AN ECONOMIC ASSESSMENT OF THE APPLICATION OF SUPER CONDUCTOR TECHNOLOGY TO MAGNETIC LEVITATION TRAINS IN OKLAHOMA

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THE RESEARCH PROBLEM

Introduction

The importance of technological innovations in the growth and development of an economy has been extensively studied in the literature (Malecki, 1983 reviewed an excellent body of literature related to this subject). Although some researchers such as Solow (1957) attribute most of economic growth to technology and others like Williamson (1980) identify technology as a major source of inequality in different regions, its role in economic growth and development has never been denied. Major technological inventions of the past, with obvious wide-ranging effects on society, are related to transportation. They include the steam engine used in railroad transportation systems, the internal combustion engine used in automobiles, and the jet engine used in air transportation. Product innovations and technological improvement associated with transportation systems, along with overall growth and development of cities and urban areas, have made the current U.S. transportation infrastructure one of the largest and most comprehensive in the world.

What many transportation experts also recognize is that some elements in this system are reaching a point of saturation. The quality of the American transportation infrastructure is barely sufficient to keep up with demand and does not seem to meet the demands of future economic development. Here are some of the current U.S. transportation infrastructure problems:

More than 60 percent of the miles of paved highways in the U.S. need some form of surface rehabilitation. The Associated General contractors of America, the largest organization of construction firms, puts the cost of infrastructure needs at $3.3 trillion, which includes $1.6 trillion for highways, $53 billion for bridges, and $142 billion for water supplies (Szabo, 1989).

Highway congestion already is serious in many areas. The Federal Highway Administration (FHWA) reports a 72% increase in vehicle miles traveled on U.S. highways since 1970 with 50% more growth expected by year 2000. The resulting congestion suggests the FHWA will, over the next 20 years, increase highway travel time 240 percent for a given trip (Itzkoff, 1988).

Airports are crowded, airways are congested, and the air-traffic control systems need substantial upgrading to maintain safety. According to a Federal Aviation Administration (FAA) report, on an average day in 1987, there were 975 flight delays totalling 2400 hours. This is equivalent to grounding 200 transport aircraft (U.S. Congress House, 1988, p. 133).

Airport capacities are not enough and demand for air travel is rising very rapidly. The FAA projects that a total of 750 million passengers will fly on scheduled commercial airlines by the year 2000. This represents a 66 percent increase over the 1987 record-breaking level and does not include over 100 million who used general aviation aircraft for business and leisure travel in 1987 (U.S. Congress House, 1988, p. 126).

The FAA estimates that the number of "seriously congested" airports will soar to 58 by the year 2000, up from 16 in 1986, and the congestion by the turn of the century will affect 75 percent of passengers, compared with 39 percent in 1986. However, only one major new airport, in Denver, is currently under construction (Szabo, 1989).

Predicted future crowding of existing modes of transportation and current problems facing the U.S. infrastructure calls for both short and long-run solutions. One promising solution to our transportation problems, as many researchers believe, is the application of Magnetic Levitation (MAG-LEV) trains using super conductor technology. The technology has been invented and with new super conductors is expected to become more practical. Dr. Kolm, one of the principal developers of this new technology at MIT describes it as " the next revolution in transportation which is inevitable and overdue" (testimony of Dr. Kolm before a subcommittee on water resources, transportation, and infrastructure, U.S. Senate, 1988, pp. 6-8).

The new, revolutionary, high-speed magnetic levitation trains offer deliverance from these impending problems and are likely to affect the economy in at least four ways: 1) improving social well-being, 2) generating extensive public infrastructure investment in transportation system, 3) inducing economy-wide private capital investment, and 4) stimulating multiplicative impacts throughout the economy.

The necessity of confronting current transportation problems has also made legislature authorities encourage the application of this new technology. New legislation, sponsored by Senator Daniel Moynihan (NY), would allow states to use interstate right-of-ways in the construction of these advanced systems (U.S. Congress, Senate, 1988). Tax law changes now also provide an incentive and avenue for public financing (Pryde, 1988). In fact several states have been seriously proposing corridor projects to boost both transportation efficiency and economic development.

For example, the state of Florida has been studying the feasibility of a three hundred mile corridor joining Orlando, Miami, and Tampa and found it quite feasible (U.S. Congress, House, 1987). Besides Florida, a number of other states in the U.S. are currently investigating the construction of high-speed trains, including Texas (Peterson, 1985) and California/Nevada, Pennsylvania, Ohio, upstate New York, Michigan/Illinois, the Northeast corridor (Boston, New York, Washington), and Missouri (U.S. Congress, Senate, 1988, p. 67).

The purpose of this research, partly inspired by recent advances in the development of MAG-LEV technology, is to investigate the possible application of this technology in the state of Oklahoma. It is believed (Amos, 1988) that those regions that apply this revolutionary means of transportation will benefit from significant economic growth.

Purpose of the Study

The first objective of this research is to develop and refine a methodology that can be used to evaluate the feasibility of high-speed MAG-LEV trains. The methodology is based on an aggregate econometric demand model and mathematical programming. Although mathematical programming models have been frequently used in the evaluation of transportation and transportation systems (e.g. Quandt, 1960; Moavenzadeh et al., 1983; Prastacos and Romanos, 1987), none have been developed to address the question of the feasibility of MAG-LEV trains.

The second objective is to apply this methodology to the state of Oklahoma. A city pair network is constructed to evaluate alternative MAG-LEV routes between Oklahoma City and nine other cities in and out of the state of Oklahoma. The nine cities are carefully selected by city size and distance from Oklahoma City. Three alternative city-size categories are selected: small (100,000 - 550,000), medium (550,000 - 1,000,000), and large (over 1,000,000). Within each city-size category, three cities are selected based on distance from Oklahoma City: close (0 - 500 miles), moderate (500 - 1000 miles), and far (1000 - 2000 miles). Table I presents the nine cities selected for this research.

One basic problem faced in this research was the lack of data. In order to estimate ridership in each corridor, a complete data set including origin-destination volume was required. The existing data sets were examined and none contained enough information for estimation techniques. For overcoming this difficulty, it was decided to test some of the previous demand models using

TABLE I

SELECTED CITIES FOR HYPOTHETICAL NETWORKS

Distance/Size	Small	Medium	Large
Close	Wichita(KS)	Tulsa(OK)	Dallas(TX)
Moderate	Corpus Christi(TX)	Nashville(TN)	St. Louis(MO)
Far	Charleston (SC)	Rochester (NY)	Los Angeles(CA)

data on their explanatory variables. The results obtained from demand models were incorporated with mathematical programming models to determine the rational behavior of travellers in each corridor.

Technology Background

Netschert (1988, p. 45) describes the super conductivity phenomenon as

> the disappearance of all resistance to the flow of an electric current in DC (direct current) mode, once started, such a current will flow in a closed loop forever, for all practical purposes, as long as the super conductive state is maintained. This is advantageous itself, but more important is what it means for the creation of magnetic fields.

The super conductivity phenomenon has been known since 1911, but its theoretical foundation was developed in 1957. Traditional "super conductivity" is obtainable through the use of liquid helium, which is expensive and very difficult to liquify. However, new research on super conductivity has made it possible to achieve this phenomenon through the use of liquid nitrogen; nitrogen is the most abundant gaseous element on earth and is readily liquified, handled and stored. Although researchers have been able to raise the minimum super conductivity temperature to about minus 243 degrees Fahrenheit (with liquid nitrogen), it is still well below the "ordinary" or "room" temperature (75^{o}F). Recent research (Douglas, 1987) on this subject hints of its productivity at room temperature. If this happens, a new revolution in science and technology will occur, but with or without room temperature, the consequences of the recent advances in super conductivity will be greatly appreciated in years ahead.

Besides its application to electricity generation, Netschert (1988) talks about a wide variety of applications. For example, one application is in more exotic generation technologies such as magnethydrodynamics (MHD), in which an electric current is generated by passing a plasma (a superheated gas) through a magnetic field. Other applications are storing electricity in a self-contained, continuous flowing loop, medical imaging machines, electric cars, computers (Stipp, 1987), batteries, and smoke detectors (Tulsa World, 1988, p. 19).

One application of super conductor technology that has a large potential use in transportation is Magnetic Levitation (MAG-LEV) trains. Super conductivity permits very strong but light weight magnets to be distributed along the vehicle. On the ground there is only a track of ordinary copper or aluminum conductors to levitate and propel the vehicle. Current is induced in the track only when the train magnets move directly overhead.

The idea of MAG-LEV trains was picked up in the 1960s in relation to congestion in the northeast corridor. Major work began in the United States when MIT initiated MAG-LEV research in 1969. There were two approaches toward developing MAG-LEV trains. By the early 1970s, two MAG-LEV studies were sponsored by the U.S. Department of Transportation (DOT), one at the

Ford Motor Company and the other at Stanford Research Institute (SRI). Two systems, repulsive (electrodynamic) and attractive (electromagnetic), were evaluated in the DOT studies; Ford and SRI concluded that the repulsive system had greater technical merit. But the research for all high-speed U.S. MAG-LEV research was terminated in 1975, based upon budgetary consideration rather than technical feasibility (U.S. Congress, Senate, 1988, pp. 6-30).

At the mean time, MAG-LEV research was pursued in West Germany and Japan using the findings of Americans. Both countries examined the attractive and repulsive systems; West Germany focused on the attractive system and Japan began to concentrate on the repulsive system. Here is a brief description of the technical difference between these two systems (Money, 1984).

The repulsive system utilizes super conducting coils on board the vehicle to generate the magnetic field. When an electric field moves over the super conducting coils it generates an electric current in the conductor and the induced current creates its own magnetic field, which repels the original field. This is much the same effect as two like magnetic poles repelling each other. The repulsive forces generated by these means will create large air gaps of 10 cm or more. This type of vehicle is equipped with "take-off' and "landing" wheels because they do not levitate at speeds of less than about 40 kilometers per hour. Japan started with an "inverted T" guideway and later changed it to a "square U" design. More than 25000 miles of tests were conducted on the first prototype vehicle along a four mile test track. The Japanese are now testing a 17 ton, 44 passenger prototype with a design speed of 300 mph. Following successful completion of these tests, a 30-mile system is planned between Narita International Airport and downtown Tokyo. This corridor is planned to begin producing revenue by 1992. Their next corridor is designed to be built between Tokyo and Osaka, a 350 mile link (U.S. Congress, Senate, 1988).

The second approach is an electromagnetic or "attractive" technique applied by West Germany in their MAG-LEV vehicles. In this system, electromagnets are arranged along the side of the vehicle and below the iron rails in the guideway so that when energized, they are attracted up to the underside of the rails. This system is inherently unstable, and the instability is handled by incorporating an air gap sensor that controls the current through the electromagnets to maintain a constant air-gap distance. This system operates with an air gap of 1cm or so; it levitates at zero speed, so no wheels are necessary. The German system is close to its commercial application. They first demonstrated such a vehicle in a 1km track at the International Transport Exhibition held in Hamburg in 1979. They are presently testing a 102 ton, 98 passenger vehicle in a 19-mile test track, and by December of 1987 more than 15,000 miles of tests were completed and a top speed of 252 miles per hour was achieved. Figures 1 and 2 show a schematic comparison between these two systems.

Although speed is the cornerstone of a MAG-LEV system, other features of this technology are equally important. The energy consumption is comparable to the automobile and is far lower than an aircraft on short distance hauls. Noise level is reduced dramatically. The vehicle does not pollute along the route. And finally, as Hellman (1983) describes it, its suspension, propulsion, guidance, and braking system operate without mechanical contact; thus, there is no friction and no wear and tear on the guideway, which will cause a huge savings in maintenance costs over conventional rail systems. Its safety and reliability are believed to be far greater than any other existing means of transportation.

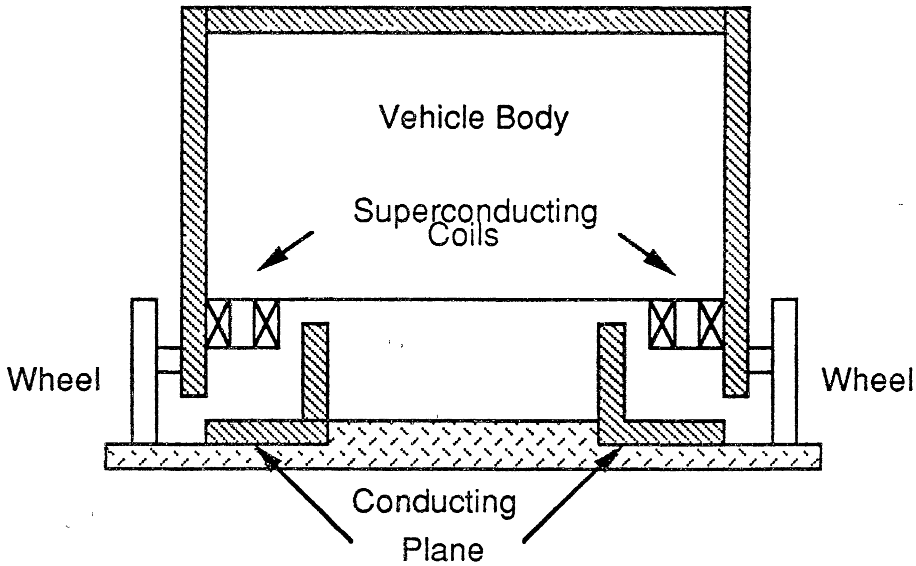

Figure 1. Electrodynamic Levitation or Repulsive System (Schematic)

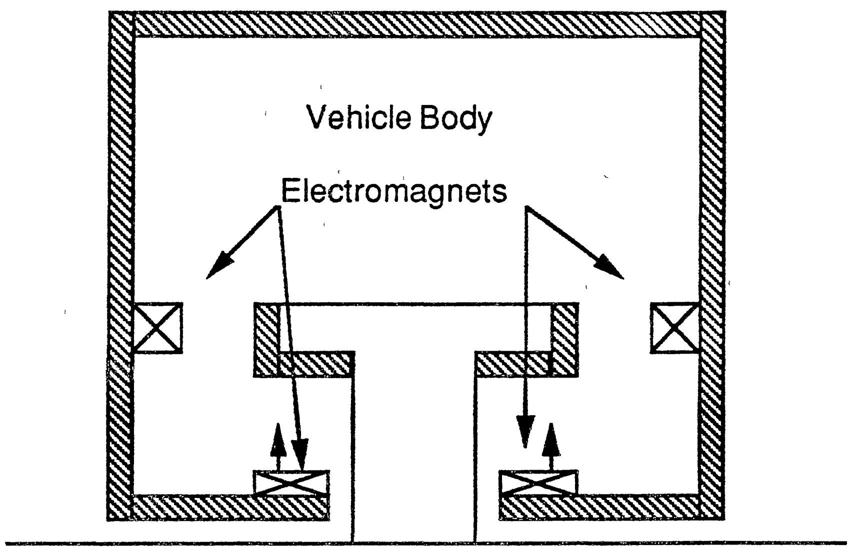

Figure 2. Electromagnetic Levitation or Attractive System (Schematic)

Organization of the Report

Chapter II reviews the literature. Demand models are reviewed in the first part and linear programming literature is discussed in the second part of the chapter. Aggregate/disaggregate demand models and linear programming models are the components of each part of this chapter.

Chapter III consists of two parts. The first part is devoted to an explanation of data collection on "Service Characteristics" variables for each mode under consideration. The second part presents data on "Socio-Economic and Demographic" variables.

Chapter IV presents a testing of so called "abstract mode" models. The first part of the chapter discusses the theoretical foundation of the Quandt and Baumol model, along with their empirical findings. In the second part, their model is tested using available data, and the results are analyzed, both in terms of the effect on existing mode of introducing a new mode of transportation, and the magnitude of diverted and induced demand.

Chapter V also consists of two parts. In the first part a single objective function linear programming model is developed, based upon information obtained from the Quandt and Baumol model. The linear programming model is solved and the results are analyzed in detail. A sensitivity analysis along with the dual problem is presented in this part. The second part of the chapter talks about developing and testing a multi-objective linear programming model. Two objectives, minimizing fare and minimizing vehicle travel time, are chosen and solved by the application of the STEM (interactive mathematical programming) algorithm.

Chapter VI is devoted to a cost analysis of MAG-LEV trains. Based upon previous MAG-LEV feasibility studies, the components of capital and operating costs are discussed and investment requirements for five different corridors are presented. In the last part of the chapter, both cost and revenue in five potentially feasible corridors (in terms of volume of ridership) have been converted to annual figures using an annual-cost method.

Chapter VII contains concluding remarks, including a summary of the research reported in the previous chapters, and recommendations for further research.

CHAPTER II

LITERATURE REVIEW

The purpose of this chapter is to review a variety of approaches that have been applied to transportation problems (mainly inter-urban as opposed to intra-urban). Although a detailed discussion of each model is not possible and does not seem to be appropriate at this point, an evaluation of both the theoretical and practical applications of the most significant works is presented.

There are many different techniques that one may face in dealing with transportation modelling. They depend on factors such as the degree of complexity, data availability, policy relevance, etc. The techniques range from 1) qualitative modelling [Direnzo and Rossi (1971)] which is based upon some simple reasoned decision rules, 2) cost/benefit analysis [e.g., Foster and Beesley (1963); Mishan (1976); American Association of State Highway and Transportation Officials (AASHTO) (1977)], 3) Econometrics, and 4) linear programming modelling.

Since most of the transportation studies use econometric modelling or linear programming techniques, the remaining two parts of this chapter will be devoted to a discussion of literature related to these techniques. In the second part, econometric models will be discussed, and part three reviews literature on linear programming.

Literature on Econometric Demand Modelling

The use of econometric modelling has long been prevalent in transportation planning. One of the very first attempts to formulate such a model used four steps, 1) trip generation, 2) trip distribution, 3) modal split, and 4) traffic assignment, to deal with intra-urban transportation planning. Unfortunately these types of sequential process models perpetuate some weaknesses, such as the inconsistency in results. Because the results obtained from each step are used as input to the next step, the inputs and outputs of each step may not be internally consistent throughout each study. These methodologies have been extensively documented in the literature [U.S. Department of Transportation, 1964, 1965, 1966, 1967].

Several other attempts have been made to either combine the sequential four step planning process or present some new versions of this common methodology. Focusing on inter-urban econometric modelling, existing models may be characterized as either time series or cross section. The application of time series models is not extensive in the literature. They are usually used for a single mode of transportation and in most cases for air transportation [a summary of these models can be found in Alcaly, (1965)]. The application of cross sectional models is more common and they are usually classified as either aggregate or disaggregate demand models. In the next few pages a discussion of both aggregate and disaggregate cross-sectional econometric models is presented in detail.

Aggregate Econometric Demand Models

The development of aggregate inter-urban models was started with the northeast corridors project (Washington-New York-Boston corridor). It was during the mid-1960s that intercity travel in this corridor became congested as a result of population and economic growth. Different demand models were developed to forecast travel volumes for new and existing travel modes. The inclusion of some demographic, socio-economic characteristics of city pairs and an estimation using aggregate data are common in most of these models.

Gravity types of models have a long history of use in the explanation of the number of people desiring to travel between city pairs. Their principal explanatory variables are population, as the city attractiveness variable, and distance, as the impedance measure. The very simple gravity model takes the following form:

$$X_{ij} = G\frac{P_i P_j}{(d_{ij})^2}$$

where

X_{ij} = number of people who are going from i to j by all modes

G = gravitational constant

P_{ij} = population at i and j

d_{ij} = distance between i and j

Ellis and Van Doren (1966) compared and tested two different gravity models (different in terms of model construction and explanatory variables included) with system theory modelling borrowed from the physical sciences, to estimate the flows between recreational parks in the state of Michigan. Their results show that although gravity models do not replicate actual data nicely, they have the potential of being improved through a series of adjustments such as developing better estimation techniques for the exponent and constant (G), and assigning a separate gravitational constant to each origin. In general, they recommended using system theory modelling compared to gravity models.

Alcaly (1967) also formulated and estimated different gravity models for total intercity demand for sixteen city pairs in California. The models use two different explanatory variables as the impedance measure, travel cost and distance. The estimation results show that when travel cost is used as an impedance measure, the goodness-of-fit is less reliable than when distance is used as an impedance measure.

Anselin (1984) attempted to test five different versions of simple gravity models and tried to compare them, with respect to their applicability, to a given set of observations on spatial flows. The models differed in the choice of explanatory variables, such as population, unemployment, and disposable income, and the functional form of the impedance measure (i.e., a negative power function or a negative exponential). The models were estimated by ordinary least squares and nonlinear least squares using observations for average yearly family moves between Canadian Provinces in the period of 1971-1976. The estimated models were tested based upon the Akaike Information Criteria (AIC) and also three different tests to compare all five different gravity models in a pairwise fashion. The tests were the Cox-Pearson-Deaton test, the J-test for linear alternatives and the P-test for the nonlinear case. Anselin's results showed that, in general, the simple gravity model with a negative power impedance measure seemed to be the best. However, he pointed out a need for a better formulation and model refinement of this type.

In general, gravity models have been subjected to the criticism that they have little economic meaning, contribute no policy significance, ignore such variables as service characteristics (time, cost, etc.) and do not represent inter-modal competition of different modes in intercity travel modelling.

A completely different set of demand models (compared to gravity type models) was developed by Kraft-Sarc (1963) and was refined by the work of

Quandt and Baumol (1966). These models were set up in such a way as to enable researchers to predict traffic volume between city pairs with a specific mode. Quandt and Baumol named the model "Abstract Mode" and included variables such as socio-economic and demographic features, and variables that represent the characteristics of the travel mode in both absolute and relative terms. The specific advantage of this model is that it is possible to use it to predict travel on a new mode or a mode for which no historic data exists. The mathematical form of the Quandt and Baumol (1966) model can be written as:

$$X_{kij} = \alpha_0 P_i^{\alpha_1} P_j^{\alpha_2} Y_i^{\alpha_3} Y_j^{\alpha_4} (T_{ij}^b)^{\alpha 5} (T_{kij}^r)^{\alpha 6} (C_{ij}^b)^{\alpha 7} (C_{kij}^r)^{\alpha 8} (F_{ij}^b)^{\alpha 9} (F_{kij}^r)^{\alpha 10}$$

where:

X_{kij} = travel volume between i and j by mode k

P = population

Y = per capita income

T_{ij}^b = best travel time between i and j by any mode

T_{kij}^r = relative travel time between i and j by mode k (the ratio of travel time by mode k divided by the best travel time between i and j by any mode)

C_{ij}^b = best cost of travelling (cheapest) between i and j by any mode

C_{kij}^r = relative travel cost between i and j by mode k (computed the same way as relative travel time)

F_{ij}^b = best departure frequency between i and j by any mode

F^{r}_{kij} = relative departure frequency between i and j by mode k (computed the same way as relative travel time)

The above model was formulated as a constant elasticity model and was estimated in log-linear form (with different sets of explanatory variables) for air, bus and auto travel using 1960 data for sixteen city pairs in California. The parameter values were tested against a variety of theoretical constraints and found to be acceptable.

