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FORECAST OF FUTURE AVIATION FUELS: THE MODEL

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FOREWORD

This report is based largely on the doctoral dissertation of M. B. Ayati, "A Dynamic Model of the Air Transport Industry," UCLA, 1980. A more detailed description of the scenario and model development may be found in the Phase 1 progress reports, "Forecast of Future Aviation Fuels - Parts 1 and 2" by English, et al., 1978, UCLA-EBG-77-78 and NASA CR-158871.

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CHAPTER I

INTRODUCTION - A CONCEPTUAL MODEL OF THE AVIATION INDUSTRY

Background

A NASA/UCLA study on the subject of "Future Aviation Fuel" started August 1976. The purpose of this study was to assess: the economics of changing aviation fuel specifications occasioned by shifting costs as well as the future availability of energy sources in general and petroleum based fuel supplies in particular; the effects of change in supply and specifications of fuels on the economics of commercial air transportation; and the advancement in aircraft technology on airline operating economics.

An integrated study to address the purposes mentioned above involves a number of related areas. (See Figure I-1). The kind of fuel and quantity for future aviation depends, on one hand, on the engine and airframe performance characteristics of aircraft; and on the other hand, the kind and availability of future aviation fuels. The aircraft itself may be considered as a component of a larger system, air transportation, which in turn is a subset of the transportation system. Similarly, availability, price and technical characteristics of aviation fuel fit into the overall energy picture of the future. Finally, transportation demand and energy requirements of the future interact with many socioeconomic variables, some of which have definite impacts on the behavior of the system.

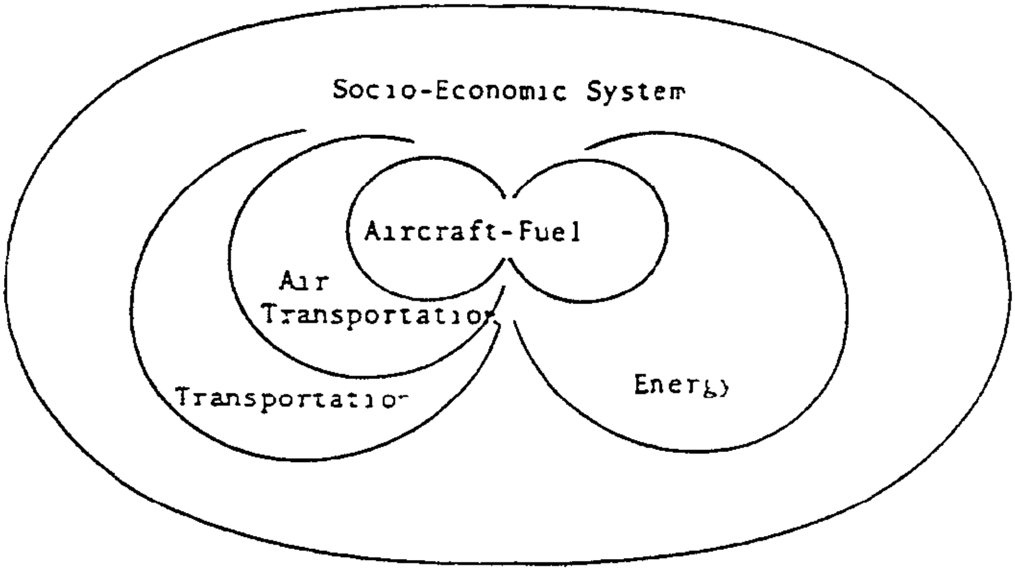


Figure I-1. Aviation Fuel and Its Related Areas

John Muir, the Scot naturalist wrote a century ago:

> "Everytime I try to separate anything out, I find it hitched to everything else in the universe. Interconnectedness: the world is not a flat, orderly sequence, but it is a hologram within which every small part contains all of the elements of out existence."

Even the small portion of that hologram we would like to study, which is conceptualized in Figure I-1, contains numerous entities and relationships. However, as it will be discussed in Chapter II, the essence of modeling is to ignore many less important details to gain clarity. Based on this premise, important factors involved in this study are abstracted in Figure I-2, a conceptualized model developed by the author (Ayati and English, 1980).

