information were never fulfilled. As a result, the only data available, which appears in Table 9, were gleaned from Jane's All The World's Aircraft 1978-79[156] as well as from an article in Transport/78.[157] From the scant information available, it can be readily seen that none of it pertains to research and development unless one were to consider the AD500 as a research prototype for a larger craft, which it is not. Turning, then to construction, any attempt to estimate the cost of an airship with a disposable load of over 500 tons based on the cost of the AD500 would be somewhat questionable. However, it must be noted that the construction cost for the AD500, $160,000/ton, is not too far removed from the $140,000/ton used in this study.

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[156] J.W.R. Taylor, ed., Jane's All the World's Aircraft, (London: Jane's Yearbooks, 1979), p. 601.

[157] Nancy Coldham-Gracey, "Airships--Have We Seen the Last of Them?" Transport/78, Vol. 1, No. 2, Fall 1978, p. 18.

Table 9

Aerospace Developments AD500 Specifications

Design	
Length	165 feet
Maximum Diameter	45 feet, 8 1/2 inches
Gross Volume	180,000 cubic feet
Maximum design gross weight	9375 pounds
Empty weight	5560 pounds
Payload capacity + fuel weight	3875 pounds
Performance (estimated at 1000 feet cruising altitude)	
Maximum level speed	71 MPH
Maximum cruising speed	64.5 MPH
Normal cruising speed	57.5 MPH
Normal range	345 miles
Costs	
Construction Cost	$450,000 ($160,000/ton)
Direct operating cost	$20/hour

Source: Jane's All the World's Aircraft, ed. J.W.R. Taylor, p. 601, and Nancy Coldham-Gracey, "Airships--Have We Seen the Last of Them?" Transport/78, Vol. 1, No. 2, Fall 1978, p. 18.

Attempts to contact other airship companies, including the Canadian Airship Development Corporation and Goodyear Aerospace, produced nothing in the way of tangible results. As such, it was decided to examine the research and development costs associated with bringing the Concorde aircraft up to commercial licensing standards. However, the $2.4 billion (1975 $)[158] price tag attributed to its conception and development was considered to be higher than that anticipated for the airship since the level of technological sophistication associated with the latter is far lower than that associated with a craft such as the Concorde. For this reason, it seemed that the cost of developing the Boeing 747 might be more in line with airship costs, since the development of the wide-bodied aircraft did not require the quantum leap in technology required for the Concorde. However, the current value of the $750 million (1969 $) Boeing research and development expenditure,[159] $1.5 billion, seemed to be on the high side as well. As such, it was determined to make use of two arbitrarily chosen estimates of airship research and development costs, $1 billion and $100 million. As well, it was decided to spread these costs over production runs of two and ten airships to see what effect this would have on airship freight charge.

Besides research and development costs, another important factor to be considered is the cost associated with ground handling and related facilities, or the ground support system. The easiest way to deal with this aspect of the cost equation is to arbitrarily assign it a value

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[158] <u>Facts on File</u> (New York: Facts on File, Inc., 1975), p. 843.

[159] Ibid., p. 843.

dependent upon the first cost of the airship. Howe follows this route and ascribes a value of 2 percent of the initial airship cost to the ground operation.[160] The more difficult determination of ground support costs involves itemizing the structures and equipment which will be required and then estimating their costs. While this latter method should theoretically provide more accurate cost figures, the uncertainty involved in the cost of specialized equipment, such as mooring masts and loading equipment, tends to render any cost estimates obtained by this method as imprecise as that obtained by Howe's method. In view of the additional work involved without any guarantee of increased accuracy, it was decided that the second method would not be employed. As such, Howe's value of 2 percent of the initial cost was adopted for the cost of ground handling equipment and facilities.

5.3 Airship Freight Rates Estimated

Having examined some of the more important assumptions which were made, it seems reasonable at this point to present the estimates of airship freight rates which were derived. It should be mentioned that due to the uncertainty surrounding many of the variables important to any cost and rate determination, it was decided to employ varying assumptions regarding some of these variables, specifically research and development costs and the cruise speed of the airship. Various values were attributed to the former because it was felt that the least hard

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[160] Howe, Feasibility, p. 18.

information was available regarding it, and also because it had no direct or indirect impact on almost all the other variables in the freight charge equation, and this impact was measurable without too much difficulty. It is for this reason that various speeds were used to calculate the rate to be charges for airship services.

Now, it can be seen that Table 10, which contains the estimates of airship freight rates, is divided into four sections. In each of the sections, the research and development costs have been held constant, while the cruise speed of the airship has been varied. Thus, at a cruise speed of 116 MPH and an R_o value of $500 x 10^6/airship, the value of F is 75.09¢/ton mile, while a cruise speed of 60 MPH coupled with the same R_o value yields a value of 103.28¢/ton mile for F. Moving down the table, the value assumed for R_o decreases, such that a cruise speed of 116 MPH in the fourth group, where R_o is assumed to be $10 x 10^6/airship, gives rise to an F value of 14.92¢/ton mile compared with the 75.09¢/ton mile indicated earlier for the same speed in the first group. Thus, it is evident that the actual research and development costs will greatly affect the rate which airships will charge for freight movement, as will the production run over which these costs are spread.