In 1969 Quandt and Young (1969) examined a number of different models to improve the basic theory. These models were different in terms of the explanatory variables included, their functional form, and techniques for obtaining estimates. Two basic improvements were made in their model specification. First, they allow each mode to have its own intercept; this enables a mode to have a specific level of demand which depends on factors not included in the model. The second improvement allowed the models to have constant elasticity over some range, but not the entire range. For example, it can be argued that air travellers or potential air travellers have a constant elasticity for the speed range of 300-600 miles per hour. Similar reasoning could be true for bus or auto travellers.

Lave et al. (1977) used the Kraft-Sarc model to test it with a national data base. An aggregate model of intercity passenger travel split by trip purpose, business or personal travel, and split by mode, air or auto, was developed. In the estimation process they were faced with serious multicollinearity in the data, but their results were highly satisfactory in terms of the sizes, signs, and pattern of coefficients across equations.

Peers et al. (1976) used a mixed form of a linear and non-linear demand model of the Kraft-SARC type to study intercity transit demand in the Sacramento- Stockton-San Francisco corridor. They used different estimation techniques and concluded that a non-linear technique performed the best. By using the concept of different elasticities, they studied a wide variety of policy changes, such as an increase in fuel prices, reduction in automobile speed, and increase in transit service frequency on travel demand. In conclusion, they felt the estimation results were satisfactory.

The "abstract mode model," or specifically Quandt and Baumol's model, has been the subject of some criticism, too. Gronau and Alcaly (1969) argue that choosing the best attributes of each mode is not a proper way of formulation, and they questioned the validity of Quandt and Baumol's results. They believe that "abstract mode models" do not fully represent the effect of "competing alternatives." Another problem that was observed as a result of the application of Quandt and Baumol models in this research is that under some circumstances an improvement in the best travel time or cost in one corridor resulted in a reduction in total travel in that corridor.

In response to problems associated with "abstract mode models," McLynn and Woronka (1969) developed a new demand model that could be used for estimating modal share and total demand and could represent inter-modal competition better than previous models. The mathematical form of the model can be shown as:

$$X_{kij} = X_{ij} \bullet S_{kij} \qquad (2.a)$$

$$X_{ij} = \alpha_0 (P_i P_j)^{\alpha 1} (Y_i Y_j)^{\alpha 2} \exp (\beta_0 \sum Wm) \qquad (2.b)$$

$$S_{kij} = \frac{W_{kij}}{\sum_m W_{mij}} \qquad (2.c)$$

$$W_{kij} = \delta_{ok} T_{kij}^{\delta 1k} C_{kij}^{\delta 2k} F_{kij}^{\delta 3k} \qquad (2.d)$$

where

X_{kij} = travel volume between i and j by mode k

X_{ij} = travel volume between i and j by all modes

S_{kij} = modal share of mode k

W_{kij} = modal utility as a function of travel time, cost and frequency of mode k

In this sequential process X_{kij} is obtained by the product of total travel volume by modal share of mode k (equation 2.a). Total travel volume between i and j (X_{ij}) is a function of population and income products and also the sum of modal utility for all modes (equation 2.b). City pair modal share is proportional to city pair modal utility (equation 2.c) and modal utility is a function of the service characteristics of each mode (equation 2.d).

This model was used by Billheimer (1972) in a study of inter-city travel in Michigan. The cities were divided according to population and distance from each other and the model was estimated by using a constrained search calibration technique. The estimation results were satisfactory and the model was able to report both diverted and induced demand. However, the author believed that by using a constrained search technique, the parameters obtained the theoretical expectation but the amount of induced demand was highly overstated.

In the same year Monsod (1969) developed another version of the McLynn model. The only difference between the Monsod and the McLynn models is that in the Monsod model parameters are of an "abstract" type, so it could be used to study the impact of a new mode. Monsod also included a "cultural index" as a measure of city pair attractiveness. Rea et al. (1977) tested the Monsod model using 1972 data for intercity passenger travel in Canada. The model was estimated and different sensitivity analyses were carried out, and the impact of each scenario on air, bus, rail, and auto travel was discussed in detail. Their results showed a reasonable indication of the directions and relative strengths of this type of model.

Crow et al. (1973) made an excellent comparison among different aggregate models focusing on "abstract mode" models. They set up seven reasonableness criteria and evaluated each model in terms of those seven. They generally believed that non-linear models perform better than linear ones, and in terms of satisfying the "reasonableness" criteria, the Monsod and McLynn model satisfies more criteria than other abstract mode models.

Besides the above mentioned models, which could be considered the major contribution to the field of aggregate travel demand modelling, a number of other studies are worth mentioning. For example, Ellis et al. (1971) used a binary share model to predict modal split between auto and air for intercity travel, with no attempt to estimate total travel. Others, like Cohen et al. (1978), combined a simple gravity model with a binary logit model to predict intercity rail travel for 31 city pairs in New York. They found that rail traffic is sensitive to travel time and that an improvement in time has the potential of diverting people to rail from other modes of transportation. Owen and Phillips (1987) and Su et al. (1977) are some examples of econometric modelling efforts that also have been used to study the impact of intercity travel in only one mode of transportation.

The evolution of aggregate econometric models in the last thirty years has enabled researchers to get quick responses to different problems. Although they suffer from some weaknesses, they have some advantages too. The contribution of such models can be summarized as the inclusion of different variables that characterize the pattern of travel, the ability to introduce both induced travel as well as diverted travel, and the ability to represent modal competition, Whereas the main criticism of these models relates to the use of aggregate data, bias in estimation, ignoring some service characteristics such as comfort, convenience, reliability and safety, and an unclear definition of geographic boundaries.

Disaggregate Econometric Demand Models

Disaggregate demand models are considered a major innovation in intercity demand modelling. It is obvious that the behavior of individual travelers and the factors which influence their behaviors can best be understood by considering the individual. Disaggregate demand models allow for the use of individual observations and, by enlarging the size of the sample, the analyst has more confidence in the results. The development of disaggregate models has been well documented in the literature [Domenich and McFadden, (1975); Richards and Ben-Akiva, (1975); Daganzo, (1979) and others]. Although the application of disaggregate demand models is not common because of data limitations, there have been a few attempts toward solving transportation problems using this particular approach.

Watson (1974) constructed and compared both disaggregate and aggregate mode choice models for the Edinburgh-Glasgow area in Scotland using the data from the Edinburgh-Glasgow Area Modal-Split (EGAMS) study. Observations were allocated to pairs of zones and 158 zone-to-zone pairs were constructed. He calibrated the aggregate model using multiple regression analysis and the disaggregate model using logit analysis. He tried to compare these two models in terms of their structure and their predictive power. In his first estimation process he included the same set of explanatory variables (relative time differences, relative cost differences, walking-waiting time, ride, or transfer time necessary to complete the trip) in both models. Based upon the statistical test, he concluded that the disaggregate model performed better than the aggregate model. However, the aggregate model was improved by adding other explanatory variables, such as convenience and accessibility, associated with the train journey. In terms of their predictive power, he conducted several statistical tests and showed that the errors associated with the aggregate model are several times as large as those associated with the disaggregate method. He argued for the predictive superiority of the disaggregate model.

Stopher and Prashkar (1976) attempted to test the feasibility of using a data source (National Travel Survey, 1972) to build a disaggregate model using the 2085 observations of that data set. The service characteristics of each mode were taken from different industry sources. They used a multinomial logit model with variables such as line-haul travel time, line-haul travel cost, service frequency, and access and egress time. Their estimation results appeared to be satisfactory with respect to parameter signs and their significance, but many elasticities were reported as counter-intuitive. For example, a 25% reduction in rail fare results in a reduction in bus, auto and rail shares. In terms of the data set, they concluded that the national travel survey is not suitable for this task.

Gantzer (1979) discussed the structure of a disaggregate model used in the Northeast corridor project. The total demand model was calibrated using cross-sectional and time-series data for nine city pairs for the period 1960-1972. The model estimated ridership for 17 origin-destinations and a Monte Carlo technique was used to generate travellers, one at a time. Some travellers' attributes, such as resident city, origin-destination zone, peak/off-peak departure, trip purpose, party size, and car availability, were taken from the National Travel Survey of 1972. He also considered the impact of different scenarios, such as socio-economic changes, institutional changes (e.g., air deregulation, speed limit changes and gasoline taxes), and factors such as congestion, new modes and tolls on rail ridership.

Grayson (1981) took a similar approach and used a disaggregate logit model based on the National Travel Survey of 1977, supplemented by service information from industry sources. His model is similar to Stopher and Prashkar (1976) except that he included access distance instead of access time. Like most of the other studies, he constructed a utility function for each traveller as a function of cost, line-haul time, waiting time, and access to each mode. His estimation result showed that every coefficient had the expected sign, and the cost and the time coefficients were significant. He also went through a number of different model variations and concluded that the model performed very well in almost all aspects of statistical measures.

Finally, Morrison and Winston (1985) made a contribution in the development of disaggregate demand analysis by modelling the behavior of travellers for both vacation and business trips. Their model is able to answer critical questions such as the potential benefits of introducing new modes, the impact of a change in modal attribute on destination choice, and how unobserved effects (such as travellers' tastes) and unmeasured effects (such as comfort) influence traveller behavior. Their methodology is based upon a nested logit model and it is different from previous models in that they were concerned with jointly analyzing three discrete choices (mode, destination, and whether to rent a car at a destination). This model is considered to be more sophisticated than all other previous models and is an important step toward development of a fully disaggregate model.

Overview of Econometric Demand Models

Both sets of econometric demand models that were discussed above have advantages and disadvantages. Development of aggregate models has made it possible to estimate the impact of modal attributes and socio-economic and demographic features of regions on the travel behavior. Although ultimately the region as a whole would be used for policy decision-making, it is believed that using aggregate data will result in biased estimation.

On the other hand, disaggregate models are able to explain the behavioral aspects of individual travellers by using individual observations. The problem with disaggregate models is that there has been no reliable source of data that could be used for developing a truly disaggregate model. That is why most researchers refer to present literature on disaggregate models as "Pseudo-disaggregate." Not a wide range of applications exists in the literature because of data limitations, but if one is to make a judgement among these models, disaggregate models are definitely preferred if a reliable data source is available.

Literature on Linear Programming Models

A large body of research has been carried out on the development of linear programming models for transportation purposes. The concept of applying linear programming to transportation problems dates back to Von Thunen in 1826 and Weber in 1929 (Stevens, 1958, p. 64). The transportation problem arises frequently in finding the optimal flows in different fields such as physics and engineering [Iri (1969), pp. 87-100 and 129-192.] or Business and Economics and other social sciences [Beale (1970); Hu and Robinson (1973); Anderson et al. (1985), pp. 178-267; Nijkamp (1986), p. 110 and pp. 172-183;

Henderson (1955)]. The distribution of flows, such as vehicles, goods and services, passengers, and electric current can be associated with the links of a graph called a network, or more specifically a transportation network [Potts and Oliver (1972), p. 26]. These networks may range from a single origin-destination (O-D) network to a multiple O-D network.

When applied to transportation infrastructure, linear programming models can be set up in different ways. For example, Quandt (1960) tried to formulate the impact of constructing a new highway to satisfy future demand by including its capital cost in the linear programming model. Two different models were set up. First, he formulated a model based on the assumption that the cost of new construction is imputed to the shippers [Quandt (1960), p. 29]. In this case, the objective function is to minimize the summation of shipping and construction costs. In the second model, he assumed that the legislature had already appropriated the sum of M dollars for highway construction. In this case, a constraint was added to the set of constraints to ensure that the total amount spent on construction did not exceed the appropriated amount [Quandt (1960), p. 34]. One of the problems with Quandt's model is that the components of the objective function have different units of measurement, and in general, they contribute little to a welfare point of view.

Prastacos and Romanos (1987) also developed an optimization model to study the impact of investment in transportation infrastructure on regional growth. Their approach employs a dynamic programming model that includes both 0-1 integer variables for transportation network investment and non-linear constraints. Consumption, demand, and investment for each sector and region are derived endogenously and the production function of the non-transportation sectors is of the input-output type with the assumption that the technical coefficients represent only the production process and do not represent the trade patterns of inter-industry relationships. To picture the spatial distribution of economic activity, they assumed that production/consumption processes are centered at specific points connected by the transport network, and trade flows are determined endogenously as functions of the transport costs and the supply/demand schedule of each region. Using a gravity type of model for estimating the flows for all sectors, investment in transportation infrastructure could take two different forms: construction of a new link or improvement of an existing one. The impact of these investments on the regional economy accounted for in the model is twofold, reduction of transportation costs of the distribution process and increase in the final demand for construction within the region in which the new links are constructed [Prastacos and Romanos (1987), p. 136].

The complete model was applied to Greece. The solution algorithm proved to be quite efficient and the model was able to indicate which of the proposed highway links had the most priority for construction or improvement during three, five-year planning spans. However, one of the basic problems was that the regional growth transport investments relationship obtained from the model was not a clear one.

When it comes to intra-urban and inter-urban simultaneous transportation planning, problems become somewhat complicated; it requires both behavioral modelling and the consideration of equilibrium between supply and demand of transportation. Once the model is built, searching for an appropriate algorithm becomes a challenging task. One of the very first attempts to solve transportation problems simultaneously was done by Beckmann et al. (1956). Assuming monotonicity of demand and performance, they viewed the equilibrium between supply of transportation and demand for it as an equivalent optimization problem. One of the advantages of this approach is that the equilibrium problem becomes a convex optimization problem that can be solved by any of several convergent algorithms [e.g., Dembo and Klencewicz (1981); Fisk and Nguyan (1982); Florian and Nguyen (1974)]. Behavioral weakness is the major drawback for these models, because they usually require strong assumptions which are unrealistic. Although later attempts by Evans (1976), and Florian and Nguyen (1978) enriched the formulation by including trip distribution and modal split in the models, they are still suffering from the lack of behavioral modelling.

Another set of equilibrium models that takes into account the behavioral aspects of the users of transportation systems can be represented by the work of Sheffi and Daganzo (1980) and Smith (1979). The weaknesses of these models is that they are not computationally as efficient as the equivalent optimization problems.

Safwat and Magnanti (1988) developed a transportation equilibrium model that satisfied both requirements of previous models; it was computationally efficient and behaviorally enriched. In their model, sequential process, trip generation, trip distribution, mode choice, and route choice are combined in one model and solved simultaneously. Trip generation depends upon the system performance through an accessibility measure that is based on the random utility theory of user behavior (instead of being fixed as in previous models). Trip distribution is given by a logit model based on the random utility theory [Safwat and Magnenti (1988), p. 17].

The Safwat and Magnanti model has been applied to a real transportation network for intercity passenger travel in Egypt [Safwat (1989)]. The results show that this model is capable of predicting rational behavioral responses of users to policy changes in the system. It also showed that it has the potential of predicting the actual behavior, if trip distribution is not misspecified. Following the "first" application of the model, Moavenzadeh et al. (1983) included an extended version of this model as a central component of a comprehensive methodology for intercity transportation planning in Egypt. The algorithm used in the Safwat and Magnenti model is called "shortest path to the most needy destination" (SPND). It predicts trip generation, trip distribution, modal split and traffic assignment simultaneously [Safwat (1989), p. 61]. The model also has been applied to the urban transportation systems of Austin, Texas [Safwat and Walton (1988)] to assess the computational efficiency of the model when applied to an urban large-scale network. Two algorithms were used in this study, namely, shortest path to the most needy destination (SPND) and logit distribution of trips (LDT). It was concluded that for large urban transportation networks, LDT appears to be much more efficient than SPND.

Overview of Linear Programming Models

In general, the linear programming method does have the ability to find complex mathematical solutions to transportation distribution between nodes. The data requirements are heavy. Past data and short-run forecast are used as inputs into the models. Historical data is usually presented through regression analysis, and prediction of the future will only be good for the short term.

The limitations of the linear programming method as a planning tool for transportation are described in Stevens (1958). Like an Input-Output model, linear programming does not allow for adjustment to economies of scale in interregional analysis. Instead, it allows only for constant returns to scale. Consumers' tastes and preferences can hardly be modeled, because they are non linear in nature.

Nevertheless, the application of linear programming models has been most successful in the production sector, especially in problems dealing with the question of the optimum allocation of goods and services in a spatial manner. However, if the behavior of individuals is to be modeled into the linear programming method, the model must be constructed to account for more realistic assumptions.

CHAPTER III

DATA DERIVATION

The purpose of this chapter is to compile the data necessary for model testing. Due to the lack of data on actual travel volume in each corridor, ridership estimates were derived by testing some of the previous demand models. The set of demand models chosen for this purpose belongs to the empirical work of Quandt and Baumol (1966). Their model, which was discussed briefly in Chapter II, assumes that each traveller would be concerned about the speed of the fastest mode, the fare of the cheapest mode, and the schedule of the most frequently used mode. They also assume that the speed of all modes would be seen relative to that of the fastest, as would fare, and the departure frequency schedule would be seen relative to the cheapest and most frequently scheduled modes. Besides the above variables (service characteristics variables), they also introduced a set of different policy variables that has some economic relevance.

The advantage of the Quandt and Baumol model is that it is possible to estimate both total ridership and ridership by a specific mode using a single equation. With the above explanation, data derivation for the explanatory variables is limited to those specified in Quandt and Baumol's model.

Due to the "cross-sectional" nature of their model, and the unavailability of data for some modes, including MAG-LEV, their model was tested using relevant data for 1984. The remainder of this chapter explains the construction of two types of variables. In the following sections, "service characteristics" variables are discussed and "socio-economic and demographic" variables are constructed. A complete description of the specified models is discussed in the next chapter.

Variable Construction

Service Characteristics Variables

Air Travel Time. The air travel time variable in each corridor is computed as the sum of the line-haul time between the cities, access and egress time, and air terminal waiting time. Each of the above components of air travel time is developed in the following way:

1) Air line-haul time. The average time given by the official Airline Guide (OAG) between two cities is used as a measure for air line-haul time.

2) Air access time. Lacking data on the exact location of the origins and destinations within the MSA's, the sum of the 1984 OAG's published limousine times for the trips to and from the airport is used.

3) Air terminal waiting time. A figure of 51 minutes per one-way trip is used throughout the study. This figure was derived by the Kraft-SARC study from data for the northeast corridor. This time will allow for early arrival at the airport and also time spent for baggage claim at destination.

Table II shows the air travel time in our hypothetical network.

Air Travel Cost. This variable is computed as the sum of the coach economy fare, access and egress costs, and value of time.

1) Coach economy fare. A one-way average coach economy fare has been computed for each origin-destination from the 1984 issue of the Official Airline Guide (OAG).

TABLE II

AIR TRAVEL TIME

	Average Flight Time (Min)	Access Time (Min)	Waiting Time (Min)	Total in Minutes	Total (Hours)
OKC-Wichita	44.25	35	51	130 2	2.17
OKC-Tulsa	34.5	35	51	120.5	2 00
OKC-Dallas	49.4	55	51	155 4	2.59
OKC-Corpus Christi	191 2	40	51	282 2	4 7
OKC-Nashville	223.6	50	51	324 6	5.41
OKC-St. Louis	187.2	50	51	288.2	4.8
OKC-Charleston	316.0	25	51	392.0	6.53
OKC-Rochester	398 6	10	51	459 6	7.66
OKC-Los Angeles	288.8	65	51	404 8	6.74

2) Access-egress cost. This cost has been taken from the OAG's travel planner book. This figure represents the sum of the OAG published taxi cost for the trips to and from the airport.

3) Value of Time. The value of travel time varies according to the purpose of the trip, time saved, mode travelled, and possible length of the trip. Oort (1969) defines travel time as the utility or disutility associated with time spent in a particular mode and the opportunity cost of travel. A high value of travel time shows a significant amount of disutility associated with time spent in one mode.

For this research, a 60/40 percent split between business and non-business trips is assumed. Based on the value of time of 14 dollars for business trips and 4 dollars for non-business trips, an average value of time of 10 dollars per hour per person is assumed for all modes of transportation throughout the analysis. In the Florida High Speed Rail Study, the value of travel time of

$8.434 per hour per person was used. Morrison and Winston (1985), used the value of $0.65 for auto trips, $8.80 per high income household persons travelling by train, and $15.37 for travelling by airplane.

With the above description of the components of the air travel cost variable, Table III represents the cost of travelling by airplane in each corridor:

TABLE III

AIR TRAVEL COST

	Average Economy Fare ($)	Access Egress Cost ($)	Value of Time ($10 an Hour)	Total Cost ($)
OKC-Wichita	88	13.5	21.7	123.20
OKC-Tulsa	71.5	15	20.1	106 60
OKC-Dallas	78	12	25.9	115.90
OKC-Corpus Christi	141	12	47	200
OKC-Nashville	235	12	54.1	301.1
OKC-St. Louis	241	12	48	301
OKC-Charleston	348.5	7	65.3	420.8
OKC-Rochester	366	5	76.6	447 6
OKC-Los Angeles	225.5	12.5	67.5	305

OAG report contained no information on the cost of going from Dallas and Nashville airports to the CBD, so a figure of 6 dollars has been used.
The value of time has been multiplied by travel time.
No access cost was reported for Rochester Airport, so a figure of 5 dollars is assumed.

Auto Travel Time. The Rand-McNally Atlas has been used to compute the auto time variable in each corridor. The distances are computed in such a way that assumes people are only travelling on interstate highways. An average speed of 55 miles per hour has been used to compute travel time between OKC and other cities.

Table IV shows travel time in the different corridors.

TABLE IV

AUTO TRAVEL TIME

	Distance	Speed (55 mph)	Time (Hrs)
OKC-Wichita	141	55	2.56
OKC-Tulsa	103	55	1.87
OKC-Dallas	207	55	3.76
OKC-Corpus Christi	630	55	11.45
OKC-Nashville	672	55	12.22
OKC-St. Louis	497	55	9.04
OKC-Charleston	1143	55	20.78
OKC-Rochester	1300	55	23.64
OKC-Los Angeles	1352	55	24.58

Auto Travel Cost. The components for the auto cost variable are vehicle operating cost (gasoline and oil, maintenance and tires), plus highway tolls, en route commercial lodging, and the value of time.

An 0.1876 cents per mile has been assumed for car operating costs in 1984. A value of 2 cents per mile has also been included for accident cost, based on National Safety Council (NSC) dollar values (NSC, 1982).

1) Highway tolls. The Atlas indicates the location and the costs of toll roads in the highway network. Our routes were matched with the Atlas, and an average of $1.50 per toll road (one way) is included in auto cost if necessary.

2) Overnight lodging. A maximum driving distance of 500 miles per day is assumed to compute the number of overnight stops on long auto trips. An average lodging cost of fifty dollars per day is assumed throughout the study.