As a self-contained portion of the NASA/UCLA study, the subject of this part is to relate technological advances of aircraft, changes in aviation fuel usage with air transportation demand, and the operation and economics of the airline industry. More specifically, a quasi-analytical framework for policy analysis is provided. Such an integrated model is a useful means for examining the consistency and logical consequences of assumed policies.

A Conceptual Economics Model of the Aviation Industry

In the conceptual scheme of the overall model, Figure I-2, the basic entities are the following:

1. Energy Model to project supply, demand, and price of the major energy types. A large energy model originally developed at Dartmouth College and known as Coal 2 is adapted for this purpose.

2. Aviation Fuel Model to project specification, availability, and price of future aviation fuel. A representative refinery model developed by Gordian Associates was originally thought to be used for this purpose. However, use of this model in the context of our study (Figure 1-2) requires some modification which has been suggested to NASA.

3. Technological Advancement in New Aircraft to project changes in engine and airframe developments. Unlike performance records, which may show a pattern and, consequently may or may not support a particular hypothesis or theory, past records of technological advancement do not always suggest any pattern. When we study opportunities

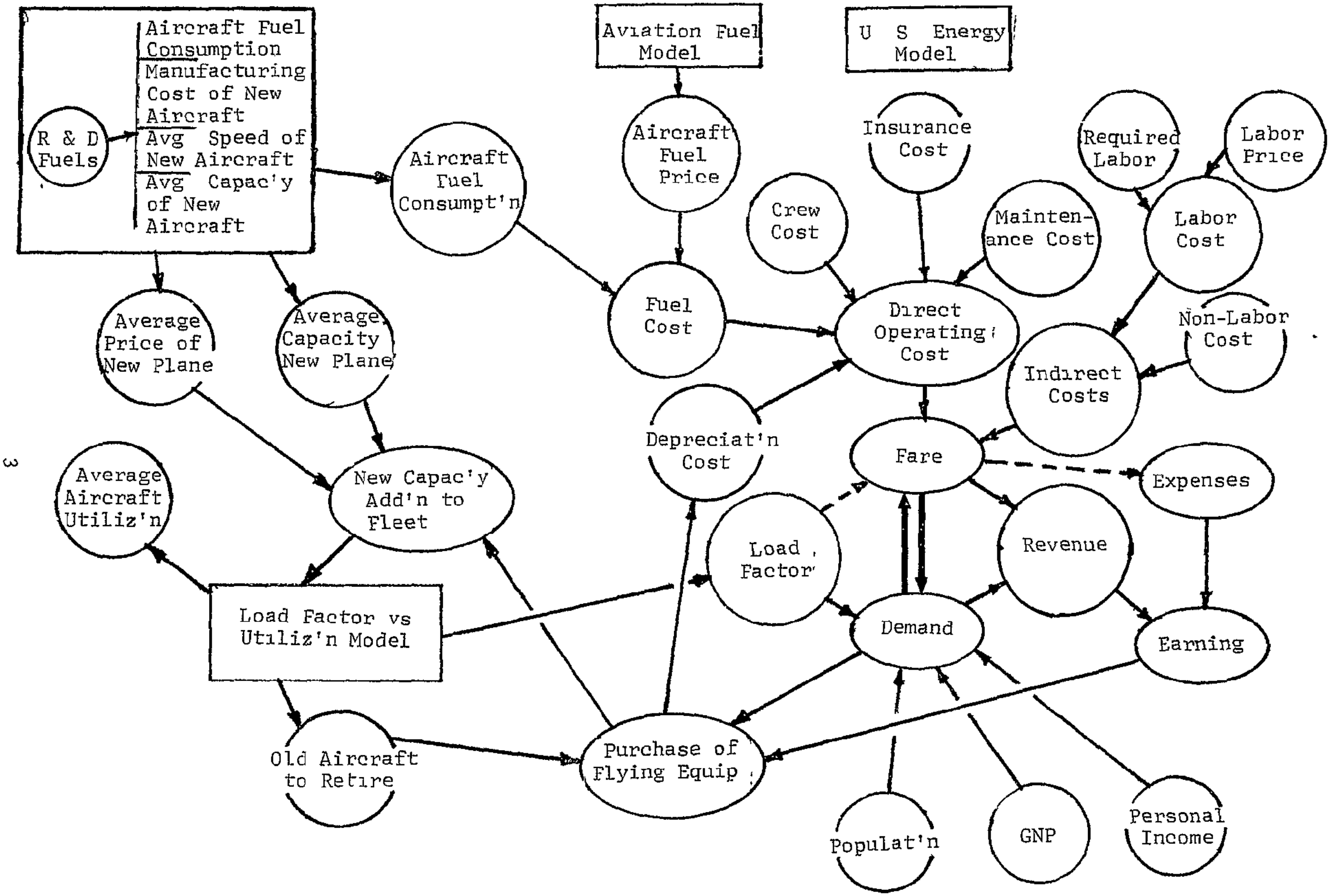


Figure 1-2 A Conceptual Model of Future Aviation Fuel, Technology and Economics

for advancement in aircraft technology such as, for example, Laminar Flow Control (LFC), past experience with other technological advancements may be of little use in forecasting the future of LFC. Therefore, in this area of technological advancements, conjecture of experts becomes essential.

As the aggregated result of all probable technological advancements in aircraft, certain areas of economic concern are more likely to be affected than others. In particular it is expected that new technologies will make aircraft more fuel efficient. Cost items such as maintenance and crew costs apparently will be less affected in the future. Outputs of this portion of the research, to be used in the rest of the model, are aviation fuel consumption per ton-mile available service, and price and capacity of new aircraft.

The above three portions of the overall model are not the subject of this report. However, necessary inputs are taken from these three for use in Part IV.

4. <u>A Model of Air Transportation Economics</u> is predicated on the conventional economic theory. The fundamental premise in this model is that a major drive of economic activity is profitability. It is acknowledged, however, that not every economist accepts this premise on the grounds that the objectives of owners and management of modern American corporations are not necessarily the same. Still profitability is the major--but not the sole--driving force.