In addition, as was mentioned earlier, the F value within a group is quite dependent upon the cruise speed envisaged for the airship. It should be noted, however, that for all groups but the first, the minimum freight charge is achieved at a cruise velocity of 100 MPH, indicating that there is indeed a trade-off between the extra ton miles

Table 10

Estimates of Airship Freight Rates

Cruise Speed (MPH)	No. of Engines	Range (miles)	Fuel Wt. (tons)	Payload (tons)	No. of Airships	R & D Cost/Airship R_0	Initial Cost C_0	Cost of Ground Support $C_E + C_{FA}$	Annual Operating Costs C_C	Helium Replacement C_{HR}	Freight Volume (ton miles/yr) T	Freight Charge (¢/ton mile) F
116	6	2,000	170	345	2	$\$500 \times 10^6$	$54,051,683	$1,073,406	$9,835,869	$557,325	1.50075×10^8	75.09
100	4	2,000	132	383	2	$\$500 \times 10^6$	$53,204,221	$1,059,000	$7,581,513	$557,325	1.43625×10^8	76.79
75	2	2,000	88	427	2	$\$500 \times 10^6$	$52,356,760	$1,044,593	$5,327,159	$557,325	1.20094×10^8	89.82
60	1	2,000	56	459	2	$\$500 \times 10^6$	$51,933,030	$1,037,390	$4,199,983	$557,325	1.03275×10^8	103.28
116	6	2,000	170	345	10	$\$100 \times 10^6$	$54,051,683	$1,073,406	$9,835,869	$557,325	1.50075×10^8	25.97
100	4	2,000	132	383	10	$\$100 \times 10^6$	$53,204,221	$1,059,000	$7,581,513	$557,325	1.43625×10^8	25.46
75	2	2,000	88	427	10	$\$100 \times 10^6$	$52,356,760	$1,044,593	$5,327,159	$557,325	1.20094×10^8	28.44
60	1	2,000	56	459	10	$\$100 \times 10^6$	$51,933,030	$1,037,390	$4,199,983	$557,325	1.03275×10^8	31.90
116	6	2,000	170	345	2	$\$50 \times 10^6$	$54,051,683	$1,073,406	$9,835,869	$557,325	1.50075×10^8	19.83
100	4	2,000	132	383	2	$\$50 \times 10^6$	$53,204,221	$1,059,000	$7,581,513	$557,325	1.43625×10^8	19.05
75	2	2,000	88	427	2	$\$50 \times 10^6$	$52,356,760	$1,044,593	$5,327,159	$557,325	1.20094×10^8	20.76
60	1	2,000	56	459	2	$\$50 \times 10^6$	$51,933,030	$1,037,390	$4,199,983	$557,325	1.03275×10^8	22.98
116	6	2,000	170	345	10	$\$10 \times 10^6$	$54,051,683	$1,073,406	$9,835,869	$557,325	1.50075×10^8	14.92
100	4	2,000	132	383	10	$\$10 \times 10^6$	$53,204,221	$1,059,000	$7,581,513	$557,325	1.43625×10^8	13.91
75	2	2,000	88	427	10	$\$10 \times 10^6$	$52,356,760	$1,044,593	$5,327,159	$557,325	1.20094×10^8	14.63
60	1	2,000	56	459	10	$\$10 \times 10^6$	$51,933,030	$1,037,390	$4,199,983	$557,325	1.03275×10^8	15.84

generated due to higher speed, and the extra costs incurred due to the higher speed. From the table, it can be seen that the absolute minimum freight charge, 13.91¢/ton mile, occurs when research and development costs of $\$100 \times 10^6$ are distributed over 10 airships which cruise at 100 MPH. While "fine tuning" the cruise speed would most likely lead to a slight reduction in the minimum freight charge, it was felt that the results obtained were sufficiently accurate for the purposes of this study.

CHAPTER 6

CONCLUSION

6.1 Summary

In the previous chapters an attempt was made to formulate a methodology for evaluating the airship's potential in the commercial freight market. Two separate and distinct parts were involved. First, after briefly reviewing the literature pertinent to estimating the demand for transportation as well as the determinants of modal split in Chapter 3, an abstract mode model was presented in Chapter 4 which could be used to estimate the demand for airship services in a particular market. In addition, Chapter 3 contained an extensive discussion of the theory upon which the abstract mode model is based. The second part of formulating the methodology was initiated in Chapter 2 with an examination of some of the more substantial studies which have recently been carried out to ascertain plausible airship cost and service characteristics. Following this, a model for determining airship cost structure, was presented. Finally, various estimates of airship rates were calculated employing differing assumptions regarding initial airship cost and performance characteristics. These were presented in Chapter 5.