3) Value of time. An average value of 10 dollars is assumed for travelling by car. With the above information on hand, Table V shows the cost of travelling by car in our hypothetical network.

TABLE V

AUTO TRAVEL COST

	Operating Cost ($)	Toll Cost ($)	Lodging Cost	Time Cost $10 Per Hour	Total ($)
OKC-Wichita	26.46	1 50	–	25 6	53.56
OKC-Tulsa	19.33	1.50	–	18.7	39 53
OKC-Dallas	38.85	–	–	37.6	76.45
OKC-Corpus Christi	119 25	–	50	114.5	283.75
OKC-Nashville	126.09	–	50	122.2	298.29
OKC-St. Louis	93.24	–	–	90.4	183.64
OKC-Charleston	214.48	–	100	207.8	522.28
OKC-Rochester	244.01	1.50	100	236.4	581.91
OKC-Los Angeles	253.73	–	100	245.8	599.53

MAG-LEV Travel Time. The MAG-LEV travel time variable between OKC and other destinations is composed of three different parts, line-haul time between cities, access and egress time, and rail station waiting time.

1) Line-haul time. Since there is no historic data about MAG-LEV characteristics in Oklahoma, information on cost, time, and frequency of MAG-LEV trains has been obtained from the Florida study of high speed trains, mainly "Report No: 6, Intercity Market Analysis."

For line-haul time between OKC and other selected cities, it is assumed that five stations, including both origin and destination, will be built along each corridor.

For calculating the travel time, an average speed in "minutes per mile" was computed from Florida's study of high speed trains. For each scenario three different sample corridors in terms of distance were chosen, and after calculating a speed in "minutes per mile" for each sample corridor, the average "minutes per mile" was taken as a measure for travel time by the MAG-LEV Train (speed of MAG-LEV train) in different corridors. For a five-station scenario, the average travel time and the samples are as shown below:

	Distance	MAG-LEV Travel Time(Min)	Speed (Min Per Mile)
Tampa/Miami	320	90.4	90.4/320 = 0.28
Tampa/Orlando	85	23.8	23.8/85 = 0.28
Orlando/W. Palm Beach	170	44.2	44.2/170 = 0.26

0.28 + 0.28 + 0.26 = 0.82/3 = 0.27 minutes per mile for the five station scenario

2) Access and egress time. Due to the lack of data on the exact location for the rail stations at this point, the same figures for travel by airplane in each corridor are assumed for MAG-LEV.

Rail terminal waiting time. A figure of 51 minutes, just like air terminal waiting time, will be assumed for rail terminal waiting time.

Based upon the above components of the rail travel time variable, Table VI shows the value of this variable in each corridor.

TABLE VI

MAG-LEV TRAVEL TIME

	Line-Haul Time (Dist) (0.27) = Min	Access and Egress Time (Min)	Terminal Waiting Time (Min)	Total Travel Time (Min)	Total Travel Time (Hrs)
OKC-Wichita	38	35	51	124	2 06
OKC-Tulsa	27.8	35	51	113.8	1 89
OKC-Dallas	55.8	55	51	161.8	2.69
OKC-Corpus Christi	170.1	40	51	261.1	4.35
OKC-Nashville	181.4	50	51	282.4	4.70
OKC-St. Louis	134.1	50	51	235 1	3.91
OKC-Charleston	308	25	51	384.61	6 41
OKC-Los Angeles	365	65	51	481	8.01
OKC-Rochester	351	10	51	412	6.87

<u>MAG-LEV Travel Cost Variable</u>. This variable is composed of three parts, 1) line-haul cost, 2) time cost, and 3) access and egress cost. The same fare structure used for Florida's study of high speed trains is adopted here. The rail system unit fare was calculated on the basis of fares of $0.25 per mile for distances between one and ninety-nine miles; $0.20 per mile for distances between one hundred and 199 miles, $0.15 per mile for trips between 200

miles and 500 miles and $0.10 for distances of more than 500 miles (Morrison and Winston, 1985). These fares are rounded to the nearest dollar. This type of fare structure ensures that shorter trips have a higher rate than longer trips.

Since one of the basic assumptions is based upon constructing MAG-LEV train facilities on interstate highways, the distance between cities will be identical to those that have been computed for travelling by car. The line-haul cost (fare) is simply the product of distance and average fare per mile.

The value of time for trips by MAG-LEV is based upon 10 dollars an hour. Access and egress costs are the same as for travelling by airplane. Table VII shows the value for the MAG-LEV travel cost variable in each corridor.

TABLE VII

MAG-LEV TRAVEL COST

	Line-Haul Cost ($) (DIST) (FARE)	Value of Time $10 Per Hour	Access & Egress Cost	Total Cost ($)
OKC-Wichita	141(0.20) = 28.00	20.7	13.5	62.2
OKC-Tulsa	103(0.20) = 21.00	19	15	55
OKC-Dallas	207(0.15) = 32.00	27	12	71
OKC-Corpus Christi	630(0.10) = 63.00	43.5	12	118.5
OKC-Nashville	672(0.10) = 67.00	47.1	12	126.1
OKC-St. Louis	497(0.15) = 75.00	39.2	12	126.2
OKC-Charleston	1143(0.10) = 114 30	64.1	7	185.4
OKC-Rochester	1300(0.10) = 130.00	68.7	5	203.7
OKC-Los Angeles	1352(0.10) = 135.00	80 2	12 5	227.7

Air Frequency Variable. The air frequency variable has been calculated from the August 1984 issue of OAG. A daily average flight frequency is computed for each corridor.

Auto Travel Frequency Variable. In order to provide complete data on all modes, it is necessary to provide a departure frequency value for automobile travel. The requirement is to select a frequency that is much higher than any of those encountered on a common carrier, to reflect the virtually instant departure capability of the automobile. In this study an average frequency of 96 per day for automobiles has been assumed.

MAG-LEV Frequency Variable. MAG-LEV frequency has been selected in such a way as to represent a minimum frequency requirement, so eight trains per day is assumed. Table VIII shows the value of frequency for each mode under consideration.

TABLE VIII

AVERAGE DAILY FREQUENCY DEPARTURE
OF DIFFERENT MODES

Corridor	Air	Car	MAG-LEV
OKC-Wichita	3	96	8
OKC-Tulsa	13	96	8
OKC-Dallas	28	96	8
OKC-Corpus Christi	10	96	8
OKC-Nashville	20	96	8
OKC-St Louis	14	96	8
OKC-Los Vegas	6	96	8
OKC-Orlando	5	96	8
OKC-Los Angeles	44	96	8

Socio-Economic and Demographic Variables

Population Variable. A factor that is expected to influence trip generation between two nodes is the size of those nodes, as measured by their population. The population variable is one of the most important factors in the gravity type model, and it seems safe to hypothesize that, other things being equal, population has an increasing effect upon travel, especially non-business travel. In this study, we examine both the population in each city and the population products as explanatory variables and show their impact on trip generation. The statistical abstract of the United States is used to obtain these data.

Employment Variable. Cities are characterized by different mixes of employment activities, and it is assumed that this variable affects the number of trips generated from each city. The number of business trips especially is closely related to the number of employees in high travel demand occupations, rather than to population in general. Again since we are testing the existing demand models, data on two variables have been collected. First is the employment in non-agricultural sectors in different MSA's and PMSA's; and the second is the employment in the manufacturing sector. Depending on the definition of each variable in each model, the relevant employment figure will be used. Employment data are taken from "employment, hours and earnings, states and areas, 1972-87," and represent employment as of 1984.

Income Variable. Researchers in most prior travel demand studies have confirmed that income significantly affects travel demand. In particular, it is believed that income is an important determinant for non-business travel. Data for per capita income in different cities for 1984 were taken from the Survey of Current Business.

Per Capita Deposits Variable. Per capita deposits were used by some of the researchers to reflect the role of these deposits in intercity travel demand (Quandt and Baumol, 1966). Although, the empirical estimate of this coefficient appears to be insignificant, since we are testing Quandt and Baumol's demand models, data on this variable have been collected.

Because of the lack of data on per capita deposits in 1984 for different MSA's, the following methodology has been chosen to construct this variable: data on bank deposits for June of 1983 and their percentage growth with respect to 1982 were taken from the state and metropolitan area data book; then it is assumed that the same growth rate pertained from 1983 to 1984. The amount of total bank deposits for 1984 for each city is computed and then is divided by the population of each city to get a per capita bank deposit variable in 1984.

Table IX represents the values for the above discussed variables.

TABLE IX

SOCIO-ECONOMIC AND DEMOGRAPHIC DATA FOR 1984

City	Population (1000)	Per Capita Income($)	Per Capita Deposits($)	Total Empl. in Non-Ag(1000)	Empl. in Manuf acturing(1000)	Empl. in Gov Sector(1000)	Percentage of Empl. in Manufacturing	Percentage of Empl. in Gov
Oklahoma City	963	13201	10337	434.6	54.1	96	12 4	22
Tulsa	726	12962	7435	301.8	51.4	34.1	17	11
Wichita	428	14173	7413	200 6	54 5	24 4	27.1	12
Dallas	2204	15861	11577	1248 7	226.7	128 6	18.1	10
ST.Louis	2398	13991	6509	133.1	13 3	27	9.9	20
Nashville	890	12125	6540	1046 7	227.8	136 2	21.7	13
Rochester	989	13874	8754	407.5	86 8	60.7	21.3	14
Los Angeles	7901	14526	8023	166.3	20	47 2	12	28
Charleston	473	10099	2517 3	436.3	149 1	60	34	13
Corpus Christi	361	10923	6470	3723.5	885	467.7	24	12

Source(Per Capita Income) Survey of Current Business, April 1986, Volume 66, #4, pp 41-43
Source(Per Capita Deposits) State and Metropolitan Area Data Book, 1986
Includes deposits for all insured and noninsured commercial and mutual savings banks Excluded public deposits
Source(Employment) Employment, Hours, and Earnings, States and Areas, 1972-87, Vol 1-5, Bureau of Labor Statistics, March 1989
Wichita figures of employment covers Harvey County too
Source(Population) Statistical Abstract of the United States, 1986, p 22
Geographic boundary for each city
OKC (MSA) includes Canadian, Cleveland, Logan, McClain, Oklahoma, and Pottawatomie counties
Tulsa (MSA) includes Creek, Osage, Rogers, Tulsa, and Wagoner county
Wichita (MSA) includes Butler and Sedgwick county
Dallas - Fort Worth (PMSA) covers Dallas, Collin, Denton, Ellis, Kaufman, and Rockwell counties
Corpus Christi (MSA) covers Nueces and San Patrico counties
St Louis (MSA) cover the following counties Franklin, Jefferson, St Charles, St Louis, St Louis City, Clinton (IL), Jersey (IL), Madison(IL), Monroe (IL), Monroe (IL), St Clair (IL)
Nashville (MSA) covers the following counties Cheatham, Davidson, Dickson, Robertson, Rutherford, Sumner, Williamson, Wilson
Rochester (MSA) includes Monroe, Orleans, Livingston, Ontario, Wayne counties
Charleston (MSA) includes Berkeley, Charleston and Dorchester counties
Los Angeles (PMSA) refers to Los Angeles and Long-Beach only

CHAPTER IV

MODEL TESTING

With the information provided in Chapter III, the present chapter accomplishes two tasks. First, it examines six different versions of Quandt and Baumol models, and second, it discusses the specific model estimates that are used as input data in the linear programming model of chapter V.

The reason that two different approaches have been used in this study is that, in any type of demand model, a few variables characterize the travel behavior of people, but there are other factors that can hardly be incorporated into these models. They are mostly qualitative rather than quantitative factors. This is why in some studies ridership estimates are derived by using linear programing models, based on some criterion such as cost minimization or other criteria. Neverthless, demand models are useful in terms of ridership estimates, relative standing of each mode, and the effect of introducing a new mode of transportation.

According to the above reasoning, the present chapter is devoted to a test of the "abstract mode demand" models of Quandt and Baumol and analysis of their results. In the next two sections, the theoritical foundation of the Quandt and Baumol model and the results of the application of their model in this research are discussed in detail.

Quandt and Baumol's Model Description

To gain an insight into the number of trips generated and distributed from the origin, namely Oklahoma City, some of the previous demand models are tested. The impact of the introduction of MAG-LEV trains on the number of trips generated and distributed by existing modes (car and airplane) is also investigated.

The existing literature on intercity travel demand modelling offers a wide variety of research that has been done on this subject, making it difficult to choose among them. However, since our problem is one of introducing a new mode, this research concentrates on those models that allow for such a goal to be achieved.

The set of demand models that have been selected belongs to the class of aggregate demand models, in which a single equation predicts the total volume of travel between two cities by each mode of transportation. Furthermore, they are also classified as "abstract mode models" in the sense that modes are characterized in terms of features such as travel time, cost, departure frequency, and other convenience factors. The choice of a mode then depends on both the absolute performance level of the best mode and the performance level of each mode relative to the best mode.

As noted earlier, Quandt and Baumol (1966) introduced the idea of abstract mode models. They specified different demand models and estimated them for sixteen city pairs in California in 1960. Other researchers, including Young (1969), Monsod (1969), Kraft (1963), Mayberry (1968), McLynn and Waronka (1969), have proposed different versions of abstract mode models and most of these models have been tested for different intercity corridors, for example Lave (1972), Lave (1977), Bertucci et al. (1985), Crow & Savitt (1974), Bennett et al. (1974), Gantzner (1979), Cohen et al. (1978).

A summary of the estimation results of different demand models along with the reported t-ratios (in parentheses) together with the coefficient of correlation and the F-statistic for testing the general linear hypothesis is shown in Table X.

TABLE X

RESULTS OF ESTIMATION FOR QUANDT AND BAUMOL MODEL

	Model						
Variable	1	2	3	4	5	6	7
Constant	-31 91	-38 04	-40 71	-33.82	-36 67	-32.56	-28.73
	(-0 95)	(-1 14)	(-0 69)	(-1 62)	(-1 62)	(-1 37)	(-1 25)
log P_i	0 95	0 92	0 94	0 93	0.91	0.95	0.88
	(5 88)	(4.44)	(3.71)	(6.99)	(7.40)	(7.54)	(6 95)
Log P_j	1 08	1.14	1.14	1.12	1 14	0 99	0 88
	(5 14)	(6.20)	(6.37)	(6.38)	(6 95)	(6.41)	(5 47)
log Y_i	1.75	4.59	3.32	2.64	–	–	–
	(0.53)	(1.30)	(0.33)	(1 05)			
log Y_j	3 71	3 11	3 02	3.72	–	–	–
	(0.99)	(1.01)	(0 99)	(1 43)			
log D_i	0.67	–	–	–	–	–	–
	(0.57)						
log D_j	0.17	–	–	–	–	–	–
	(0.19)						
log W_i	–	–	-0.36	–	–	–	–
			(-0.05)				
log W_j	–	–	2.38	–	–	–	–
			(0.76)				
M_i	–	-0 73	–	–	–	–	–
		(-0 53)					
M_j	–	-0 96	–	–	–	–	–
		(-1 15)					
log C^b_{ij}	-0 99	-0 61	-1.57	-1 20	-1 12	-0 62	-0.57
	(-1 19)	(-0.70)	(-1 75)	(-1 69)	(-1 68)	(-1 04)	(0.99)

TABLE X (Continued)

Variable	Model 1	2	3	4	5	6	7
$\log C^{r}_{kij}$	-3.17	-3.15	-3.18	-2.62	-3.17	-3.15	-2 34
	(-11.40)	(-11 51)	(-11 48)	(3.59)	(11.82)	(-11.62)	(-4.54)
$\log H^{b}_{ij}$	-0 32	-0.92	0 59	-0.15	-0.20	-1.19	-1 20
	(-0.21)	(-0 59)	(0 36)	(-0 12)	(-0 16)	(-1.17)	(-1 23)
$\log H^{r}_{kij}$	-2 04	-2 01	-2.05	-1.73	-2.04	-2 01	-1 75
	(-5.45)	(-5.45)	(-5.51)	(-3.23)	(-5.66)	(-5.51)	(-4.59)
$\log (Y_i + Y_j/2)$	–	–	–	–	6.83	–	–
					(2 35)		
$\log (P_iY_i + P_jY_j/P_i+P_j)$	–	–	–	–	–	6.33	5.82
						(2.08)	(1 96)
$\log F^{r}_{kij}$	–	–	–	–	–	–	0 44
							(1.83)
$\log A_{ij}$	–	–	–	0.66	–	–	–
				(0 81)			
R	0.9355	0.9376	0.9360	0.9361	0 9350	0.9331	0.9386
F	25 94	26 91	26.18	29.92	39.70	38.49	36 09

Source Quandt (1966)

Notations.

Tk_{ij} = travel volume from city i to city j by mode k;
P = population;
Y_i = per capita income in the ith city,
D_i = per capita deposits in the ith city,
M_i = percent of employment in manufacturing in the ith city;
W_i = percent of employment in white collar occupations in the ith city,
H^{b}_{ij} = best travel time between i and j,
H^{r}_{kij} = relative travel time between i and j by mode k;
C^{b}_{ij} = least travel cost between i and j;
C^{r}_{kij} = relative travel cost between i and j by mode k;
A_k = a dummy variable indicating the availability of a car at the end of the trip, if one takes mode k; if k refers to automobile, the value of A_k was set at e = 2.718 . ., otherwise $A_k = 1$;
F^{r}_{kij} = relative frequency by departure from i to j by mode k. It is assumed that daily departures by automobile is 96

The first and one of the most important assumptions in the Quandt and Baumol models is modal neutrality, which is quite comparable to the neutrality towards risk exhibited by persons who have a Von-Neumann Morgenstern utility index (Quandt & Baumol, 1966, p. 15). In other words, a modally neutral person chooses among modes purely in terms of the type of service it provides to the traveller and not in terms of what they are called. Furthermore, all of these models contain at least some socio-economic and demographic variables, because it is assumed that travel propensities not only depend on modal characteristics, but also on the environment in which travel takes place. Another assumption is the use of aggregate data.

Quandt and Baumol (1966) estimated seven different demand models, the demand models are in logarithmic form; i.e., the logarithm of the demand is linear in the logarithms of variables included. Population at each node, being a demographic variable, is common in all these models, and it is the most important demographic factor that influences the volume of travel between node i and j. It is quite rational to hypothesize that, other things being equal, population has an increasing effect upon travel. Household disposable income is also included in the models in one form or another. The justification for including this variable in demand models has been expressed by Quandt (1970) as, "(a) it provides an indirect way of including the budget constraint of the consumer, expressing the belief that travel is not an inferior good and that higher incomes will lead to more travel, and (b) it can be used to account for the frequent observation that the value of time increases with income" (Quandt, 1970, p.1). Other variables, basically measuring the degree of concentration of service industries, financial activity, and employment have been tested in some of these models. The variables which characterize the mode of travel will include at least two characteristics:

(a) the least required travel time between i and j (termed the "best "one), H^{b}_{ij}, and relative travel time for the k^{th} mode, H^{r}_{kij}, computed as the ratio of the travel time by the k^{th} mode divided by the "best" travel time.

(b) the least cost of travel between i and j, C^{b}_{ij} ("best" cost), and the relative cost for the k^{th} mode, C^{r}_{kij}, computed as the ratio of the cost of travelling by the k^{th} mode divided by the "best" cost of travelling by any mode. Convenience of travel between i and j represented by relative departure frequency F^{r}_{kij} has been tested in one of the demand equations.

Quandt and Baumol made the following comments on their estimation results:

(1) In every single demand model, the estimated coefficient of populations at both i and j are highly significant and of the expected sign. They range from 0.88 to 1.14, showing a positive relationship between the demand for travel and population at each mode.

(2) The inclusion of the per capita income variable in separate form in the first four demand models yields a positive but not statistically significant elasticity of income. It is apparent that income elasticity is greater than zero but less than 4. In one equation (model number 5), Y_i and Y_j are replaced with average per capita incomes at two nodes, in this case the coefficient has the correct sign. In equations 6 and 7, Y_i and Y_j are replaced by a weighted average of population and income.

(3) In equation number 4, A_{ij}, the dummy variable of the availability of a car at the end of the trip has the correct sign but is not significant. The variable F^{r}_{kij} (relative departure frequency) in equation 7 has the correct sign and is nearly significant.

(4) The coefficients of variables D_i and M_i in the first two equations have the correct sign but contribute no significant explanatory power to the models. The coefficient of w_i has the expected sign in one case but in another it did not.

(5) The coefficients of the variables related to best cost, relative cost, best time, and relative time all are negative as we expect (except for one coefficient in model three (H^{b}_{ij}) which is positive). As Quandt and Baumol hypothetized, the demand for travel is more sensitive to relative cost and time than to best cost and best time. This observation can be confirmed by looking at the sign and magnitude of relative cost and relative time coefficients in all equations. They seem all to be highly significant in all models.

(6) F-values are all significant, a problem of multicollinearity not reported, and correlation of coefficients indicates a successful explanation of a great fraction of the variation in the dependent variables.

(7) It seems that the set of estimated coefficients for variables in each equation is quite consistent from one regression to another.

Results from the Application

We now turn our attention to the discussions of the results that have been obtained by the application of our data in each model. For estimating ridership by each mode for each model mentioned in the previous section, two scenarios have been assumed. First, ridership is computed based upon the existence of car and airplane as sole providers of transportation services for the people. Second, the same ridership is computed based upon the assumption of introducing MAG-LEV trains as a third possible choice for those wishing to undertake an intercity trip.

Since the models are built upon the combination of two different variables, a) socio-economic and demographic, and b) modal characteristics such as best travel time and cost and relative travel time and cost, the choice of the MAG-LEV train is introduced only in terms of its characteristics, such as travel time, cost, and departure frequency.

Out of the seven estimated models analyzed, three models have been eliminated from further consideration. Model (5) generated a very low ridership. In model (7), a reduction of ridership in the OKC-Los Angeles corridor was observed once we introduced MAG-LEV trains. Model (4) resulted in the same problem in the OKC-Wichita corridor. Model (3) was not estimated because of data limitations. From the remaining models, (1), (2), and (6), the results are very consistent (at least percentage wise, if not in magnitude).