The profitability premise leads the analysis to its constituents--revenue and cost. On the revenue side we deal with demand and price (fare). On the cost side the various types of costs are categorized as direct cost, indirect cost, and investment.

The model is a simulation model in which an attempt is made to project the responses of the airline industry and its customers. Both behave under the influence of the dynamic socioeconomic environment. The dynamic process of mutual response of the two parties manifests itself in four variables--demand, fare, load factor, and investment. The influencing factors on these variables and how they interact is the subject of Chapter VI. Although there are a number of models for demand for air transportation, all have serious inadequacies. First, they represent only a section of the industry (e.g., domestic trunk passenger service, freight, et cetera). Second, demand for that section of the industry is the only endogenous variable of the system and the rest of the variables, including fare and investment, are treated exogenously. (See CAB, 1967; 1971). In the model presented in this report the air transportation system is treated dynamically, with feedbacks within itself as well as with its socio-economic environment.

Furthermore, a digraph methodology for presenting and simulating a class of socio-economic systems, such as the aviation industry, is suggested. (See Chapter III). The methodology has been successfully applied to model economics of the air transportation industry. Validation result of the model, based on the data of the last three decades, show the degree of success of this application.

Presentation of the research is mainly the description of final results. The modeling process, by nature, is an iterative one in the sense that the final product comes into being after, perhaps, hundreds of hypotheses on the structure of the model or details of relationships have been rejected or ignored in the absence of enough confirming evidence. Only a few of these experiences have been included in the report. (See Chapter VI).

This report is presented in seven chapters. Figure I-3 shows the organization and relationships of the chapters. Chapter I introduces the background and conceptual framework of the research. Chapter II describes a philosophical approach to modeling socio-economic systems. Chapter III shows development of a digraph methodology for presenting and simulating socio-economic systems. Chapter IV reviews the history of air transportation and serves as a databank and historical reference for the rest of the research. Chapter V outlines a variety of scenarios based on which future trends of the exogenous variables of the system can be inferred. Chapter VI describes, in detail, development of air transportation models using digraph methodology. And finally, Chapter VII suggests future research for improvement and expansion of the present model.