6.2 The Airship in the Present Freight Market

Having estimated a range of airship freight rates in Chapter 5, logically the next step should have been to make use of the abstract mode model which was presented in Chapter 4 to predict the amount of freight traffic, both old and new, which the airship might be expected to handle when it came into being. Unfortunately, a necessary requisite of the prediction process, the estimation of the parameters of the abstract mode model, has not been fulfilled due to the fact that the data necessary for such a determination were unobtainable. As such, no attempt could be made at this time to evaluate the potential market for airship services.

While no formal estimation of the demand for airship services was undertaken, a brief appraisal of airship costs and capabilities compared with rail, truck and airplane revealed that even at the lowest estimated rate, airships were still more expensive on a ton-mile basis than either rail or truck, but were less expensive than airplane. However, Table 11 indicates that while airships are somewhat slower than airplanes, they offer a faster delivery time than either road or rail freight movement by a fairly significant margin. Thus, while it is impossible to draw any definite conclusions regarding the "cost versus time" decisions which shippers will make, it does not seem unreasonable to say that the airship seems to offer a reasonable alternative to existing modes, especially in the movement of commodities where speed is an important factor.

While nothing concrete can be said about the commercial viability of the freight airship, the model which was employed to calculate airship freight rates, although somewhat incomplete, seems to offer a reasonable method for any further determination of airship charges. It must be kept in mind that the results which are obtained are highly sensitive to the quality of the data which are used, and, as such, the accuracy and

Table 11

Comparative Rates and Delivery Times: Airships, Trains, Trucks and Airplanes

	C_G[1]	C_S[2]	C_L[3]	C_O[4]	T[5]
Airship	13.91- 31.90[6]	13.91- 31.90[6]	13.91- 31.90[6]	13.91- 31.90[6]	2nd-3rd morning
Rail				5.35[7]	13th-16th morning[6]
Truck	4.76- 8.05[8]	4.76- 8.05[8]	5.73- 9.70[8]	4.76- 8.05[8]	4th morning[7]
					same day of
Airplane	33.50[9]	33.50[9]	33.50[9]	33.50[9]	2nd morning

[1] Cost of transporting grapes, ¢/ton mile.

[2] Cost of transporting strawberries, ¢/ton mile.

[3] Cost of transporting lettuce, ¢/ton mile.

[4] Cost of transporting oranges, ¢/ton mile.

[5] Delivery time.

[6] The range of airship freight charges given here does not include those estimated assuming a research and development cost of $1 billion spread over two airships.

[7] Rate and time on movement of the commodity from California to Winnipeg courtesy Burlington Northern Railway.

[8] Rates and time on movement of the commodity from California, Florida and Texas to Winnipeg furnished by Pacific Midwestern Express Lines.

[9] Rates and time on movement from California to Winnipeg courtesy Air Canada.

reliability of the estimates which are made will improve as more accurate information becomes available regarding airship structures. For the present, however, the costing model has served to illustrate that airships appear to have the potential to become a competitive transport mode.

6.3 Future Research Possibilities

Unfortunately, little can be said about the viability of the abstract mode model in the demand model market. The fact that the data required to test the model were not available may indicate a poor choice of commodities to be tested as much as it may underline the difficulties involved in using this type of model. In any case, while the theory and methodology involved in formulating the model seem feasible, its application to the freight market may be an idea whose time has not yet arrived. In order to ascertain whether or not the abstract mode model has practical application, it is recommended that future research be directed toward estimating the parameters of a model of this type using different commodity movements and possibly different existing modes, such as ship or airplane. However, it should first be determined beforehand that data in a form suitable for use with the abstract mode approach is available in sufficient quantity to complete any study which is undertaken.

While very little of a conclusive nature has emerged from this study concerning the airship's ability to compete in the transport market, the worsening energy crisis should enhance the airship's potential for successful penetration of the freight market. As such, it would seem to be worthwhile to determine the oil price at which the airship could compete against trucking strictly on a cost per ton mile basis.

In addition, while the present study may have provided airship freight charges of the correct order of magnitude, the most urgent requirement at this time is a more precise determination of the costs of building and operating a large airship. With regard to the former, the results which were obtained in Chapter 5 clearly demonstrate the need for a more accurate assessment of the cost associated with the development of a lighter than air craft to the point where it obtained certification for commercial use. With regard to operating an airship, an area which has received little attention is loading and unloading. In addition to the technical difficulties involved in maintaining the position of a large craft, future research should be directed toward the costs associated with both the facilities and the time required for what would appear to be the most delicate and demanding phase of airship operation.

Finally, it might be extremely productive to explore the feasibility of employing smaller airships with a cargo capacity of 10-20 tons for delivering food supplies in developing countries. The use of these smaller airships may aid greatly in alleviating bottlenecks associated with antiquated or rudimentary transport infrastructure without incurring the relatively high initial investment costs associated with the large airship described in this thesis.

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