Tables XI and XII present the results obtained by the application of Quandt and Baumol's models before and after the introduction of MAG-LEV trains. These tables show that ridership has a direct relationship to city size, distance and modal characteristics, so ridership is higher by car in close distances because of its cost advantages. The situation is reversed as distance increases and people place more value on time rather than cost. Table XIII (total ridership) shows that, as a result of introducing MAG-LEV trains, not only does total ridership increase but some people who were travelling by car and airplane before the existence of MAG-LEV trains now show preferences for choosing MAG-LEV as their mode of transportation. The total percentage change in ridership (Table XIII) shows that for small and medium size cities which are located close to Oklahoma City (such as Wichita and Tulsa), the introduction of MAG-LEV trains increases total ridership by an average of 52 percent, including modal shift. This is partly because the car travel stands best andpeople would rather use cars and little induced demand for travel is

TABLE XI

RIDERSHIP IN DIFFERENT MODELS BEFORE THE INTRODUCTION OF MAG-LEV

	Car Ridership In Model						Air Ridership In Model					
	1	2	4	5	6	7	1	2	4	5	6	7
OKC-Wichita	7100	7068	609	25	1691	10352	709	715	20	2	171	428
OKC-Tulsa	17912	23540	1547	68	4733	26239	673	904	22	3	182	950
OKC-Dallas	29703	35741	2574	103	7303	37884	16991	20386	361	59	4166	15976
OKC-Corpus Christi	35	65	4	0	13	138	652	1160	10	2	224	545
OKC-Nashville	312	470	28	1	74	554	1593	2338	24	6	370	1128
OKC-St. Louis	3763	4852	361	14	746	4459	2852	3644	65	11	560	1817
OKC-Charleston	11	28	1	0	5	55	240	555	4	1	102	378
OKC-Rochester	83	80	9	0	15	145	1907	1761	27	6	329	828
OKC-Los Angeles	270	345	44	1	50	532	32012	38844	532	120	5569	17561

TABLE XII

RIDERSHIP IN DIFFERENT MODELS AFTER THE INTRODUCTION OF MAG-LEV

	Car Ridership, Model						Airplane Ridership, Model						MAG-LEV Ridership, Model					
	1	2	4	5	6	7	1	2	4	5	6	7	1	2	4	5	6	7
OKC-Wichita	6493	6679	561	23	1620	10060	592	675	18	2	164	416	6296	6453	121	22	1565	3475
OKC-Tulsa	17912	23540	1547	68	4733	26239	614	904	22	3	182	950	6152	8141	140	23	1637	3985
OKC-Dallas	25281	29620	2318	88	6057	33236	13189	16895	325	51	3455	14015	63284	73296	1099	221	14988	23792
OKC-Corpus Christi	10	16	2	0	3	52	166	282	4	1	56	207	1122	1715	19	4	340	730
OKC-Nashville	38	45	7	0	8	112	175	225	6	1	37	227	4026	4634	72	16	769	1490
OKC-St Louis	1168	1496	153	4	244	2051	807	1124	27	3	183	836	21147	26235	381	81	4281	7152
OKC-Charleston	2	3	0	0	1	13	35	68	1	0	13	88	543	931	11	3	173	373
OKC-Rochester	12	10	2	0	2	34	257	211	7	1	41	193	4311	3159	71	15	614	1161
OKC-Los Angeles	143	164	29	1	24	317	15438	18488	352	66	2658	10468	30064	32814	561	117	4718	7243

TABLE XIII

TOTAL DAILY RIDERSHIP BY ALL MODES

	Ridership Before MAG-LEV			Ridership After MAG-LEV			Percentage Increase		
	Model1	Model 2	Model 6	Model 1	Model 2	Model 6	Model 1	Model 2	Model 6
OKC-Wichita	7809	7783	1682	13381	13807	3349	71 3	77.3	99
OKC-Tulsa	18585	25555	4915	24678	32585	6552	32.7	33 3	33.3
OKC-Dallas	46694	56127	11469	101754	119811	24500	117 9	113.4	113 6
OKC-Corpus Christi	687	1225	237	1298	2013	399	88.9	65	68.3
OKC-Nashville	1905	2808	444	4239	4904	814	122.5	74.6	83.3
OKC-St. Louis	6615	8496	1306	23122	28855	4708	249.5	239.6	260.4
OKC-Charleston	251	583	107	580	1002	187	131	71.8	74
OKC-Rochester	1990	1841	344	4580	3380	657	130	83.5	90
OKC-Los Angeles	32282	39185	5619	45645	51466	7400	41.3	31.3	31

generated.

However, when we introduce MAG-LEV in other corridors, a great deal of increase in total ridership is observed; some of this increase is due to modal switch, but the greatest portion comes as an induced demand. Table XIV compares diverted and induced demand in different models of Quandt and Baumol for different corridors.

One of the interesting implications of this table is that not too many people were interested in switching their mode of transportation to MAG-LEV trains for close distances, such as Wichita, Tulsa, and Dallas. However, the greatest portion of increase in total ridership comes from induced demand; it is shown that almost 90% (on average) of total increase in ridership in Wichita, Tulsa, and Dallas corridors are due to the introduction of MAG-LEV. This situation is different in other corridors, in which a higher percentage of people are willing to switch to MAG-LEV trains. It can also be observed that the average percentage share of induced demand in the last six corridors is about 60% of total MAG-LEV ridership.

In order to draw a general conclusion about the effect of introducing the MAG-LEV trains, Table XIV is analyzed in more detail and the following comments are made for each corridor:

1) OKC-Wichita: (small city and close distance from OKC). As a result of the introduction of high speed trains, total ridership has been increased by 71.3, 77.3 and 99 percent in models (1), (2), and (6), respectively. MAG-LEV has been able to attract an average of 6 percent of car ridership and an average of 8.6 percent from airplane ridership. These two will contribute only about 7.7 percent (on average) of total MAG-LEV ridership, the remaining (92.3 percent)

TABLE XIV

DIVERTED AND INDUCED DEMAND IN DIFFERENT MODELS

	Diversion From Car to MAG-LEV in Model (Person)			Percentage of Diversion From Car to MAG-LEV			Diversion From Airplane to MAG-LEV in Model (Person)			Percentage of Diversion From Airplane to MAG-LEV in Model			Induced Demand For MAG-LEV in Model			Total MAG-LEV Ridership in Model			Percentage of Induced Demand in Model		
	1	2	6	1	2	6	1	2	6	1	2	6	1	2	6	1	2	6	1	2	6
OKC-Wichita	607	389	71	8 5	5 5	4 1	117	40	7	16 5	5 5	4	5572	6024	1487	6296	6453	1565	88 5	93 3	95
OKC-Tulsa	0	0	0	0	0	0	59	0	0	8 7	0	0	6093	8141	1637	6152	8141	1637	99	100	100
OKC-Dallas	4422	6121	1246	14 8	17 1	17	3802	3491	711	22 3	17 1	17	55060	63684	13031	63284	73296	14988	87	86 8	87
OKC-Corpus Christi	25	49	10	71 4	75 3	77	486	878	168	74 5	75 6	75	601	788	162	1112	1715	340	54	45 9	48
OKC-Nashville	274	425	66	87 8	90 4	89 2	1418	2113	333	89	90 3	90	2334	2096	370	40260	4634	769	57 9	45 2	48
OKC-St Louis	2595	3356	502	68 9	69 1	67 3	2045	2520	377	71 7	69 1	67 3	16507	20359	3402	21147	26235	4281	78	77 6	79 5
OKC-Charleston	9	25	4	81.8	89 2	80	205	487	89	85 4	87 7	87 2	329	419	80	543	931	173	60 5	45	46 2
OKC-Rochester	71	70	13	85 5	87 5	86 7	1650	1550	288	86 5	88	87 8	2590	1539	313	4311	3159	614	60	48 7	51
OKC-Los Angeles	127	181	26	47	52 4	52	16574	20350	2911	51 7	52 3	52 2	13363	12283	1781	30064	32814	4718	44 4	37 4	38

of total MAG-LEV ridership comes from induced demand that is created by the characteristics of this new mode of transportation.

2) OKC-Tulsa: (medium size city and close distance from OKC). In this corridor, total ridership has been increased by 32.7, 33.3 and 33.3 in the three models, respectively. Furthermore, the introduction of MAG-LEV trains did not attract any new travellers from car ridership to MAG-LEV, in all three models, and attracted only 8.7 percent of airplane passengers in model (1) and none in the other two models. So introducing MAG-LEV trains in this corridor attracts none from other modes of transportation, and almost 100 percent of MAG-LEV ridership is caused by the introduction of this particular mode of transportation.

3) OKC-Dallas: (large city size and close distance from OKC). This corridor showed a 117.9, 113.4 and 113.6 percent increase in total ridership in all three models. An average of 16.3 percent of car travellers and 18.8 percent of airplane ridership shifted to MAG-LEV trains as a result of introducing this mode of transportation. The modal shift in this corridor contributes about 13 percent of total MAG-LEV ridership and the rest of it (87 percent) is created by MAG-LEV characteristics themselves.

4) OKC-Corpus Christi: (small city size and medium distance from OKC). In this corridor, total ridership has been increased by 88.9, 65 and 68.3 percent in the three models, respectively, after introducing MAG-LEV trains. The decreases in car ridership in the three models are very close and average 74.5 percent. The percentage reductions in airplane ridership in the models are also very close and average about 75 percent. Although introducing MAG-LEV in this corridor causes about 75 percent reduction in both air and auto ridership, this contributes about 50.7 percent of the total MAG-LEV ridership and the other 49.3 percent is induced demand.

5) OKC-Nashville: (medium city size and medium distance from OKC). This corridor also showed a good potential for increase in total ridership; for example, the increase ranges from 74.6 to 122.5 percent. The introduction of MAG-LEV trains was able to motivate people to switch their mode of transportation from car and airplane with an average of 89.4 percent for all three models; however, this percentage contributes 49.7 percent of total MAG-LEV ridership. So 50.3 percent of ridership by MAG-LEV was generated by its characteristics as a new choice to people.

6) OKC-St. Louis: (large city size and medium distance from OKC). This route shows a ridership increase of 249.5, 239.6 and 260.4 percent by all three models, respectively. Introducing MAG-LEV results in an average shift of 68.4 and 69.3 percent from car and airplane ridership, respectively. These figures only contribute about 22 percent of the total MAG-LEV ridership, showing that almost 78.3 percent of the MAG-LEV ridership is generated by itself.

7) OKC-Charleston: (small city size and far distance from OKC). This corridor generates a 131, 71.8 and 74 percent increase in total ridership in the three models after introducing MAG-LEV trains. An average shift of 83.6 and 86.7 percent in car and airplane ridership is observed in all three models. However, these contribute 49.5 percent of total MAG-LEV ridership, and the rest of it (50.5 percent) is generated as new trips.

8) OKC-Rochester: (medium city size and far from OKC). An average increase of 101 percent in total ridership is shown by all three models. An average shift of 87 percent in car and airplane ridership is observed, which in turn, contributes to 46.8 percent of total MAG-LEV ridership; the rest of it (53.2 percent) is generated by MAG-LEV itself.

9) OKC-Los Angeles: (large city size and far distance). Once MAG-LEV is introduced in this corridor, an increase of 41.3, 31.3 and 31 percent in total

ridership is observed. Changes in car and airplane ridership are estimated at about 51.2 percent for both. The share of new trips generated by MAG-LEV is not more than 39.9 percent of total MAG-LEV ridership, and the rest of it comes from people's switching their modes of transportation to MAG-LEV.

CHAPTER V

LINEAR PROGRAMMING APPROACH FOR ESTIMATING OPTIMAL RIDERSHIP

In this chapter, two methods for searching the optimal ridership on each mode under consideration are examined. The technique is based upon linear programming. The first part of this chapter utilizes a single objective function, while the second part uses a multi-objective function approach. Each part consists of two subparts that discusse 1) the theoretical foundation of the model under consideration and an appropriate algorithm, and 2) an analysis of the results.

Single Objective Function

Model Description

In the standard transportation model in linear programming, many centroids act as producers and attractors of traffic (Potts and Oliver, 1972). So there exist "n" origins and "m" destinations and the objective is to design an optimization problem that gives a least-cost shipping schedule. The transportation network constructed in this research is a single O-D network, with one origin and one destination. All other traffic, except that between the O-D pair under question, is ignored.

The model in this research also adopts Kirchhoff's law, which is a conservation law stating that the sum of all flows leaving the centroid equals the flow produced at that centroid. Potts and Oliver (1972, p.26) define Kirchhoff's law:

> for steady or static condition, flows are neither created nor destroyed. The steady condition for traffic applications implies that we are not concerned with the microscopic and stochastic characteristics of a traffic stream of individual vehicles travelling at random or in platoons on a city street network, but rather with the gross macroscopic behavior of traffic as, for example, on a main road network. We ignore fluctuations over time.

Since transportation projects usually require forecasts of various types, difficult statistical problems of estimation may arise, especially with the lack of data. It is thus assumed that travellers' destinations are known with certainty, and demand at each destination will be met. It is also assumed that transportation services are needed for transporting a single type of homogeneous commodity, namely people. In addition, this model requires the assumption that the routes (modes) between any pair of centroids do not have an infinite capacity. There is some maximum number of vehicles per day that a given interstate highway can accommodate, or a maximum number of people that can travel by airplane or MAG-LEV train per unit of time. In general, it is assumed that route (mode) capacities are fixed in the short-run.

With these above assumptions in consideration, the model discussed below shows a general framework of a linear programming model dealing with transportation.

The objective function is total cost associated with a solution and is given by:

$$Z = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} C_{ij}^{k} X_{ij}^{k}$$

where

i, j, k = origin, destination, and mode

C_{ij}^{k} = cost of travelling from i to j by mode k (constant). The constancy of C_{ij}^{k} implies the absence of congestion. (The only difference between the present model and orthodox transportation models, is that in this case constant cost shipments are possible only up to the capacity of the arc between i and j and beyond that, not at all, while in the orthodox transportation problem, constant-cost shipments from i to j are possible in any volume not inconsistent with the capacity of i. To take into account the problem of congestion, C_{ij}^{k} should be a function of degree of utilization and that makes the problem non-linear.)

X_{ij}^{k} = number of people who are travelling from i to j by k.

The optimum solution of ridership is defined as one that has minimum total cost subject to the following constraints:

1) The first set of constraints ensures that the ridership from any origin to all possible destinations equals the total trips generated from that origin. This equality is expressed as:

$$\sum_{j=1}^{m} \sum_{k=1}^{P} X_{ij}^{k} = G_i \qquad i = 1, ..., n$$

where

G_i = total trip generated from each i.

2) The second set of constraints ensures that the demand at each destination is met. Demand for travel at each destination may be characterized by any number of relevant socio-economic and demographic variables. This constraint can be written as:

$$\sum_{k=1}^{P} \sum_{i=1}^{n} X_{ij}^{k} \geq d_j \qquad j = 1, ..., m$$

where

d_j = demand at each j

The constraint states that the number of people who are going from any i by different modes to a particular destination j, should be greater than, or equal to demand at that destination.

3) The third set of constraints is set up to take into account the capacity constraint for each mode. It states that the number of people who are travelling by a particular mode should be less than or equal to its capacity. This inequality can be shown as:

$$X_{ij}^{k} \leq K_k \qquad \text{for} \quad i = 1, ..., n$$

$$j = 1, ..., m$$

$$k = 1, ..., P$$

where

K_k = capacity of the Kth mode. It should be noted that in terms of travelling by car, it refers to interstate highway capacity.

4) The last set of constraints deals with the nonnegativity of variables such as:

$$X_{ij}^{k} \geq 0 \qquad \text{for} \quad i = 1, ..., n$$

$$j = 1, ..., m$$

$$k = 1, ..., P$$

A complete linear programming model then is:

$$\text{Min } Z = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{p} C_{ij}^{k} X_{ij}^{k}$$

subject to

$$\sum_{j=1}^{m} \sum_{k=1}^{P} X_{ij}^{k} = G_i \qquad i = 1, ..., n$$

$$\sum_{k=1}^{P} \sum_{i=1}^{n} X_{ij}^{k} \geq d_j \qquad j = 1, ..., m$$

$$X_{ij}^{k} \leq K_k \qquad i = 1, ..., n; \quad j = 1, ..., m; \quad k = 1, ..., P$$

$$X_{ij}^{k} \geq 0 \qquad i = 1, ..., n; \quad j = 1, ..., m; \quad k = 1, ..., P$$

The data of the model are the demand for travel, the trip generation at each i, and the unit transportation (travel) cost from i to j. The levels of travel are the variables of the first LP model. They are selected to minimize the total transportation cost. The variables in the second LP model (dual) are the price (fare) which maximizes total revenue subject to the condition that every possible travel volume must yield a non-negative profit. The optimum solution for these two problems provides a complete description of the perfectly competitive short-run equilibrium for the transportation industry.

Since in this research there are nine different O-D networks, with Oklahoma City chosen as the origin in all these corridors, and the modes under consideration are car, airplane and MAG-LEV trains, the following LP model is estimated:

$$\text{Min } Z = \sum_{j=1}^{9} \sum_{k=1}^{3} C_{OKC,j}^{k} \, X_{OKC,j}^{k}$$

subject to

1) $\sum_{j=1}^{9} \sum_{k=1}^{3} X^k_{OKC,j} = G_{OKC}$

2) $X^C_{OKC,j} + X^A_{OKC,j} + X^M_{OKC,j} \geq d_j$ $\qquad j = 1, ..., 9$

3) $X^k_{OKC,j} \leq K_k$ $\qquad j = 1, ..., 9$

$k = 1, ..., 3$

4) $X^k_{OKC,j} \geq 0$ $\qquad j = 1, ..., 9$

$k = 1, ..., 3$

The objective function consists of 27 terms (9 corridors by three modes of transportation) and each term is defined as the product of the one-way cost of travelling to a particular destination by a specific mode times the number of people who are travelling by that mode to that particular destination. The objective function as a whole shows the total cost for people who are travelling from Oklahoma City to all nine destinations.

The first constraint consists of 27 terms on the left hand side of the equality and is the summation of the number of people who are travelling out of Oklahoma City by the three modes of transportation. The right hand side of the equality is the total trips generated (G_{OKC}) out of Oklahoma City.

The second set of constraints consists of 9 different constraints, one for each corridor. The left hand side of each inequality shows the number of persons who are travelling to a particular destination by the different modes of transportation. The right hand side of each inequality is the minimum demand requirement for each destination.

The right hand side values (total trip generation and demand at each destination) for the above constraints are taken from model number 6 of Quandt and Baumol discussed in Chapter 4. This selection is based upon the reasonableness of ridership estimates. Out of the seven models tested, only one model (number 6) generated realistic numbers in terms of ridership estimates. The rest of the models either generated a very low, or a very high volume of ridership demand in each corridor.

The third set of constraints specifies the capacity constraints by each mode to each destination. There are 27 inequalities of this type. For airplane travel, it is assumed that the frequency of flight remains the same and capacity is calculated as the number of flights per day times the average capacity of each airplane (120 passengers). For MAG-LEV trains a maximum frequency of 24 trains per day times the average capacity of 300 passengers per train is assumed. For car travel, an average capacity of 20,000 cars per day is assumed in each corridor. This figure best represents the capacity of interstate highways, according to the best knowledge of industry experts.

Dual Problem

Like every linear programming model, this problem also has an associated dual. Referring to the original formulation of the linear programming problem as the primal, the following steps are taken to derive the dual problem:

1) Since the primal is a minimization problem, it is first converted to a maximization problem in canonical form (a maximization problem with all less-than-or-equal-to constraints and nonnegativity requirements for the decision variables). This step is performed by multiplying both the objective function and the greater-than-or-equal-to constraints by -1. For the equality constraint, two inequality constraints have been formed, one with a less-than-or-equal-to form and one with a greater-than-or-equal-to form. Then the greater-than-or-equal-to constraint is converted to a less-than-or-equal-to by multiplying by -1.

2) The dual of this maximization problem in canonical form will be a minimization problem with all greater-than-or-equal-to constraints.

3) The primal has 27 decision variables, so the dual will have 27 constraints. The first constraint of the dual is associated with variable x_1 in the primal, the second constraint in the dual is associated with variable x_2 in the primal, and so on.

4) The primal has 38 constraints (including the required changes in step 1), so the dual will have 38 decision variables. Dual variable u_1 is associated with the first primal constraint, dual variable u_2 is associated with the second primal constraint, and so on.

5) The right-hand-side values of the primal become the objective function coefficients in the dual.

6) The objective function coefficients of the primal become the right-hand side values in the dual.

7) The constraint coefficients of the ith primal variable become the coefficients in the ith constraint of the dual.

8) Both the primal and the dual have non-negativity restrictions for the decision variables.

One of the properties of primal and dual problems is that if the primal problem has an optimal solution, the dual will have one. The objective function values of the dual and primal problems are equal. It should be noted that the interpretation of the dual variables differs from the primal problem. Each variable in the dual problem carries the interpretation of being the price (or $ value) per unit of resources. In other words, the value of the dual variable identifies the per unit value of each additional resource or input unit at the optimal solution. This interpretation is the same as the definition of shadow prices.

In short, the primal problem and the dual problem in this research can be interpreted as:

1) The Primal Problem: Given the one-way costper person of travelling to each destination, determine how many persons for each mode of transportation will travel to different destinations such that the total transportation cost is minimized.

2) The Dual Problem: Given the availability of people to travel to different destinations with different modes of transportation, determine the price (fare) per person such that the total revenue will be maximized.

In terms of a suitable computer package, there are a wide variety of computer programs available to solve LP models. The computer program used in this research is LINDO/PC (Linear, Interactive, Discrete Optimizer/Personal Computer). LINDO is command-oriented rather than menu-oriented, and a wide range of commands can be executed at any time. In addition to the simplicity of working with this program, LINDO provides valuable information such as range analysis, dual prices, and reduced cost information which is very helpful in sensitivity analysis.

Analysis of LP Solution

In this part, the primal LP solution along with supplement information from the computer report will be analyzed. A complete computer solution for both the primal (minimization problem) and the dual are presented in the Appendix. It should be noted that the solution of the primal problem, in this research, is a degenerate solution. Degeneracy is recognizable when a constraint has both zero slack (or surplus) and a zero dual price. It is also apparent when the number of nonzero variables is strictly less than the number of constraints, which is the case in this primal solution.

The output of the primal solution has two sections, a "variable" section and a "row" section. Table XV shows an optimal distribution of ridership with different modes to different destinations that has minimized the total travel cost. This table shows that, car ridership attracts about 56 percent of the total travel demand in corridors such as Wichita, Tulsa, and Dallas.

TABLE XV

OPTIMAL RIDERSHIP IN PRIMAL SOLUTION

Variable	Ridership
XA9	200
XC1	3349
XC2	6552
XC3	17300
XT3	7200
XT4	399
XT5	814
XT6	4708
XT7	187
XT8	657
XT9	7200

The following notations are used throughout the discussion in this Chapter.

OKC-Wichita	=	1
OKC-Tulsa	=	2
OKC-Dallas	=	3
OKC-Corpus Christi	=	4
OKC-Nashville	=	5
OKC-St. Louis	=	6
OKC-Charleston	=	7
OKC-Rochester	=	8
OKC-Los Angeles	=	9
XA1	=	number of people who are travelling by airplane from OKC to Wichita
XC1	=	number of people who are travelling by car from OKC to Wichita
XT1	=	number of people who are travelling by MAG-LEV train from OKC to Wichita and so on.

The cost advantages of MAG-LEV trains have also created demand in all corridors except Wichita and Tulsa. Although MAG-LEV ridership is substantial in some corridors such as Dallas, St.Louis, and Los Angeles, the remaining corridors do not show a considerable amount of demand for MAG-LEV trains.

The nature of this problem calls for an extensive data set and reliable information. With regard to data limitations, one might be concerned to see how the recommendations of the models are altered as we change the input data. This task can be accomplished by using sensitivity analysis in the LP model. With the aid of sensitivity analysis we are able to answer how the optimal solution changes as we change the coefficients of the objective function or the right-hand side value of the constraints. Fortunately, an LP solution report provides additional information which is useful in sensitivity analysis.

Looking at the "variable" section in the primal LP report in the Appendix, there is a column called "Reduced Cost." Each variable has a quantity associated with it. One of the interpretations for the reduced cost is that it is the rate at which the objective function value will deteriorate if a variable currently at zero is arbitrarily forced to increase by one unit [Schrage (1984), p. 17]. The units of reduced cost values are dollars per person.

It is clear that those corridors with no travellers will have a positive reduced cost. It seems that the destinations which are located in medium-to-far distances from OKC have a higher value of reduced cost associated with them. For example, in some corridors such as OKC-Wichita and OKC-Tulsa, although no travellers are willing to travel by MAG-LEV trains, their reduced cost value ($8.63, and 15.47 respectively) shows that if we increase the value of these nonbasic variables, the objective function value, total transportation cost, will increase by some small magnitude. However, in the same corridors, increasing the number of people that are travelling by airplane (XA1 and XA2) will cause the value of the objective function to increase by $69.64, and 67.07. The same is true for the other corridors. Figure 3 shows the relationship between the reduced cost value and those variables (nonbasic) that have zero values in the primal LP solution.

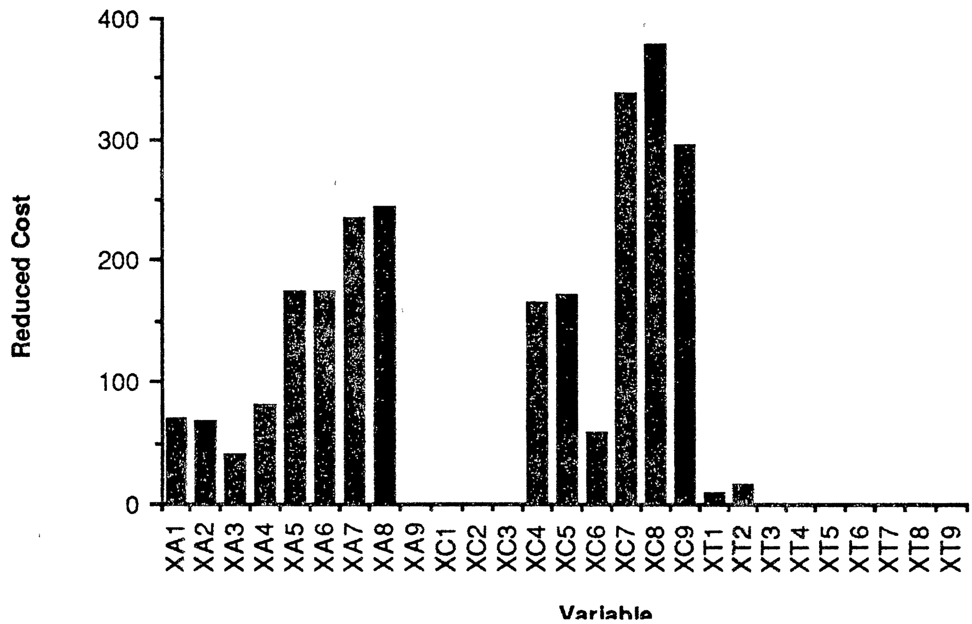

Figure 3 The Role of Reduced Cost Values in LP Solution

In sensitivity analysis, one may be concerned about the effect that changes in the right-hand side of a constraint would have on the value of the objective function. These are called shadow prices (in the case of a minimization problem, shadow prices are defined as the negative of dual prices in the LP solution) and are reported under the "row" section of the LP report. One dual price is associated with each constraint and in our problem its units are dollars per person. In a conventional sense [e.g., Schrage (1984) p. 21, Anderson et al. (1985), pp. 130-132], the shadow price of a constraint can be defined as:

The change in the value of the objective function per unit increase in the value of the right-hand side of each constraint.

In LINDO a positive shadow price associated with a constraint means that increasing the right-hand side in question will raise the objection function value and for negative shadow prices, the opposite occurs. A zero shadow price means that the constraint is non-binding and a unit change in the right-hand side of that constraint will have no effect on the solution value.

There is also an economic intuition behind shadow prices and reduced costs. If shadow prices are interpreted as charges for resources, and if we take into account these charges, then the reduced cost of an activity is really its net cost contribution, or in other words, if one unit of an activity is forced into the solution, it effectively reduces the availability of the resources it uses and it makes other constraints more binding. These resources have an attributed value by way of the shadow prices; therefore, the activity should be charged for the value used.

The shadow prices in our LP solution show that, in general, a one-person increase in the right-hand side value of the first constraint (total available people who are travelling out of OKC) will cause the objection function value to increase by 39.53 dollars. Figure 4 shows the effect of binding constraints and their shadow prices on the objection function value.

Figure 4 shows that the increase in the right-hand side of the capacity constraints for MAG-LEV trains in Dallas and Los Angeles corridors will cause the value of the objective function to be reduced by 5.44 and 77.3 dollars, respectively. This change will divert travellers from other modes to MAG-LEV trains. For OKC-Charleston, OKC-Rochester, and OKC-Los Angeles corridors (constraints number 36, 37, and38, respectively) a "one-unit" increase in the

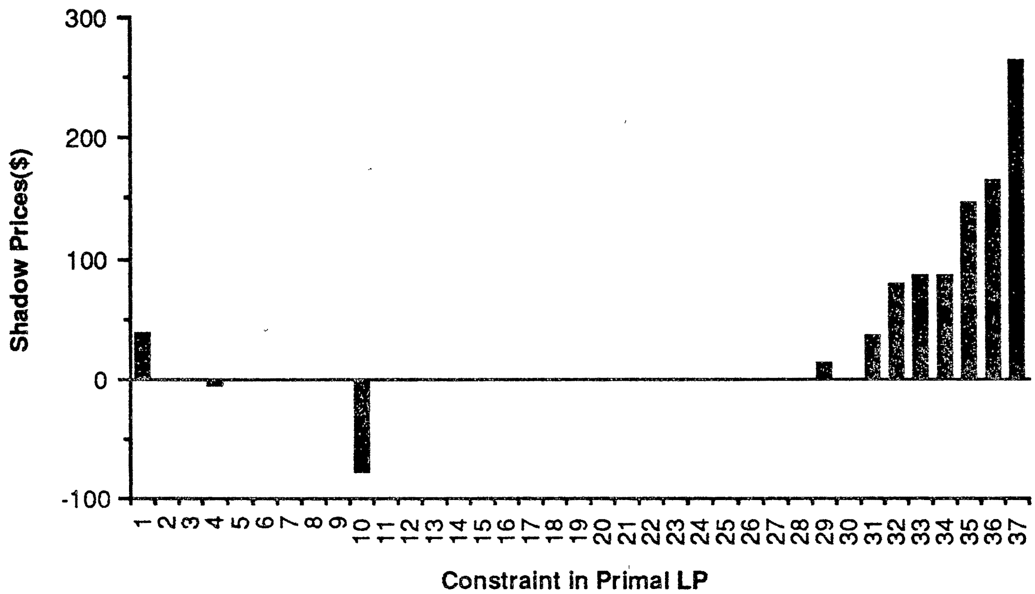

Figure 4. The Effect of Binding Constraints on Objective Function Value

right-hand side of the constraints will cause a very high increase in objection function values, ranging from 145.8-265.4 dollars per person. An increase in the number of people who are travelling from OKC to Wichita (constraint number 30) will cause the lowest increase in the value of the objective function.

In describing the reduced cost and shadow prices, we limited ourselves to "small" changes. One of the aspects of sensitivity analysis is to see the ranges or amounts by which individual right-hand sides (range of feasibility) or objective function coefficients (range of optimality) can be changed unilaterally without affecting the basis or optimal solution. Fortunately LINDO output provides such information.

In general, if the objective function coefficient of a single variable is changed within the range of optimality specified in the first section of the LP solution, then the optimal value of the decision variables will not change. However, the reduced cost, dual prices, and the value of the objective function may change.

Also, if the right-hand side of a single constraint is changed within the range specified in the second section of the LP solution, then the optimal values of the dual prices and reduced costs will not change. However, the values of the decision variables and the value of the objective function may change.

Table XVI shows the range of optimality for the current objective function coefficients that will maintain the optimal solution. Adding the increases to the current coefficients and subtracting the decreases provides the following range of optimality.

Sensitivity Analysis

Based on information provided in the range of optimality (Table XVI), ten different scenarios have been selected for the purpose of sensitivity analysis. Note that in LINDO, sensitivity analysis takes place when only one cost coefficient is changed while others are held constant. In this section, sensitivity analysis deals with changing the cost coefficients of each mode of transportation across different corridors. The scenarios are chosen in such a way as to avoid duplicating the current optimal solution and they are:

1) A model based on a 50 percent decrease in total air travel cost in different corridors (coefficients of variables XA1 ... XA9). Although unrealistic, this scenario has been selected to see how the optimal solution changes under extreme assumption. It should be noted that an increase in total air travel cost

has not been considered because even an infinite increase in total air travel cost coefficients will not affect the basic optimal solution (except in the OKC-Los Angeles corridor).

2) A model with a 20 percent decrease in total car travel cost, coefficients of variables XC1 ... XC9.

3) A model with a 40 percent decrease in total car travel cost.

4) A model with a 40 percent increase in total car travel cost.

TABLE XVI

RANGE OF OPTIMALITY

Variable	Variable
53.56 ≤ CA1 ≤ ∞	126.2 ≤ CC6 ≤ ∞
39.53 ≤ CA2 ≤ ∞	185.4 ≤ CC7 ≤ ∞
76.45 ≤ CA3 ≤ ∞	203.7 ≤ CC8 ≤ ∞
118.5 ≤ CA4 ≤ ∞	305 ≤ CC9 ≤ ∞
126.1 ≤ CA5 ≤ ∞	53.57 ≤ CT1 ≤ ∞
126.2 ≤ CA6 ≤ ∞	39.53 ≤ CT2 ≤ ∞
185.4 ≤ CA7 ≤ ∞	-∞ ≤ CT3 ≤ 76.4
203.7 ≤ CA8 ≤ ∞	39.53 ≤ CT4 ≤ 200
227.7 ≤ CA9 ≤ 599.53	39.53 ≤ CT5 ≤ 298.2
39.53 ≤ CC1 ≤ 62.19	39.53 ≤ CT6 ≤ 183.6
-∞ ≤ CC2 ≤ 53.56	39.6 ≤ CT7 ≤ 420
71.01 ≤ CC3 ≤ 115.9	39.6 ≤ CT8 ≤ 447.6
118.5 ≤ CC4 ≤ ∞	-∞ ≤ CT9 ≤ 305
126.1 ≤ CC5 ≤ ∞	

Note: CA1 corresponds to the XA1 variable, etc.

3) A model with a 40 percent decrease in total car travel cost.

4) A model with a 40 percent increase in total car travel cost.

5) A model with a 20 percent decrease in total MAG-LEV travel cost.

6) A model with a 40 percent decrease in total MAG-LEV travel cost.

7) A model with a 20 percent increase in total MAG-LEV travel cost.

8) A model with a 40 percent increase in total MAG-LEV travel cost.

9) A model with a 20 percent increase in total number of available people who are willing to travel out of Oklahoma City. This scenario is related to the change in the right-hand side value of the first constraint.

10) A model with a 50 percent increase in total number of available people who are willing to travel out of Oklahoma City.

The above scenarios have been run by the computer and the results are shown in Table XVII. Results from the primal solution and the different sensitivity analyses suggest the following:

Airplane travel demand will change in three corridors. In the OKC-Dallas corridor, under the assumption of a 50 percent reduction in airplane travel cost, 3360 passengers will switch their travel mode from car to airplane. In the OKC-Los Angeles corridor, based on the same scenario and also a 40 percent increase in MAG-LEV travel cost, 5080 passengers will switch from MAG-LEV to airplane. The smallest change occurs in the OKC-Corpus Christi corridor in which 399 passengers will switch from MAG-LEV to airplane as a result of a 50 percent reduction in airplane travel cost.

In terms of car travelling, four corridors are affected by different scenarios. OKC-Wichita is sensitive to four different scenarios. In senario 4, 5, and 6 as a result of increase in car travel cost or decrease in MAG-LEV travel cost, all of the ridership is shifted to MAG-LEV trains. As a result of a 50 percent increase in total trip generation (scenario 10), demand for travelling by car increases drastically from 3,349 to 14,184. OKC-Tulsa is also sensitive to four different scenarios. Scenarios 4 and 6 respectively will shift all car ridership to MAG-LEV trains. In scenario 9 and 10, an increase in total trips generated out of OKC has caused an increase in demand for car travel in this corridor. OKC-St.Louis is only sensitive to one scenario, and that is a 40 percent reduction in car travel cost. This change will make people take a car rather than MAG-LEV trains. And finally, OKC-Dallas is sensitive to five different scenarios. The demand for travelling by car is decreased only by a 50 percent reduction in air travel cost (scenario 1); this change attracts more travellers to airplanes. Decrease in car travel cost (scenario 2 and 3) and increase in MAG-LEV travel cost (scenarios 7, and 8) will increase demand for car travel in this corridor.

For MAG-LEV travel, both primal and sensitivity analyses show that at least three corridors have a very good potential for being constructed, OKC-Dallas, OKC-St.Louis, and OKC-Los Angeles. However, under some scenarios, such as increase in car travel cost, and decrease in MAG-LEV travel cost , OKC-Wichita and OKC-Tulsa corridors become good candidates for MAG-LEV trains.

TABLE XVII

SENSITIVITY ANALYSIS RESULTS IN PRIMAL PROBLEM

	XA1	XA2	XA3	XA4	XA5	XA6	XA7	XA8	XA9	XC1	XC2	XC3	XC4	XC5	XC6	XC7	XC8	XC9	XT1	XT2	XT3	XT4	XT5	XT6	XT7	XT8	XT9
Original Primal LP Solution	0	0	0	0	0	0	0	0	200	3349	6552	17300	0	0	0	0	0	0	0	0	7200	399	814	4708	187	657	7200
1)50% Decrease In Air Travel Cost	0	0	3360	399	0	0	0	0	5280	3349	6552	13940	0	0	0	0	0	0	0	0	7200	0	814	4708	187	657	2120
2)20% Decrease In Car Travel Cost	0	0	0	0	0	0	0	0	200	3349	6552	20000	0	0	0	0	0	0	0	0	4500	399	814	4708	187	657	7200
3)40% Decrease In Car Travel Cost	0	0	0	0	0	0	0	0	200	3349	6552	20000	0	0	4708	0	0	0	0	0	4500	399	814	0	187	657	7200
4)40% Increase In Car Travel Cost	0	0	0	0	0	0	0	0	200	0	0	17300	0	0	0	0	0	0	3349	6552	7200	399	814	4708	187	657	7200
5)20% Decrease In MAG-LEV Travel Cost	0	0	0	0	0	0	0	0	200	0	6552	17300	0	0	0	0	0	0	3349	0	7200	399	814	4708	187	657	7200
6)40% Decrease In MAG-LEV Travel Cost	0	0	0	0	0	0	0	0	200	0	0	17300	0	0	0	0	0	0	3349	6552	7200	399	814	4708	187	657	7200
7)20% Increase In MAG-LEV Travel Cost	0	0	0	0	0	0	0	0	200	3349	6552	20000	0	0	0	0	0	0	0	0	4500	399	814	4708	187	657	7200
8)40% Increase In MAG-LEV Travel Cost	0	0	0	0	0	0	0	0	5280	3349	6552	20000	0	0	0	0	0	0	0	0	4500	399	814	4708	187	657	7200
9)20% Increase In Trip Generated From OKC	0	0	0	0	0	0	0	0	200	3349	16265	17300	0	0	0	0	0	0	0	0	7200	399	814	4708	187	657	7200
10)50% Increase In Trip Generated From OKC	0	0	0	0	0	0	0	0	200	14184	20000	17300	0	0	0	0	0	0	0	0	7200	399	814	4708	187	657	7200

Multiobjective Function Analysis

The application of single objective linear programming models has been the subject of debate among many researchers in the last two decades. Most of these models have been criticized [Brill (1979)] because of limitations such as the existence of more than one objective that must be considered by both policy makers and analysts, the conflicting nature of some objectives, and their formulation in a single objective function.

In a dynamic decision-making environment, planning methodologies should be able to take into account conflicts involved in economic-decision problems with multiple goals and multiple actors. Multiple objective decision analysis provides such tools and in the past decade has become one of the moe powerful methodologies in programming theory. A wide variety of applications can be found in the field of regional economics, environment and energy economics, management science, industrial engineering, and other social sciences.

In general, the multiobjective decision problem can be defined as a problem in which there is more than one objective and objectives cannot be combined in any way. Mathematically it can be characterized by a p-dimensional vector optimization problem:

$$\text{Max } Z(X) = [Z_1(X), Z_2(X), ..., Zp(X)]$$

subject to

$$g_i(X) \leq 0 \qquad i = 1, 2, ..., m$$

$$X_j \geq 0 \qquad j = 1, 2, ..., n$$

where Z(X) is the P - dimensional objective function; X is an n dimensional vector of decision variables; and the $g_i(X)$ represents the constraints associated with the problem [Cohon and Marks (1975), p. 210]. The solution to this problem is not a single optimal solution because the optimal value of one objective function usually implies non-optimal values for the rest of the objective functions. However, the solution seeks a set of "nondominated" solutions. The "nondominant" solution is a subset of the feasible region and it shows that for each solution outside the set (but still within the feasible region) there is a nondominated solution for which all objective functions are unchanged or improved, and at least one is strictly improved [Goicoechea et al. (1982), p. 19].

One of the early contributors to this field is Koopmans (1951). Although he did not formulate a multi-objective problem, he identified a way to distinguish between efficient and inefficient production processes in the absence of any information about the prices of inputs and outputs. The literature on vector optimization was not extended until the late 1960s when Geoffrion (1968) introduced efficiency and discussed necessary and sufficient conditions in the context of linear programming. It has been during the last two decades that a large body of vector maximization problems has been documented in the literature.

The applications of multi-objective decision making are so numerous that summarizing them in this research is not practical [e.g., see Nijkamp and Spronk (1981) pp. 11-35 for capital budgeting and financial planning, Nijkamp (1976) for different models related to environmental economics, Lakshmanan and Nijkamp (1983) for issues related to energy policies]. Depending upon the exact nature of the problem, whether it is discrete or continuous, several solution algorithms have been proposed.

One way of solving multi-objective problems is to construct a utility (or welfare) function with the successive objective function. This implies that trade-offs between the various functions need to be defined [some examples of this approach are given in Anderson et al., pp. 127-140].

A second way of dealing with vector optimization is that the decision-maker needs to have an implicit multi-attribute utility function to compare two objectives at a time, and by successive variation of constraint set L, a trade-off function between two objective functions can be constructed. This method is known as "surrogate worth tradeoff" (SWT) and was developed by Haimes and Hall (1973).

Another way of solving multi-objective problems is called hierarchical programming methods [Van Delft and Nijkamp (1977)]. These methods require a hierarchical rank order of the objective functions, according to relative importance. In this way, low-order objective functions are considered only after high-order objective functions. This technique is known as the Electre method, and concordance analysis is a modified version of this method. Concordance analysis has been applied to the Santa Ana Transportation Corridor (SATC) [Giuliano (1985), p. 31].

The last approach discussed here for solving multi-objective problems relies on progressive articulation of preferences. In this method, first a nondominated solution is identified and then the decision maker (DM) is asked for tradeoff information concerning this solution. The problem is modified accordingly. Some well-known examples of this method in this category are the Geoffrion [Geoffrion, Dyer and Feinberg (1972)], STEM [Benayoun et al. (1971)], and Zionts-Wallenius [Zionts and Wallenius (1976)]. Since this research uses the STEM method for solving a multi-objective function, a detailed discussion is presented in the following section.

STEM Method for Solving Multi-Objective Problems

The STEM method was developed by Benayoun et al. (1972). It is an interactive Man-Machine technique for solving linear programming problems with multiple objectives. The procedure begins by finding extreme solutions for each linear objective function considered independently from the others. A payoff table is then constructed. Row j in the pay-off table contains values of the f_i's for one of the actions, which maximizes f_j for a given set of constraints. The diagonal of this table contains the optimum values and represents an "ideal" solution which, in general, does not exist (otherwise the problem is trivial).

In each iteration, weights are introduced to define the relative importance of the distances to the ideal solution. In the decision phase, the ideal solution and the compromise solutions are shown to the decision maker. If the decision maker decides that the solution is satisfactory, the algorithm terminates; if not, he/she indicates the maximum amount of relaxation that can be accepted. Then, the method returns to the calculation phase for the next iteration. Below is a complete description of the STEM method by Benayoun et al. (1972). Consider the following multi-objective programming problem:

$$\text{Max} \quad [F_1X, F_2X, \ldots, F_rX] \qquad 5.3.1$$

subject to

$$Ax \leq b \qquad 5.3.2$$

$$X \geq 0$$

where $F_jX = F_{j1}X_1 + F_{j2}X_2 + \ldots + F_{jn}X_n$. Let D be the feasible region defined by constraints (5.3.2) with the matrix A and the vector b. In general, there are no feasible solutions such that all the F_j's can simultaneously take their maximum values within the feasible region D. Let M_j be the optimum value of F_j within D.

As was mentioned earlier, the procedure starts with the calculation of a pay-off table. For the feasible region D, defined by constraints (5.3.2), the optimum for each objective in turn is calculated and Table XVIII is constructed.

TABLE XVIII

PAY-OFF TABLE

	F_1	F_2		F_j	...	F_r
F_1				z_j^1		
F_2				z_j^2		
:				:		
F_j	z_1^j	z_2^j	.	M^j		z_k^j
:				:		
F_r				z_j^k		

Row j in the pay-off table corresponds to the solution vector X^j maximizing the objective function F_j, under the constraints (5.3.2); therefore z_i^j is the value taken by the objective function F_i when F_j reaches its maximum at M^j (assuming that each objective is maximized).

The main diagonal of the above table gives the maximum values of all objectives. Let $\tilde{X}$ be an ideal solution, which usually does not exist, at which the various objective functions F_j would take on the values M^j.

<u>Calculation Phase</u>. For each cycle m, the feasible solution X^m, which is the nearest in the MINIMAX sense, to the ideal solution $\tilde{X}$, is found. The following linear programming problem is then solved:

$$LP(m) \begin{cases} \text{Minimize } d \\ d \geq [M^j - F_j(X)] \cdot \pi^j \\ X \in D^m;\ d \geq 0 \end{cases}$$

The coefficients π^j will give the relative importance of the distances to the optima. Each π^j will be calculated in the following manner:

Let M^j and m^j be the maximum and minimum values of the column j, respectively, in the pay-off table. Then the following formula is used to determine π^j.

$$\pi^j = \frac{\alpha^j}{\sum_{j=1}^{r} \alpha^j} \quad \text{in which} \quad \alpha^j = \frac{M^j - m^j}{M^j} \left(\frac{1}{\sqrt{\sum_{i=1}^{n_j} (F_{ji})^2}} \right)$$

(Term 1) **(Term 2)**

where F_{ji} are the coefficients of the objective F_j and n_j is the total number of terms in objective j. Term 2 normalizes the values taken by the objective functions. For Term 1, Banayoun et al. make the following assertion: if the value of F_j does not vary much from the optimum solution for varying X, the corresponding objective is not sensitive to a variation in the weighting values, so a small weight π^j can be assigned to this objective function. As the variation $(M^j - m^j)$ gets larger, the weight π^j will become correspondingly bigger. The a^j are used to define the weights π^j in such a way that the sum of π^j is 1, which means that different solutions obtained from different weighting strategies can be easily compared.

Decision-Making Phase. The new feasible compromise solution X^m is proposed to the decision-maker, who compares its objective vector Z^m with $\tilde{Z}$, the ideal one. If some of the components $F_j(X^m)$ of Z^m are satisfactory and others are not, the decision-maker must accept a certain amount of relaxation of a satisfactory objective F_{j^*} to allow an improvement in the unsatisfactory ones in the next cycle. Therefore, he is asked to indicate what F_j^* can be relaxed, and the amount of relaxation, ΔF_j^*, he can accept.

For the next cycle the feasible region is modified:

$$D^{m+1} \begin{cases} D^m \\ F_j^* (X) \geq F_j^* (X^m) - \Delta F_j^* \\ F_j (X) \geq F_j (X^m) \quad j \neq j^* \end{cases}$$

The weights π^{j^*}, objectives for which the decision-maker is satisfied, are set to 0 and for others, the weights are recalculated again $\Sigma\pi^j = 1$. Now the calculation phase of cycle m + 1 begins to find the feasible solution which is nearest, in the MINIMAX sense, to the ideal solution $\tilde{X}$.

Application of STEM Model

The STEM approach is applied in this research based on the problem that can be described as follows: given the existing modes of transportation (including MAG-LEV), the known travel demand, and a set of goals, design the best ridership combination which satisfies the demand and different goals of the problem.

A large number of goals are involved in intercity transport planning, but in this research, only three objectives are considered. The reason is to keep the problem to a level which can be easily solved, while illustrating all of the concepts involved in the application of an interactive, multi-criteria optimization technique to intercity transport planning.

The objectives selected are as follow:

1. Minimize travel cost (line-haul cost in dollars)
2. Minimize vehicle travel time (in minutes)

The first step in STEM is to construct the pay-off table (Table XIX). It should be noted that each objective function has been run individually and results are attached in Appendix (each individual function is run as a minimization problem).

TABLE XIX

PAY-OFF TABLE IN APPLICATION

	Cost (F_1)	Time (F_2)
Cost (F_1)	2,674,329 M^1	9,382,796 Z_2^1
Time (F_2)	3,279,172 Z_1^2	7,463,144 M^2

The diagonal of the above table shows the ideal values of the objective functions (M^j's) that can not be reached. Z_2^1 is the value of the time function when the cost function reaches its minimum; in other words, the value of Z_2^1 is computed by substituting the minimizing (cost) function solution into the time objective function and so on.

Table XX shows a summary of the pay-off table with maximums and minimums for each column.

TABLE XX

SUMMARY OF THE PAY-OFF TABLE

Objective	Units	Minimum Value of m^J	Maximum Value of M^J
F_1: Cost	Dollars/day	2,674,329	3,279,172
F_2: Time	Minutes/day	7,463,144	9,382,796

The next step is to calculate the weights, π^j. The calculation of these weights is done using the following relationships:

$$\pi^j = \frac{\alpha^j}{\sum_{j=1}^{2} \alpha^j} \qquad \alpha^j = \frac{M^j - m^j}{M^j} \cdot \left(\frac{1}{\sqrt{\sum_{i=1}^{27} (F_{ji})^2}} \right)$$

(Term 1) (Term 2)

The values of α^J were the following:

$\alpha^1 = 0.0002153$

$\alpha^2 = 0.0000719$

Using π^i formula, π^i are:

$$\pi^1 = \frac{0.0002153}{0.0002872} = 0.749$$

$$\pi^2 = \frac{0.0000719}{0.0002872} = 0.250$$

Then the following linear program was solved.

Min d

S.t

1) Constraints of single objective function +

2) $d \geq [F_j\,(\text{Cost, time}) - m^j] \bullet \pi^j \qquad j = 1, 2$

For our problem, the above (2) becomes

$0.749[88\ XA1 + 71.5\ XA2 + 78\ XA3 + \ldots + 135\ XT9]-d \leq 0.749\ m^1$

$0.250[44\ XA1 + 35\ XA2 + 49\ XA3 + \ldots + 365\ XT9]-d \leq 0.250\ m^2$

where (from Table XX)

$F_1^{min} = m^1 = 2{,}674{,}329$

$F_2^{min} = m^2 = 7{,}463{,}144$

Solving the above LP model and substituting the solution value of different variables in each of the objective functions resulted in the following objective function values:

$F_1 = 2{,}814{,}612$

$F_2 = 7{,}882{,}097$

At this point, the first iteration ends, and it is assumed that the decision-maker is satisfied with the outcome of the first iteration. Table XXI shows a summary of the values for different variables. A complete computer analysis is presented in Appendix.

TABLE XXI

RIDERSHIP ESTIMATES AFTER FIRST ITERATION
IN MULTI-OBJECTIVE FUNCTION

Variable	Ridership
XA3	3173
XA9	200
XC3	14126
XT1	3349
XT2	6552
XT3	7200
XT4	399
XT5	814
XT6	4708
XT7	187
XT8	657
XT9	7200

Summary

In this chapter, two methods were applied for estimating the optimal ridership. In the first part, based upon a single objective LP model, it was shown that under normal circumstances three corridors have a very good potential for MAG-LEV, 1) OKC-Dallas, 2) OKC-St.Louis, and 3) OKC-Los Angeles. The primal LP solution shows that only large cities that are located at various distances from OKC have potential demand for MAG-LEV trains.

In the second part, according to the solution obtained by the application of the STEM method into a multiple objective function, five corridors were identified (Table XXI) as the best candidates for application of MAG-LEV trains. They are OKC-Wichita and OKC-Tulsa along with those corridors identified in the single objective LP solution. This selection is based upon the level of ridership for MAG-LEV trains.

In the next chapter, a cost analysis is performed for the five corridors, taking into account the cost side of the equation. Comparing annualized cost and revenue in each corridor indicates whether each project can be internally financed or requires some external financing.

CHAPTER VI

COST ANALYSIS

The analysis of linear programming in Chapter V indicated that in the single objective LP model, OKC-Dallas, OKC-St.Louis, and OKC-Los Angeles provided significant volumes of ridership, and in the multiobjective LP model, the above mentioned routes plus OKC-Wichita and OKC-Tulsa corridors could be considered as the best candidates for construction of MAG-LEV trains. The rest of the corridors showed either zero or a very low volume of ridership. Thus, the purpose of this chapter is to derive cost estimates for the routes that are potentially feasible, or at least have considerable volume of demand for MAG-LEV trains. For this reason, the cost estimates are limited only to five corridors.

In the first part of this chapter, a generalized, preliminary capital cost of MAG-LEV trains is developed for those corridors. The second part develops operating costs, and in the third part, a revenue/cost analysis is done based upon the cost estimates. Using an annual-cost method and focusing on different discount rate scenarios, both revenue and cost estimates are converted to annual figures and the results are compared and discussed accordingly. It must be emphasized that the following estimates are not detailed costs due to the unavailability of engineering designs and plans for each corridor. The accuracy of the figures is expected to be in the range of plus or minus 20 percent. Basic unit cost information is obtained from Florida's study of high speed trains and is modified to estimate the capital and operating cost in the above three corridors.

Assumptions and Unit Capital Cost

Except for the Right-of-Way Cost, which is not included in this analysis, the capital cost consists of the following items:

a. Elevated Guide Way. In estimating this cost, it is assumed that a 100 percent new structure is needed. Furthermore, it is assumed that 60 percent of the new structure would be in the form of single-track and 40 percent would be double-track guideway. Based upon previous MAG-LEV studies, a figure of $4.0 million/guideway-mile for single-track and $7.0 million/guideway-mile for double-track guideway has been assumed. These figures include all foundations, structural supports, girders, acoustical barrier walls, guideway drainage, site preparation, etc.

b. Highway Overpasses. Since no engineering designs are available at this point, it is assumed that every 100 miles of guideway would require at least 10 "simple" and 5 "complex" overpasses. A figure of $800,000 is used for "simple" overpasses not requiring entrance and exit ramps; a figure of $1,500,000 is used for more "complex" overpasses requiring entrance and exit ramps.

c. Traction Power. This item includes all traction power provided through electrification for the MAG-LEV technology. It includes substation construction and equipment and the distribution system along the route. A substation spacing of approximately 25 miles is assumed and the cost of providing the power feed to substations by utility companies is not included in the estimate. Costs of $2.5 million per mile for double-track guideway and $1.4 million for single-track guideway are assumed for MAG-LEV technology.

d. Stations. The estimated cost for stations includes the following assumptions:

d.1. All stations will have an elevated platform.

d.2. All stations will generally be open-air, with a minimum of enclosed air-conditioned space.

d.3. Platform canopies will cover at least 70 percent of the platforms.

d.4. Vertical circulation elements consisting of escalators, stairs, and at least one elevator.

d.5. Three hundred parking spaces at each station.

An estimated cost of $13,500 per line foot of platform was assumed for each station. A construction cost of $3,000 per parking space, including property acquisition cost, is also assumed.

e. Central Control Center. A cost of $3 million is assumed for this item. This figure is based upon the actual bid price for the Dade County Metrorail system in Florida.

f. Communication and Signals. Previous European experiences show usual requirements of at least 33 signal blocks/track per 100 miles. A figure of $1.1 million per route mile is assumed for MAG-LEV technology, again based upon previous MAG-LEV studies.

g. Vehicles. Since only prototype vehicles of MAG-LEV are in operation so far, the exact cost of MAG-LEV vehicles is not known at this time. Based upon previous MAG-LEV studies, a fleet of 60 vehicles for each corridor with a cost of $3.5 million per vehicle is assumed for this item.

h. Contingencies. Because of uncertainty about technology itself and the engineering design of each corridor, a figure of 20 percent of the above items is included.

i. Preliminary Engineering. Three percent of total construction cost (including contingencies) is assumed in computing this item.

j. Final Design. Seven percent of total construction cost (including contingencies) is assumed for this purpose.

k. Construction, Engineering, and Inspection (C.E&I.). A figure of eight percent of the total construction cost (including contingencies) is assumed for this item. This cost category includes not only the supervision of all civil work, but also the supervision and inspection of the manufacture of all mechanical and electrical equipment and components.

Tables XXII through XXVI summarize the preliminary capital cost estimates for five different corridors.

Assumptions and Unit Operating Costs

The objective of this part is to develop a preliminary yearly expense estimate for MAG-LEV operation in each corridor. Again, due to unavailability of the technical characteristics of MAG-LEV trains at this point, estimates based upon previous MAG-LEV studies are used. In developing estimated operating costs, a 12-hour operating day is assumed for 365 days per year. Operating costs consist of the following items:

I. Energy Consumption. Assuming an energy consumption equal to 0.10 kilowatt/hour (KWH) per seat mile, (approximately 344 BTU per seat mile),a figure of $0.105 per KWH, a12-hour operating day and 16 one-way

TABLE XXII

GENERALIZED CAPITAL COST ESTIMATES FOR OKLAHOMA CITY-WICHITA CORRIDOR (1983 $)

	Unit	Quantity	Unit Price (Million $)	Cost (Million $)	Remarks
Single Track Guideway	Mile	85	4 0	340	
Double Track Guideway	Mile	56	7 0	392	
Highway Overpasses		1	21.7	21.7	14 "simple" overpasses and 7 "complex" overpasses
Traction Power		1	259	259	(85 x $1.4 = 119) + (56 x $2 5 = 140) = 259
Stations	Each	5	7 65	38 2	(500' platforms x $13500/L F. = 6.75) + (300 x 3000 = 0.9) = 7 65 million
Maintenance Facilities		1	45.5	45.5	
Central Control Center		1	3.0	3.0	
Communication and Signals	Mile	141	1.1	155	
Vehicles	Each	60	3.5	210	
Subtotal Construction Costs				$1464 4	
Contingencies		1	292.8	292.8	20% of construction cost
Total Construction Costs				$1757.2	
Preliminary Engineering		1	52.7	52.7	
Final Design		1	123	123	
C. E. & I		1	140.5	140.5	
Subtotal Engineering Costs				$316.2	
Total				$2073.4	

TABLE XXIII

GENERALIZED CAPITAL COST ESTIMATES FOR OKLAHOMA CITY-TULSA CORRIDOR (1983 $)

	Unit	Quantity	Unit Price (Million $)	Cost (Million $)	Remarks
Single Track Guideway	Mile	62	4 0	248	
Double Track Guideway	Mile	41	7 0	287	
Highway Overpasses		1	15 5	15 5	10 "simple" overpasses and 5 "complex" overpasses
Traction Power		1	189 3	189 3	(62 x $1.4 = 86.8) + (41 x $2 5 = 102 5) = 189 3
Stations	Each	5	7.65	38 2	
Maintenance Facilities		1	45 5	45 5	
Central Control Center		1	3 0	3.0	
Communication and Signals	Mile	103	1 1	113 3	
Vehicles	Each	60	3 5	210	
Subtotal Construction Costs				$1149.8	
Contingencies		1	229 9	229 9	20% of construction cost
Total Construction Costs				$1379 7	
Preliminary Engineering		1	41.3	41.3	
Final Design		1	96.5	96 5	
C E & I		1	110.3	110.3	
Subtotal Engineering Costs				$248.1	
Total				$1627.8	

TABLE XXIV

GENERALIZED CAPITAL COST ESTIMATES
FOR OKLAHOMA CITY-DALLAS
CORRIDOR (1983 $)

	Unit	Quantity	Unit Price (Million $)	Cost (Million $)	Remarks
Single Track Guideway	Mile	124	4 0	496	
Double Track Guideway	Mile	83	7.0	581	
Highway Overpasses		1	31	31	20 "simple" overpasses and 10 "complex" overpasses
Traction Power		1	381	381	(124 x $1.4 = 173.6) + (83 x $2 5 = 207.5) = 381
Stations	Each	5	7.65	38.2	
Maintenance Facilities		1	45 5	45.5	
Central Control Center		1	3 0	3.0	
Communication and Signals	Mile	207	1.1	227.7	
Vehicles	Each	60	3.5	210	
Subtotal Construction Costs				$2013.4	
Contingencies		1	402 6	402.6	20% of construction cost
Total Construction Costs				$2416	
Preliminary Engineering		1	72 4	72 4	
Final Design		1	169 1	169.1	
C E. & I		1	193 2	193.2	
Subtotal Engineering Costs				$434.7	
Total				$2850.7	

TABLE XXV

GENERALIZED CAPITAL COST ESTIMATES
FOR OKLAHOMA CITY-ST.LOUIS
CORRIDOR (1983 $)

	Unit	Quantity	Unit Price (Million $)	Cost (Million $)	Remarks
Single Track Guideway	Mile	298	4 0	1192	
Double Track Guideway	Mile	199	7 0	1393	
Highway Overpasses		1	77 5	77 5	50 "simple" overpasses and 25 "complex" overpasses
Traction Power		1	914 7	914 7	(298 x $1.4 = 417.2) + (199 x $2 5 = 497 5) = 914 7
Stations	Each	5	7.65	38.2	
Maintenance Facilities		1	45 5	45 5	
Central Control Center		1	3.0	3 0	
Communication and Signals	Mile	497	1.1	546.7	
Vehicles	Each	60	3 5	210	
Subtotal Construction Costs				$4420 6	
Contingencies		1	884 1	884.1	20% of construction cost
Total Construction Costs				$5304.7	
Preliminary Engineering		1	159 1	159.1	
Final Design		1	371 3	371 3	
C E & I		1	424.3	424 3	
Subtotal Engineering Costs				$954 7	
Total				$6259 4	

TABLE XXVI

GENERALIZED CAPITAL COST ESTIMATES
FOR OKLAHOMA CITY-LOS ANGELES
CORRIDOR (1983 $)

	Unit	Quantity	Unit Price (Million $)	Cost (Million $)	Remarks
Single Track Guideway	Mile	811	4 0	3244	
Double Track Guideway	Mile	541	7 0	3787	
Highway Overpasses		1	208.5	208.5	135 "simple" overpasses and 67"complex" overpasses
Traction Power		1	2487.9	2487 9	(811 x $1.4 = 1135.4) + (541 x $2.5 = 1352.4) = 2487 9
Stations	Each	5	7 65	38 2	
Maintenance Facilities		1	45.5	45 5	
Central Control Center		1	3 0	3 0	
Communication and Signals	Mile	1352	1 1	1487 2	
Vehicles	Each	60	3 5	210	
Subtotal Construction Costs				$11511.3	
Contingencies		1	2302 2	2302 2	20% of construction cost
Total Construction Costs				$13813	
Preliminary Engineering		1	414.4	414.4	
Final Design		1	966.9	966 9	
C E & I		1	1105	1105	
Subtotal Engineering Costs				$2486.3	
Total				$16299.8	

trips per day, the yearly energy consumption cost for each corridor is calculated in the following manner:

- OKC-Wichita: 0.10/KWH x $0.105 KWH/seat-mile x 300 seats x 141 miles x 16 trips/day x 365 days = $2,593,836
- OKC-Tulsa: 0.10/KWH x $0.105 KWH/seat-mile x 300 seats x 103 miles x 16 trips/day x 365 days = $1,894,788
- OKC-Dallas: 0.10/KWH x $0.105 KWH seat-mile x 300 seats x 207 miles x 16 trips/day x 365 days = $3,807,972
- OKC-St.Louis: 0.10/KWH x $0.105 KWH/seat-mile x 300 seats x 497 miles x 16 trips/day x 365 days = $9,142,812
- OKC-Los Angeles: 0.10/KWH x $0.105 KWH seat-mile x 300 seats x 1352 miles x 16 trips/day x 365 days = $24,871,392

m. Rolling Stock Maintenance. Since there is no history of operation for MAG-LEV trains, a figure of 15 percent of the vehicle capital cost was assumed for each corridor.

- MAG-LEV equipment yearly costs: 0.15 x $210 million = $31.5 million in each corridor.

n. Maintenance-of-Way, Signal and Communications, and Facilities. Because of the lack of information for this item and the high speed nature of this mode of transportation, an assumption of 0.5 person/mile has been made for calculating the work force requirement for maintenance-of-way.

- Maintenance-of-way for OKC-Wichita: 0.5 person/mile x 141 miles = 70.5, (70 persons)
- Maintenance-of-way for OKC-Tulsa: 0.5 person/mile x 103 miles = 51.5, (51 persons)

- Maintenance-of-way for OKC-Dallas: 0.5 person/mile x 207 miles = 103.5, (103 persons)
- Maintenance-of-way for OKC-St.Louis: 0.5 person/mile x 497 miles = 248.5, (248 persons)
- Maintenance-of-way for OKC-Los Angeles: 0 5 person/mile x 1352 miles = 676 persons

For signals and communications, it was assumed that approximately one employee would be required for every 10 miles in each route.

- Signal and communications for OKC-Wichita: 0.1 person/mile x 141 miles = 14.1, (14 persons)
- Signal and communications for OKC-Tulsa: 0.1 person/mile x 103 miles = 10.3, (10 persons)
- Signal and communications for OKC-Dallas: 0.1 person/mile x 207 miles = 20.7, (21 persons)
- Signal and communications for OKC-St.Louis: 0.1 person/mile x 497 miles = 49.7, (50 persons)
- Signal and communications for OKC-Los Angeles: 0.1 person/mile x 1352 miles = 135.2, (135 persons)

For facility maintenance, the existence of two yards and shops, the administration buildings, and the five stations is assumed. So the personnel requirements for each corridor are:

- Main yard and shop facilities maintenance = 8 persons/yard x 2 yards = 16 persons
- Two satellite yards = 10 person/yard x 2 = 20 persons
- Five stations = 3 persons/station x 5 = 15 persons
- Total personnel for facilities maintenance = 51 persons for each corridor

The various personnel requirements in the maintenance category for each corridor yield the following work force for each corridor:

- OKC-Wichita Corridor: 70 + 14 + 51 = 135 persons
- OKC-Tulsa Corridor: 51 + 10 + 51 = 112 persons
- OKC-Dallas Corridor: 103 + 21 + 51 = 175 persons
- OKC-St.Louis Corridor: 248 + 50 + 51 = 349 persons
- OKC-Los Angeles Corridor: 676 + 135 + 51 = 862 persons

Assuming an average yearly salary of $25,000 and an overhead rate of 80 percent on the preceding maintenance work force figures yields the following annual maintenance costs:

- OKC-Wichita: 135 persons x $25,000 x 1.8 = $6,075,000, (6.0 million)
- OKC-Tulsa: 112 persons x $25,000 x 1.8 = $5,040,000, (5.0 million)
- OKC-Dallas: 175 persons x $25,000 x 1.8 = $7,875,000, (7.9 million)
- OKC-St.Louis: 349 persons x $25,000 x 1.8 = $15,705,000, (15.8 million)
- OKC-Los Angeles: 862 persons x $25,000 x 1.8 = $38,790,000, (38.8 million)

o. Transportation and Operations Personnel Costs. Again, a 12-hour day, 16 one-way trips for 365 days per year is assumed in computing this item. The annual transportation person-days for all corridors are calculated as: 16 trips x 4 persons/crew (1 engine man, 1 conductor, and 2 trainmen) x 365 = 23,360 person-days per year.

For simplicity, a rate of $100 per day was used in conjunction with a 60 percent overhead rate. This yields the following annual transportation personnel costs: 23,360 person-days per year x $100/day x 1.60 = $3,737,600.

In developing non-transportation operations costs, the following work force assumptions are made:

• train dispatchers	3 persons per day
• technicians	6 persons per day
• superintendents	3 persons per day
• managers	3 persons per day
	15 persons per day

Using the same unit cost figures assumed above yields annual non-transportation operation costs: 15 person-days x $100/day x 365 days x 1.60 = $876,000 per year. Thus, the total transportation costs per year = $3,737,600 + $876,000 = $4,613,600, (4.6 million/year).

p. Traffic and General Administration Expenses. A figure of 10 percent of total operating costs is assumed for categories such as advertising, office supplies, insurance, health and welfare benefits, pensions, and expenses related to the traffic department. Table XXVII summarizes the estimated annual operating costs for the five corridors.

TABLE XXVII

ESTIMATES OF MAG-LEV ANNUAL OPERATING COSTS (1983 $)

Cost Item (Million $)	OKC-Wichita	OKC-Tulsa	OKC-Dallas	OKC-St Louis	OKC-Los Angeles
Energy Consumption Cost	$2.6	$1.9	$3 8	$9.1	$24.8
Rolling Stock Maintenance	$31.5	$31.5	$31 5	$31 5	$31 5
Maintenance-of-Way, Signal and Communications and Facility Maintenance	$6 0	$5 0	$7.9	$15 8	$38 8
Transportation and Operations Personnel Costs	$4 6	$4 6	$4 6	$4 6	$4.6
Subtotal	$44 7	$43 0	$47 8	$61	$99.7
Traffic and General Administration Expenses[1]	$4.4	$4.3	$4.7	$6 1	$9.9
Total[2]	$49.1	$47.3	$52.5	$67.1	$109.6

1 10% of above subtotals

2 Does not include debt service, taxes, franchise fees, and security costs.

Revenue/Cost Analysis

In order to compare different projects, taking into account both costs and revenue factors, it was decided to express all benefits and costs in equivalent dollars in a uniform annual figure. The annual cost method has been used to accomplish this task. The technique requires calculation of the present worth of each project and, once the present worth is obtained, it is multiplied by the appropriate capital-recovery factor.

Assuming all capital costs as the initial cost for each corridor, the present-worth method selects the project with the largest present worth. The formula can be written in the following manner:

$$\text{PW of each project} = -K + B\left(\frac{P}{A}, i\%, n\right)$$

where

K = initial cost

B = net annual benefit (Bt - Ct) which is constant over the project life except for the initial cost.

$$\left(\frac{P}{A}, i\%, n\right) = \frac{(1 + i)^n - 1}{i(1 + i)^n},$$

is called series present-worth factor and is defined as the number of dollars one must initially invest at i percent interest to withdraw $1 at the end of each of N years (James and Lee, 1971, p. 18).

The annualized cost and revenue figures are then to be computed by multiplying the net present worth of each project by a capital-recovery factor. Capital-recovery factor $\frac{A}{P}$ is the inverse of series present-worth factor $\frac{P}{A}$.

It shows the number of dollars one can withdraw in equal amounts at the end of each of N years if $1 is initially deposited at i percent interest. The results show whether a project needs external financing (negative value) or if it is capable of having an excess of revenue over costs in annual equivalent figures.

In order to perform an annual-cost method, the following table is constructed. It shows the assumption concerning the life of each project as well as the discount rate. The annual revenue is the product of ridership in each corridor by the relevant fare over 365 days.

As indicated in Table XXVIII, if the annual revenue based on multiobjective LP estimates is considered, all projects except OKC-Wichita show substantial excess of annual passenger revenue over annual operating costs. However, if single objective LP estimates are taken into account, only OKC-Dallas, OKC-St.Louis, and OKC-Los Angeles corridors show an excess of annual revenue over annual operating costs.

Using the information provided in Table XXVIII, the present worth of each project is computed, and by multiplying each project worth times its corresponding Capital Recovery Factor, the net annual worth for each project is obtained and the results are presented in Table XXIX.

Table XXIX shows that under any circumstances, considering the volume of ridership with single or multiobjective LP estimates, all of the corridors require substantial external financing. In the OKC-Wichita corridor, the amount of external financing ranges between 124 and 255 million dollars depending on which discount rate and which ridership estimates are considered. In the OKC-Tulsa corridor, external financing is between 83 and 208 million; in the OKC-Dallas corridor, it ranges between 120 and 208 million dollars. In the OKC-St.Louis external financing ranges between 271 and 566 million dollars, and finally in the OKC-Los Angeles corridor it ranges between 622 and 1394 million dollars, depending upon which estimates and which discount rates are chosen.

It must be mentioned that this is only a crude approximation, since the variety of potential financing options for system construction as well as additional potential revenues (such as freight and shorter trips) would strongly influence these annualized figures.

TABLE XXVIII

DATA FOR ANNUAL-COST METHOD

Corridor	Capital Cost (million$)	Annual Operating Cost (million$)	Annual Revenue Model Estimates (million $)		Economic Life and Period of Analysis (years)	Discount Rate		
			Single	Multiobjective		Scenario 1	Scenario 2	Scenario 3
OKC-Wichita	2073.4	49 1	0	34.2	35	4%	7%	10%
OKC-Tulsa	1627.8	47.3	0	50.2	35	4%	7%	10%
OKC-Dallas	2850.7	52.5	84.0	84.0	35	4%	7%	10%
OKC-St.Louis	6259.4	67.1	128.8	128.8	35	4%	7%	10%
OKC-Los Angeles	16299.8	109.6	354.7	354.7	35	4%	7%	10%

TABLE XXIX

RANGE OF FEASIBILITY FOR DIFFERENT CORRIDORS

Corridor	Range of Present Worth (million $)						Capital Recovery Factor			Range of Net Annual Worth (million $)					
	Scenario 1		Scenario 2		Scenario 3		Scenario 1	Scenario 2	Scenario 3	Scenario 1		Scenario 2		Scenario 3	
OKC-Wichita	(-2987)	(-2350)	(-2709)	(-2266)	(-2547)	(-2217)	0 053	0 077	0 10	(-158)	(-124)	(-208)	(-174)	(-255)	(-222)
OKC-Tulsa	(-2508)	(-1574)	(-2240)	(-1590)	(-2084)	(-1600)	0 053	0 077	0 10	(-133)	(-83)	(-172)	(-122)	(-208)	(-160)
OKC-Dallas	(-2265)	(-2265)	(-2443)	(-2443)	(-2547)	(-2547)	0 053	0 077	0 10	(-120)	(-120)	(-188)	(-188)	(-255)	(-255)
OKC-St Louis	(-5112)	(-5112)	(-5460)	(-5460)	(-5665)	(-5665)	0 053	0 077	0 10	(-271)	(-271)	(-420)	(-420)	(-566)	(-566)
OKC-Los Angeles	(-11741)	(-11741)	(-13135)	(-13135)	(-13937)	(-13937)	0 053	0 077	0 10	(-622)	(-622)	(-1011)	(-1011)	(-1394)	(-1394)

CHAPTER VII

CONCLUDING REMARKS

In the first part of this chapter, a summary of research and findings is presented. The second part of this chapter is devoted to a discussion of suggestions for future research.

Summary and Conclusions

The purpose of this research was to evaluate the feasibility of MAG-LEV trains in Oklahoma. Although reliable data sources were not found, ridership in different corridors were estimated by utilizing an aggregate demand model and using it into two linear programming formulations.

In Chapter I, the problems facing the U.S. transportation infrastructure emphasizing the need for both long and short-run solutions were briefly discussed. A technology background on MAG-LEV trains, their development, and the fact that they are one alternative for solving current problems was also explained. The selection of different corridors in terms of city size and distance from Oklahoma City and the objective of this research were discussed in the last part of this Chapter.

In Chapter II, relevant work in both the travel demand and linear programming modelling was discussed. In terms of travel demand models, it was argued that aggregate demand modelling offers a quick response for transportation problems, but may suffer from estimation bias due to the use of aggregate data. On the other hand, disaggregate demand modelling improves estimation results, but its application has been very limited because of the lack of appropriate data sets. Linear programming on the other hand offers an extensive application in transportation projects.

Data collection on socio-economic and demographic explanatory variables along with information for the service characteristics of three means of transportation were gathered in Chapter III. The derivation of service characteristics such as speed, cost, and frequency for MAG-LEV trains, for which there was no historic data, was explained. The data were used to test different versions of an aggregate abstract mode model in Chapter IV. The results for three models were presented. Two main conclusions are derived from this chapter: 1) based upon the characteristics of MAG-LEV trains, both in terms of speed and cost, they compete with existing modes of transportation very well in almost every corridor; 2) the MAG-LEV has the potential for both producing induced demand and diverting people from other modes of transportation to MAG-LEV. In almost every corridor, the introduction of the MAG-LEV train increases total ridership significantly and the pattern for diverted demand shows that over short distances, the car is still a dominant means of transportation, while with farther distances, the amount of diverted demand becomes greater.

The information obtained in Chapter IV was incorporated into a single and a multi-objective linear programming model in Chapter V. The single objective function was set up to obtain the optimal amount of ridership that minimizes the total transportation cost. Non-linear constraints were ignored in this research and the required constraints were set up based upon information on model 6 of Quandt and Baumol in Chapter IV. The results of the primal model identified Oklahoma City-Dallas, Oklahoma City-St.Louis, and Oklahoma City-Los

Angeles corridors as the best candidates for construction of MAG-LEV trains. Another experiment with a multi-objective function LP was done using the STEM method of Benayoun et al. (1972). Two objectives, minimization of cost and of travel time, were considered and the results of this analysis show five different corridors, OKC-Wichita, OKC-Tulsa, OKC-Dallas, OKC-St.Louis, and OKC-Los Angeles as the best candidates for potential MAG-LEV train corridors.

In Chapter VI, a generalized estimate of both capital and operating cost in constant dollars ($ 1983) was presented and, using an annual cost method, both revenue and costs were converted to annualized figures. The results in this chapter show that in all of the three corridors, external financing is required.

In general, the results of this research offer the following comments. First, the application of MAG-LEV trains needs serious attention in the state of Oklahoma. Service characteristics of MAG-LEV trains show that it competes very well both in terms of cost of travelling and speed with other existing modes of transportation. The competition is true in almost every corridor in the study. Second, although the service characteristics of MAG-LEV are competitive with other modes, the socio-economic and demographic characteristics of different cities prevent all the corridors from having enough travel demand for different modes of transportation. The results of this study show that car is the dominant means of transportation in close distances. However, MAG-LEV travel demand exists and it is concentrated between OKC and large cities located at various distances from OKC. The amount of external financing requirement also suggests that this technology might be more attractive close-to-medium rather than far distances.

So, based upon the above comments, it can be concluded that the application of this technology should be limited to large cities that are located at a close-to-medium distance from Oklahoma City. As was mentioned earlier, Dallas and St.Louis are the best candidates for MAG-LEV operation. A more detailed analysis considering the suggestion in the next section must be conducted for further confirmation of the results.

Suggestions for Further Research

The suggestion for further research directly related to this subject can be divided into three areas. The first is related to the emergence of magnetic levitation trains as an alternative for solving current transportation problems, the second is related to the need for a new and complete data set, and the last part involves selecting an appropriate methodology to deal with this type of analysis.

High-speed Magnetic Levitation trains, once considered a pipe-dream, are quickly becoming reality. The technology has been invented and will be in the commercial stage during the next few years. Although it is considered an aerospace rather than a railroad technology, its goal is not only to move people faster from one city to another, but to provide relief in air congestion, capacity problems, and delays, along with energy savings. It also reduces the maintenance cost of transportation infrastructure and externalities associated with current transportation means. The fact that many regions in the United States are seriously studying the application of this technology makes this new "transportation revolution" attractive to both planners and policy-makers.

The exact cost estimates of MAG-LEV are not known at this point, but based upon the current stage of development of this technology, they are estimated at around $10 million per mile, with a range of $5 to $15 million. To put this cost in perspective, it is lower than the interstate highway construction costs in suburban areas ($15 to $25 million per mile) and is quite comparable with construction costs in rural areas ($5 to $10 million per mile). The expected cost of new airports (Denver) is between $2 and $3 billion and each new aircraft will cost from $40 to $50 million.

The results of this research show that the technology is excellent for short-to-medium distances (200 - 500 miles); this is confirmed by most other studies. We specifically recommend this new mode of transportation as an alternative for airline travel and we believe that airlines could substitute their short and medium flights with MAG-LEV trains. The fact that MAG-LEV vehicles are essentially fuselages without wings makes aircraft manufacturers capable of producing these vehicles with substantial savings in developing such facilities.

The second suggestion relates to the need for a new and complete data set. Most of the studies that have been done (both aggregate and disaggregate analyses) so far suffer from one major weakness, the lack of behavioral modelling. With current transportation problems, no attempts have been made, either by the Federal government or by individual states, to conduct a comprehensive travel survey during the last 13 years. It is definitely time to collect such a data set. Each data set must be composed of the following information: data at the individual or household level, including personal and family characteristics, and actual behavior of intercity travel over some period of time (with a full description of party size, income, purpose of trip, destination choice, characteristics of available modes to individual, duration of stay at destination, and mode chosen at destination). A clear and unique definition of geographical boundaries must be made for this purpose, and information such as the service characteristics of each mode (e.g., daily flights/available seats, different fare structure, vehicle occupancy, peak/off peak travel period, level of service etc.), intercity distances, and the characteristics of new modes such as MAG-LEV and their possible effect on travel behavior must be available in a data base.

Another aspect of the data base could be the information on intercity freight movement. Since most of the studies have concentrated on the passenger side, it is essential to incorporate such a factor into the feasibility of new modes of transportation such as MAG-LEV. It seems reasonable to assume that even if passenger movement does not make a new means of transportation feasible, a combination of freight and passenger might turn it into a feasible project.

Because no data set has been available to conduct a fully disaggregate analysis, a new questionnaire must be designed. Before conducting surveys, relevant terms related to intercity travel or freight movements must be defined clearly. Population framework (geographic boundary), sample size, and sampling procedure have to be addressed. It is also recommended that such a survey be conducted throughout an entire year to capture all the seasonal effects of travel. A method must be developed to update this data base every five years. And finally, we suggest that the sampling area cover at least two or three of the largest metropolitan areas in each state.

The third suggestion deals with choosing an appropriate methodology for this kind of analysis. Most of the research conducted so far is related to the demand side of the equation. A comprehensive study on transportation projects requires an understanding of the supply side of transportation, too. A model needs to be developed to consider both the demand for transportation and the supply of transportation simultaneously. Using a fully disaggregate analysis, we recommend the use of a multi-objective linear programming model to achieve such an equilibrium between the supply of and demand for transportation. As was discussed earlier, the objectives usually conflict. Users of transportation services are concerned with goals such as minimizing travel cost, travel time, and distance travelled; on the other hand, transportation suppliers have a completely opposite goal, which is maximizing net profit.

Other objectives that are not related to either users or operators and have some direct impact on the community, environment, and economy as a whole must be considered (e.g., safety, accessibility, enhancing air and water quality, noise impact, energy consumption, etc.). These need to be gathered and should be incorporated into a single model and should be utilized for evaluating the effect of introducing a new mode of transportation.

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APPENDIX

COMPUTER RESULTS FOR SINGLE AND MULTI-OBJECTIVE FUNCTIONS

PRIMAL LP MODEL AND ITS SOLUTION

```
MIN     123 2 XA1 + 106.6 XA2 + 115 9 XA3 + 200 XA4 + 301 1 XA5
     + 301 XA6 + 420 XA7 + 447 6 XA8 + 305 XA9 + 53 56 XC1 + 39 53 XC2
     + 76 45 XC3 + 283 75 XC4 + 298 29 XC5 + 183 64 XC6 + 522 28 XC7
     + 581 91 XC8 + 599 53 XC9 + 62 2 XT1 + 55 XT2 + 71 XT3 + 118 5 XT4
     + 126 1 XT5 + 126 2 XT6 + 185 4 XT7 + 203 7 XT8 + 227 7 XT9
SUBJECT TO
       2)  XA1 + XA2 + XA3 + XA4 + XA5 + XA6 + XA7 + XA8 + XA9 + XC1 + XC2
     + XC3 + XC4 + XC5 + XC6 + XC7 + XC8 + XC9 + XT1 + XT2 + XT3 + XT4
     + XT5 + XT6 + XT7 + XT8 + XT9 =    48566
       3)  XT1 <=   7200
       4)  XT2 <=   7200
       5)  XT3 <=   7200
       6)  XT4 <=   7200
       7)  XT5 <=   7200
       8)  XT6 <=   7200
       9)  XT7 <=   7200
      10)  XT8 <=   7200
      11)  XT9 <=   7200
      12)  XC1 <=   20000
      13)  XC2 <=   20000
      14)  XC3 <=   20000
      15)  XC4 <=   20000
      16)  XC5 <=   20000
      17)  XC6 <=   20000
      18)  XC7 <=   20000
      19)  XC8 <=   20000
      20)  XC9 <=   20000
      21)  XA1 <=   360
      22)  XA2 <=   1560
      23)  XA3 <=   3360
      24)  XA4 <=   1200
      25)  XA5 <=   2400
      26)  XA6 <=   1680
      27)  XA7 <=   720
      28)  XA8 <=   600
      29)  XA9 <=   5280
      30)  XA1 + XC1 + XT1 >=   3349
      31)  XA2 + XC2 + XT2 >=   6552
      32)  XA3 + XC3 + XT3 >=   24500
      33)  XA4 + XC4 + XT4 >=   399
      34)  XA5 + XC5 + XT5 >=   814
      35)  XA6 + XC6 + XT6 >=   4708
      36)  XA7 + XC7 + XT7 >=   187
      37)  XA8 + XC8 + XT8 >=   657
      38)  XA9 + XC9 + XT9 >=   7400
END
```

LP OPTIMUM FOUND AT STEP 27

OBJECTIVE FUNCTION VALUE

1) 4885175 00

VARIABLE	VALUE	REDUCED COST
XA1	000000	69 640000
XA2	000000	67 070000
XA3	000000	39 450000
XA4	000000	81 500000
XA5	000000	175 000000
XA6	000000	174 800000
XA7	000000	234 600000
XA8	000000	243 900000
XA9	200 000000	000000
XC1	3349 000000	000000
XC2	6552 000000	000000
XC3	17300 000000	000000
XC4	000000	165 250000
XC5	000000	172 190000
XC6	000000	57 440000
XC7	000000	336 880000
XC8	000000	378 210000
XC9	000000	294 530000
XT1	000000	8 639999
XT2	000000	15 470000
XT3	7200 000000	000000
XT4	399 000000	000000
XT5	814 000000	000000
XT6	4708 000000	000000
XT7	187 000000	000000
XT8	657 000000	000000
XT9	7200 000000	000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	000000	39 530000
3)	7200 000000	000000
4)	7200 000000	000000
5)	000000	5 449997
6)	6801 000000	000000
7)	6386 000000	000000
8)	2492 000000	000000
9)	7013 000000	000000
10)	6543 000000	000000
11)	000000	77 300000
12)	16651 000000	000000
13)	13448 000000	000000
14)	2700 000000	000000
15)	20000 000000	000000
16)	20000 000000	000000
17)	20000 000000	000000
18)	20000 000000	000000
19)	20000 000000	000000
20)	20000 000000	000000
21)	360 000000	000000
22)	1560 000000	000000
23)	3360 000000	000000
24)	1200 000000	000000
25)	2400 000000	000000
26)	1680 000000	000000
27)	720 000000	000000
28)	600 000000	000000
29)	5080 000000	000000
30)	000000	14 030000
31)	000000	000000
32)	000000	36 920000
33)	000000	78 970000
34)	000000	86 570000
35)	000000	86 670000
36)	000000	145 870000

PRIMAL LP MODEL AND ITS SOLUTION (continued)

37)	.000000	164.170000
38)	.000000	265.470000

NO. ITERATIONS= 27

RANGES IN WHICH THE BASIS IS UNCHANGED

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
XA1	123.200000	INFINITY	69.640000
XA2	106.600000	INFINITY	67.070000
XA3	115.900000	INFINITY	39.450000
XA4	200.000000	INFINITY	81.500000
XA5	301.100000	INFINITY	175.000000
XA6	301.000000	INFINITY	174.800000
XA7	420.000000	INFINITY	234.600000
XA8	447.600000	INFINITY	243.900000
XA9	305.000000	294.530000	77.300000
XC1	53.560000	8.639999	14.030000
XC2	39.330000	14.030000	INFINITY
XC3	76.450000	39.450000	5.449997
XC4	283.750000	INFINITY	165.250000
XC5	298.290000	INFINITY	172.190000
XC6	183.640000	INFINITY	57.440000
XC7	522.280000	INFINITY	336.880000
XC8	581.910000	INFINITY	378.210000
XC9	599.530000	INFINITY	294.530000
XT1	62.200000	INFINITY	8.639999
XT2	55.000000	INFINITY	15.470000
XT3	71.000000	5.449997	INFINITY
XT4	118.500000	81.500000	78.970000
XT5	126.100000	172.190000	86.570000
XT6	126.200000	57.440000	86.670000
XT7	185.400000	234.600000	145.870000
XT8	203.700000	243.900000	164.170000
XT9	227.700000	77.300000	INFINITY

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	48566.000000	13448.000000	.000000
3	7200.000000	INFINITY	7200.000000
4	7200.000000	INFINITY	7200.000000
5	7200.000000	17300.000000	2700.000000
6	7200.000000	INFINITY	6801.000000
7	7200.000000	INFINITY	6386.000000
8	7200.000000	INFINITY	2492.000000
9	7200.000000	INFINITY	7013.000000
10	7200.000000	INFINITY	6543.000000
11	7200.000000	200.000000	5080.000000
12	20000.000000	INFINITY	16651.000000
13	20000.000000	INFINITY	13448.000000
14	20000.000000	INFINITY	2700.000000
15	20000.000000	INFINITY	20000.000000
16	20000.000000	INFINITY	20000.000000
17	20000.000000	INFINITY	20000.000000
18	20000.000000	INFINITY	20000.000000
19	20000.000000	INFINITY	20000.000000
20	20000.000000	INFINITY	20000.000000
21	360.000000	INFINITY	360.000000
22	1560.000000	INFINITY	1560.000000
23	3360.000000	INFINITY	3360.000000
24	1200.000000	INFINITY	1200.000000
25	2400.000000	INFINITY	2400.000000
26	1680.000000	INFINITY	1680.000000
27	720.000000	INFINITY	720.000000
28	600.000000	INFINITY	600.000000
29	5280.000000	INFINITY	5080.000000
30	3349.000000	.000000	3349.000000
31	6552.000000	.000000	INFINITY
32	24500.000000	.000000	13448.000000
33	399.000000	.000000	399.000000
34	814.000000	.000000	814.000000
35	4708.000000	.000000	4708.000000
36	187.000000	.000000	187.000000
37	657.000000	.000000	657.000000
38	7400.000000	.000000	200.000000

DUAL LP MODEL AND ITS SOLUTION

```
 MIN     48566 U1 - 48566 U2 + 7200 U3 + 7200 U4 + 7200 U5 + 7200
U6
      + 7200 U7 + 7200 U8 + 7200 U9 + 7200 U10 + 7200 U11 + 20000
U12
      + 20000 U13 + 20000 U14 + 20000 U15 + 20000 U16 + 20000 U17
      + 20000 U18 + 20000 U19 + 20000 U20 + 360 U21 + 1560 U22 +
3360 U23
      + 1200 U24 + 2400 U25 + 1680 U26 + 720 U27 + 600 U28 + 5280
U29
      - 3349 U30 - 6552 U31 - 24500 U32 - 399 U33 - 814 U34 - 4708
U35
      - 187 U36 - 657 U37 - 7400 U38
 SUBJECT TO
          2)    U1 - U2 + U21 - U30 >= - 123 2
          3)    U1 - U2 + U22 - U31 >= - 106.6
          4)    U1 - U2 + U23 - U32 >= - 115 9
          5)    U1 - U2 + U24 - U33 >= - 200
          6)    U1 - U2 + U25 - U34 >= - 301.1
          7)    U1 - U2 + U26 - U35 >= - 301
          8)    U1 - U2 + U27 - U36 >= - 420
          9)    U1 - U2 + U28 - U37 >= - 447.6
         10)    U1 - U2 + U29 - U38 >= - 305
         11)    U1 - U2 + U12 - U30 >= - 53.56
         12)    U1 - U2 + U13 - U31 >= - 39.53
         13)    U1 - U2 + U14 - U32 >= - 76 45
         14)    U1 - U2 + U15 - U33 >= - 283 75
         15)    U1 - U2 + U16 - U34 >= - 298.29
         16)    U1 - U2 + U17 - U35 >= - 183 64
         17)    U1 - U2 + U18 - U36 >= - 522.28
         18)    U1 - U2 + U19 - U37 >= - 581 91
         19)    U1 - U2 + U20 - U38 >= - 599 53
         20)    U1 - U2 + U3 - U30 >= - 62.2
         21)    U1 - U2 + U4 - U31 >= - 55
         22)    U1 - U2 + U5 - U32 >= - 71
         23)    U1 - U2 + U6 - U33 >= - 118.5
         24)    U1 - U2 + U7 - U34 >= - 126 1
         25)    U1 - U2 + U8 - U35 >= - 126 2
         26)    U1 - U2 + U9 - U36 >= - 185.4
         27)    U1 - U2 + U10 - U37 >= - 203 7
         28)    U1 - U2 + U11 - U38 >= - 227.7
 END

 LP OPTIMUM FOUND  AT STEP     12

         OBJECTIVE FUNCTION VALUE

  1)        -4885175.00
```

VARIABLE	VALUE	REDUCED COST
U1	.000000	000000
U2	39.530000	.000000
U3	.000000	7200.000000
U4	.000000	7200 000000
U5	5 449997	.000000
U6	000000	6801 000000
U7	000000	6386 000000
U8	000000	2492 000000
U9	000000	7013.000000
U10	000000	6543 000000
U11	77 300000	000000
U12	000000	16651 000000
U13	000000	13448 000000
U14	000000	2700 000000
U15	.000000	20000 000000
U16	000000	20000 000000
U17	000000	20000 000000
U18	000000	20000 000000
U19	000000	20000 000000
U20	000000	20000 000000
U21	000000	360 000000
U22	000000	1560 000000
U23	000000	3360 000000
U24	000000	1200 000000
U25	000000	2400 000000
U26	.000000	1680 000000
U27	000000	720 000000
U28	.000000	600 000000
U29	000000	5080 000000
U30	14 030000	.000000
U31	000000	000000
U32	36 920000	000000
U33	78 970000	000000
U34	86.570000	000000
U35	86 670000	000000
U36	145 870000	000000
U37	164 170000	.000000
U38	265 470000	.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	69.640000	000000
3)	67 070000	.000000
4)	39 450000	000000
5)	81 500000	000000
6)	175 000000	000000
7)	174 800000	000000
8)	234 600000	000000
9)	243 900000	000000
10)	000000	-200 000000
11)	.000000	-3349 000000
12)	000000	-6552 000000
13)	000000	-17300 000000
14)	165 250000	000000
15)	172 190000	000000
16)	57 440000	000000
17)	336 880000	000000
18)	378 210000	000000

19)	294.530000	000000
20)	8 639999	000000
21)	15 470000	000000
22)	.000000	-7200.000000
23)	.000000	-399 000000
24)	.000000	-814 000000
25)	.000000	-4708.000000
26)	.000000	-187.000000
27)	000000	-657 000000
28)	.000000	-7200 000000

NO ITERATIONS= 12

RANGES IN WHICH THE BASIS IS UNCHANGED.

OBJ COEFFICIENT RANGES

VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
U1	48566 000000	INFINITY	000000
U2	-48566 000000	000000	000000
U3	7200 000000	INFINITY	7200 000000
U4	7200 000000	INFINITY	7200 000000
U5	7200.000000	17300 000000	2700 000000
U6	7200 000000	INFINITY	6801 000000
U7	7200 000000	INFINITY	6386 000000
U8	7200.000000	INFINITY	2492 000000
U9	7200.000000	INFINITY	7013 000000
U10	7200.000000	INFINITY	6543 000000
U11	7200 000000	200 000000	5080 000000
U12	20000 000000	INFINITY	16651 000000
U13	20000.000000	INFINITY	13448 000000
U14	20000.000000	INFINITY	2700 000000
U15	20000 000000	INFINITY	20000 000000
U16	20000.000000	INFINITY	20000 000000
U17	20000.000000	INFINITY	20000 000000
U18	20000.000000	INFINITY	20000 000000
U19	20000.000000	INFINITY	20000 000000
U20	20000.000000	INFINITY	20000 000000
U21	360.000000	INFINITY	360 000000
U22	1560.000000	INFINITY	1560 000000
U23	3360 000000	INFINITY	3360 000000
U24	1200 000000	INFINITY	1200 000000
U25	2400.000000	INFINITY	2400 000000
U26	1680 000000	INFINITY	1680 000000
U27	720.000000	INFINITY	720.000000
U28	600 000000	INFINITY	600 000000
U29	5280 000000	INFINITY	5080 000000
U30	-3349.000000	3349 000000	000000
U31	-6552 000000	INFINITY	000000
U32	-24500 000000	13448 000000	000000
U33	-399.000000	399 000000	000000
U34	-814 000000	814 000000	000000
U35	-4708 000000	4708 000000	000000
U36	187 000000	187 000000	000000
U37	-657 000000	657 000000	000000
U38	-7400 000000	200 000000	.000000

RIGHTHAND SIDE RANGES

ROW	CURRENT RHS	ALLOWABLE INCREASE	ALLOWABLE DECREASE
2	-123 200000	69 640000	INFINITY
3	-106 600000	67 070000	INFINITY
4	-115 900000	39 450000	INFINITY
5	-200 000000	81 500000	INFINITY
6	-301 100000	175 000000	INFINITY
7	-301 000000	174 800000	INFINITY
8	-420 000000	234 600000	INFINITY
9	-447 600000	243 900000	INFINITY
10	-305 000000	77 300000	294 530000
11	-53 560000	14 030000	8 639999
12	-39 530000	39 530000	14 030000
13	-76 450000	5 449997	39 450000
14	-283 750000	165 250000	INFINITY
15	-298 290000	172 190000	INFINITY
16	-183 640000	57 440000	INFINITY
17	-522 280000	336 880000	INFINITY
18	-581 910000	378 210000	INFINITY
19	-593 530000	294 530000	INFINITY
20	-62 200000	8 639999	INFINITY
21	-55 000000	15 470000	INFINITY
22	-71 000000	INFINITY	5 449997
23	-118 500000	78 970000	81 500000
24	-126 100000	86 570000	172 190000
25	-126 200000	86 670000	57 440000
26	-185 400000	145 870000	234 600000
27	-203 700000	164 170000	243 900000
28	-227 700000	INFINITY	77 300000

MINIMIZATION OF FIRST OBJECTIVE FUNCTION (COST)

```
MIN     88 XA1 + 71.5 XA2 + 78 XA3 + 141 XA4 + 235 XA5 + 241 XA6
     + 348.5 XA7 + 366 XA8 + 225 XA9 + 26.46 XC1 + 19 33 XC2 + 38 85 XC3
     + 119 25 XC4 + 126.09 XC5 + 93.24 XC6 + 214.48 XC7 + 244.01 XC8
     + 253.73 XC9 + 28 XT1 + 21 XT2 + 32 XT3 + 63 XT4 + 67 XT5 + 75 XT6
     + 114.3 XT7 + 130 XT8 + 135 XT9
SUBJECT TO
       2)   XA1 + XA2 + XA3 + XA4 + XA5 + XA6 + XA7 + XA8 + XA9 + XC1 + XC2
     + XC3 + XC4 + XC5 + XC6 + XC7 + XC8 + XC9 + XT1 + XT2 + XT3 + XT4
     + XT5 + XT6 + XT7 + XT8 + XT9 =     48566
       3)   XT1 <=   7200
       4)   XT2 <=   7200
       5)   XT3 <=   7200
       6)   XT4 <=   7200
       7)   XT5 <=   7200
       8)   XT6 <=   7200
       9)   XT7 <=   7200
      10)   XT8 <=   7200
      11)   XT9 <=   7200
      12)   XC1 <=   20000
      13)   XC2 <=   20000
      14)   XC3 <=   20000
      15)   XC4 <=   20000
      16)   XC5 <=   20000
      17)   XC6 <=   20000
      18)   XC7 <=   20000
      19)   XC8 <=   20000
      20)   XC9 <=   20000
      21)   XA1 <=   360
      22)   XA2 <=   1560
      23)   XA3 <=   3360
      24)   XA4 <=   1200
      25)   XA5 <=   2400
      26)   XA6 <=   1680
      27)   XA7 <=   720
      28)   XA8 <=   600
      29)   XA9 <=   5280
      30)   XA1 + XC1 + XT1 >=   3349
      31)   XA2 + XC2 + XT2 >=   6552
      32)   XA3 + XC3 + XT3 >=   24500
      33)   XA4 + XC4 + XT4 >=   399
      34)   XA5 + XC5 + XT5 >=   814
      35)   XA6 + XC6 + XT6 >=   4708
      36)   XA7 + XC7 + XT7 >=   187
      37)   XA8 + XC8 + XT8 >=   657
      38)   XA9 + XC9 + XT9 >=   7400
END

LP OPTIMUM FOUND  AT STEP    27

        OBJECTIVE FUNCTION VALUE

 1)        2674329.00
```

VARIABLE	VALUE	REDUCED COST
XA1	.000000	61.540000
XA2	.000000	52.170000
XA3	.000000	39.150000
XA4	.000000	78.000000
XA5	.000000	168.000000
XA6	.000000	166.000000
XA7	000000	234.200000
XA9	200.000000	.000000
XC1	3349.000000	.000000
XC2	6552.000000	.000000
XC3	17300.000000	.000000
XC4	.000000	56.250000
XC5	.000000	59.090000
XC6	.000000	18.240000
XC7	.000000	100.180000
XC8	000000	114.010000
XC9	.000000	28 730000
XT1	.000000	1 540001
XT2	.000000	1 670000
XT3	7200.000000	.000000
XT4	399 000000	.000000
XT5	814.000000	.000000
XT6	4708.000000	.000000
XT7	187.000000	.000000
XT8	657.000000	.000000
XT9	7200.000000	000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-19.330000
3)	7200.000000	.000000
4)	7200.000000	.000000
5)	.000000	6 849998
6)	6801.000000	.000000
7)	6386.000000	.000000
8)	2492.000000	.000000
9)	7013 000000	000000
10)	6543.000000	.000000
11)	.000000	90 000000
12)	16651.000000	000000
13)	13448.000000	.000000
14)	2700.000000	.000000
15)	20000.000000	000000
16)	20000.000000	.000000
17)	20000.000000	.000000
18)	20000.000000	000000
19)	20000.000000	.000000
20)	20000.000000	.000000
21)	360.000000	.000000
22)	1560.000000	.000000
23)	3360.000000	.000000
24)	1200.000000	.000000
25)	2400.000000	.000000
26)	1680.000000	.000000
27)	720.000000	.000000
28)	600.000000	.000000
29)	5080.000000	.000000
30)	.000000	-7.129999
31)	.000000	000000
32)	.000000	-19.520000
33)	.000000	-43.670000
34)	.000000	-47 670000
35)	.000000	-55 670000
36)	.000000	-94 970000
37)	.000000	-110 670000
38)	.000000	-205.670000

NO ITERATIONS=   27

MINIMIZATION OF SECOND OBJECTIVE FUNCTION (TIME)

```
MIN     44 XA1 + 35 XA2 + 49 XA3 + 191 XA4 + 224 XA5 + 187 XA6 + 316 XA7
     + 399 XA8 + 289 XA9 + 154 XC1 + 112 XC2 + 226 XC3 + 687 XC4 + 733 XC5
     + 542 XC6 + 1247 XC7 + 1418 XC8 + 1475 XC9 + 38 XT1 + 28 XT2 + 56 XT3
     + 170 XT4 + 181 XT5 + 134 XT6 + 309 XT7 + 351 XT8 + 365 XT9
SUBJECT TO
       2)   XA1 + XA2 + XA3 + XA4 + XA5 + XA6 + XA7 + XA8 + XA9 + XC1 + XC2
     + XC3 + XC4 + XC5 + XC6 + XC7 + XC8 + XC9 + XT1 + XT2 + XT3 + XT4
     + XT5 + XT6 + XT7 + XT8 + XT9 =    48566
       3)   XT1 <=   7200
       4)   XT2 <=   7200
       5)   XT3 <=   7200
       6)   XT4 <=   7200
       7)   XT5 <=   7200
       8)   XT6 <=   7200
       9)   XT7 <=   7200
      10)   XT8 <=   7200
      11)   XT9 <=   7200
      12)   XC1 <=   20000
      13)   XC2 <=   20000
      14)   XC3 <=   20000
      15)   XC4 <=   20000
      16)   XC5 <=   20000
      17)   XC6 <=   20000
      18)   XC7 <=   20000
      19)   XC8 <=   20000
      20)   XC9 <=   20000
      21)   XA1 <=   360
      22)   XA2 <=   1560
      23)   XA3 <=   3360
      24)   XA4 <=   1200
      25)   XA5 <=   2400
      26)   XA6 <=   1680
      27)   XA7 <=   720
      28)   XA8 <=   600
      29)   XA9 <=   5280
      30)   XA1 + XC1 + XT1 >=   3349
      31)   XA2 + XC2 + XT2 >=   6552
      32)   XA3 + XC3 + XT3 >=   24500
      33)   XA4 + XC4 + XT4 >=   399
      34)   XA5 + XC5 + XT5 >=   814
      35)   XA6 + XC6 + XT6 >=   4708
      36)   XA7 + XC7 + XT7 >=   187
      37)   XA8 + XC8 + XT8 >=   657
      38)   XA9 + XC9 + XT9 >=   7400
END

LP OPTIMUM FOUND  AT STEP     26

        OBJECTIVE FUNCTION VALUE

 1)          7463144.00
```

VARIABLE	VALUE	REDUCED COST
XA1	.000000	6.000000
XA2	.000000	7.000000
XA3	3360.000000	.000000
XA4	000000	21.000000
XA5	.000000	43 000000
XA6	.000000	53 000000
XA7	.000000	7 000000
XA8	.000000	48 000000
XC1	000000	116.000000
XC2	.000000	84 000000
XC3	13940 000000	000000
XC4	000000	517 000000
XC5	.000000	552 000000
XC6	000000	408 000000
XC7	000000	938 000000
XC8	000000	1067 000000
XC9	000000	1110 000000
XT1	3349 000000	000000
XT2	6552.000000	000000
XT3	7200 000000	000000
XT4	399 000000	.000000
XT5	814 000000	000000
XT6	4708 000000	000000
XT7	187 000000	000000
XT8	657.000000	000000
XT9	2120 000000	000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	.000000	-28.000000
3)	3851 000000	.000000
4)	648.000000	.000000
5)	000000	170 000000
6)	6801 000000	.000000
7)	6386 000000	000000
8)	2492 000000	000000
9)	7013 000000	000000
10)	6543.000000	000000
11)	5080 000000	.000000
12)	20000.000000	000000
13)	20000.000000	000000
14)	6060.000000	000000
15)	20000.000000	.000000
16)	20000.000000	.000000
17)	20000.000000	.000000
18)	20000 000000	000000
19)	20000 000000	.000000
20)	20000 000000	000000
21)	360.000000	000000
22)	1560 000000	000000
23)	.000000	177 000000
24)	1200 000000	000000
25)	2400 000000	000000
26)	1680 000000	000000
27)	720 000000	.000000
28)	600 000000	000000
29)	000000	76 000000
30)	000000	-10 000000
31)	.000000	000000
32)	.000000	-198.000000
33)	.000000	-142.000000
34)	.000000	-153.000000
35)	.000000	-106 000000
36)	000000	-281.000000
37)	.000000	-323 000000
38)	000000	-337.000000

NO ITERATIONS= 26

MULTIOBJECTIVE FUNCTION LP MODEL

```
MIN      D
SUBJECT TO
      2)   XA1 + XA2 + XA3 + XA4 + XA5 + XA6 + XA7 + XA8 + XA9 + XC1 + XC2
    + XC3 + XC4 + XC5 + XC6 + XC7 + XC8 + XC9 + XT1 + XT2 + XT3 + XT4
    + XT5 + XT6 + XT7 + XT8 + XT9 =    48566
      3)   XT1 <=   7200
      4)   XT2 <=   7200
      5)   XT3 <=   7200
      6)   XT4 <=   7200
      7)   XT5 <=   7200
      8)   XT6 <=   7200
      9)   XT7 <=   7200
     10)   XT8 <=   7200
     11)   XT9 <=   7200
     12)   XC1 <=   20000
     13)   XC2 <=   20000
     14)   XC3 <=   20000
     15)   XC4 <=   20000
     16)   XC5 <=   20000
     17)   XC6 <=   20000
     18)   XC7 <=   20000
     19)   XC8 <=   20000
     20)   XC9 <=   20000
     21)   XA1 <=   360
     22)   XA2 <=   1560
     23)   XA3 <=   3360
     24)   XA4 <=   1200
     25)   XA5 <=   2400
     26)   XA6 <=   1680
     27)   XA7 <=   720
     28)   XA8 <=   600
     29)   XA9 <=   5280
     30)   XA1 + XC1 + XT1 >=   3349
     31)   XA2 + XC2 + XT2 >=   6552
     32)   XA3 + XC3 + XT3 >=   24500
     33)   XA4 + XC4 + XT4 >=   399
     34)   XA5 + XC5 + XT5 >=   814
     35)   XA6 + XC6 + XT6 >=   4708
     36)   XA7 + XC7 + XT7 >=   187
     37)   XA8 + XC8 + XT8 >=   657
     38)   XA9 + XC9 + XT9 >=   7400
     39)   D + 65 91 XA1 + 53 55 XA2 + 58 47 XA3 + 105 6 XA4 + 176 01 XA5
    + 180 5 XA6 + 261 02 XA7 + 274 13 XA8 + 168 52 XA9 + 19 81 XC1
    + 14 47 XC2 + 79 09 XC3 + 89 31 XC4 + 94 44 XC5 + 69 83 XC6
    + 160 64 XC7 + 182 76 XC8 + 190 04 XC9 + 20 97 XT1 + 15 72 XT2
    + 23 96 XT3 + 47 18 XT4 + 50 18 XT5 + 56 17 XT6 + 85 61 XT7
    + 97 37 XT8 + 101 11 XT9 <=   2003072
     40)   D + 11 XA1 + 8 75 XA2 + 12 25 XA3 + 47 75 XA4 + 56 XA5
    + 46 75 XA6 + 79 XA7 + 99 75 XA8 + 72 25 XA9 + 38 5 XC1 + 28 XC2
    + 55 5 XC3 + 171 75 XC4 + 183 25 XC5 + 135 5 XC6 + 311 75 XC7
    + 354 5 XC8 + 368 75 XC9 + 9 5 XT1 + 7 XT2 + 14 XT3 + 42 5 XT4
    + 45 25 XT5 + 33 5 XT6 + 77 25 XT7 + 87 75 XT8 + 91 25 XT9
    <=   1965796
END

LP OPTIMUM FOUND  AT STEP    33

        OBJECTIVE FUNCTION VALUE

  1)        104788 300
```

VARIABLE	VALUE	REDUCED COST
D	104788 300000	000000
XA1	000000	27 624220
XA2	000000	23 448020
XA3	3173 147000	000000
XA4	000000	37 225710
XA5	000000	79 957530
XA6	000000	80 051920
XA7	000000	106 186700
XA8	000000	111 084400
XA9	200 000000	000000
XC1	000000	10 862190
XC2	000000	7 619155
XC3	14126 850000	000000
XC4	000000	76 857220
XC5	000000	81 626050
XC6	000000	48 873540
XC7	000000	138 596900
XC8	000000	157 682600
XC9	000000	131 130800
XT1	3349 000000	000000
XT2	6552 000000	000000
XT3	7200 000000	000000
XT4	399 000000	000000
XT5	814 000000	000000
XT6	4708 000000	000000
XT7	187 000000	000000
XT8	657 000000	000000
XT9	7200 000000	000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	000000	12 244090
3)	3851 000000	000000
4)	648 000000	000000
5)	000000	20 026200
6)	6801 000000	000000
7)	6386 000000	000000
8)	2492 000000	000000
9)	7013 000000	000000
10)	6543 000000	000000
11)	000000	32 965810
12)	20000 000000	000000
13)	20000 000000	000000
14)	5873 147000	000000
15)	20000 000000	000000
16)	20000 000000	000000
17)	20000 000000	000000
18)	20000 000000	000000
19)	20000 000000	000000
20)	20000 000000	000000
21)	360 000000	000000
22)	1560 000000	000000
23)	186 853100	000000
24)	1200 000000	000000
25)	2400 000000	000000
26)	1680 000000	000000
27)	720 000000	000000
28)	600 000000	00000
29)	5080 000000	00000
30)	000000	4 15381
31)	000000	00000
32)	000000	27 77192
33)	000000	33 07040
34)	000000	-35 97075
35)	000000	34 88934
36)	000000	70 03350
37)	000000	81 29127
38)	000000	117 90140
39)	000000	60138
40)	000000	39851

NO ITERATIONS= 33

VITA

Majid Sabbagh Kermani

Candidate for the Degree of

Doctor of Philosophy

Thesis: AN ECONOMIC ASSESSMENT OF THE APPLICATION OF SUPER CONDUCTOR TECHNOLOGY TO MAGNETIC LEVITATION TRAINS IN OKLAHOMA

Major Field: Economics

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Personal Data: Born in Tehran, Iran, April 11, 1956, the son of Asghar and Zahra Sabbagh Kermani. Married with two children.

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Professional Experience: Graduate research assistant and instructor, Oklahoma State University, Stillwater, OK, January 1988 to December 1990. Visiting Assistant Professor at Southeastern Louisiana University, Hammond, LA, January-May 1991.