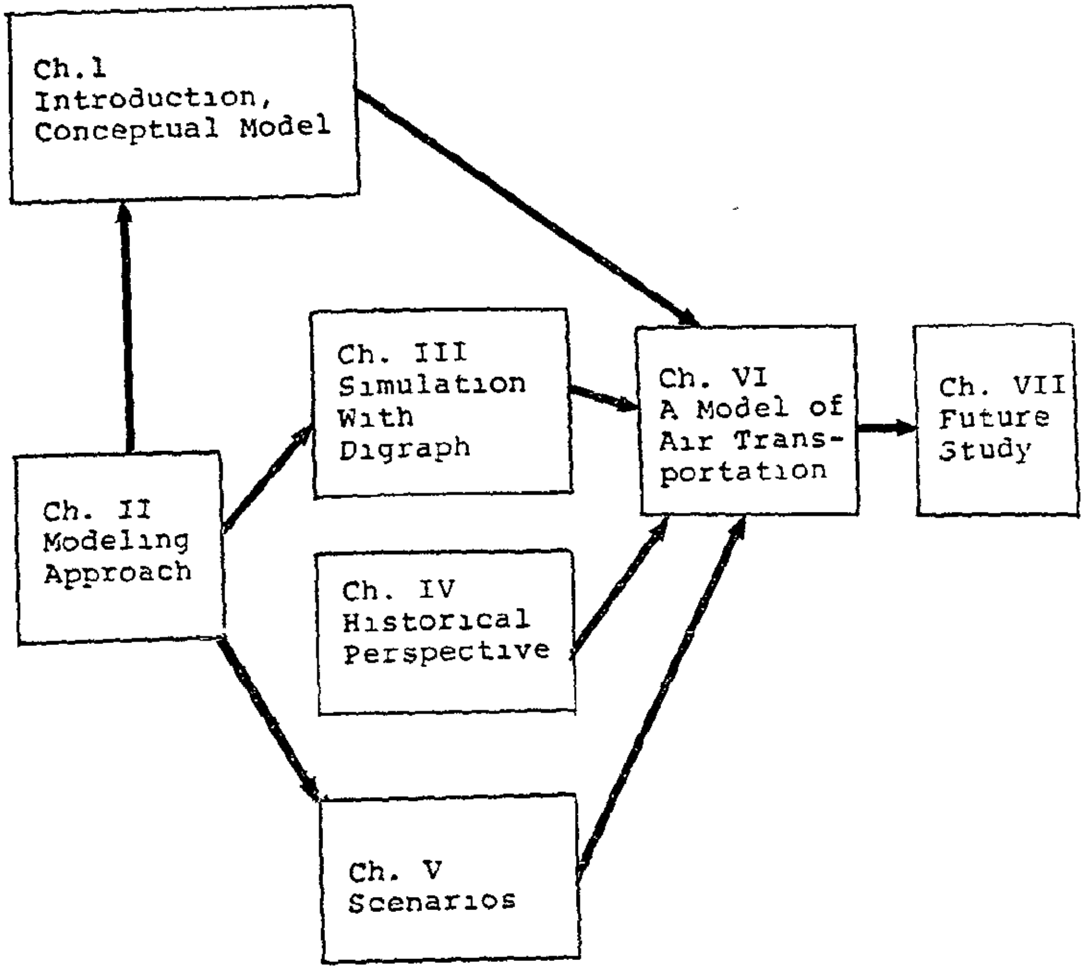


Figure I-3 Organization of Chapters

CHAPTER II
A GENERAL APPROACH TO MODELING

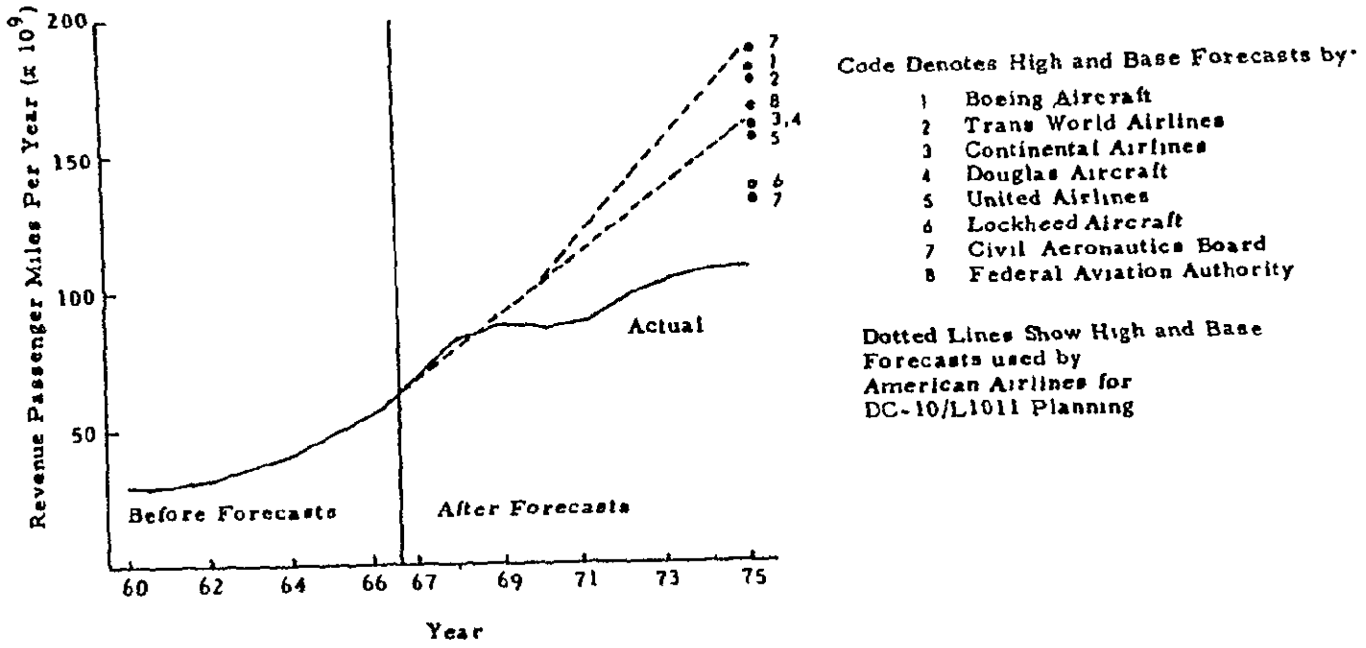
When comparing the results of various forecasts made in the past with the actual outcomes, it seems, on the surface, that forecasting has been one of the least successful enterprises of man. An example of such an effort is demonstrated in Figure II-1 where the forecast of eight respectable agencies on the future of air passenger demand proved to be all drastically unrealistic. Should we give up a seemingly future practice? Certainly not. Tomorrow's shape is made by our action today based on today's expected outcomes. We act upon our expectations which are, in effect, the implied forecasts derived from our mental models. In spite of the inaccuracy of our forecasts, the consequences of our actions have more often been successes than failures. And so, adaptively, by trial and error, we have progressed; we have learned much. From a superficial extrapolation of phenomena to a detailed search for cause and effect, we have succeeded in narrowing the boundaries of error in forecasting more things in the future.

Meanwhile, we have been able to recognize increasingly more actors in the scene, more entities in the system, and more complex relations. Whenever complexity got out of hand, whenever confusion overwhelmed, the command of hope was "abstract," and so scientific man has evolved.

Terms and phrases such as "theory," "formula," "system of equations," and recently "model," all refer more or less to the same thing: An abstraction of the real system for the purpose of representation. To form them we have to look hard at the system to identify the major entities, attributes and relations in order to form abstractions. However, different connotations may be implied for each word in different contexts. This is basically related to the possible error band or uncertainty associated with each. Generally speaking, in a sense, the concept of system, a long practiced, recently defined knowledge, is the subject of new ways to make this abstraction more suitable to the real system and to the purpose of the user.

Modeling Approaches

Existing modeling approaches fall into 4 major categories: physical, descriptive, mathematical, and simulation. A mathematical model is a set of equations that describe the behavior of the system, and by solving these equations we obtain an analytical solution. The solution expresses the system's condition at any future time. Mathematical models are explicit and unambiguous, but their applicability is limited to less complex systems with few variables. For most complex systems, the construction of a realistic (representative enough) model is impractical. However, since World War II large mathematical



SOURCE: Aerospace 1978

Figure II - 1 Past Air Traffic Forecasts models have been developed under the category of optimization model. These models are specifically applicable to a class of systems in which the decision maker has certain controls over their input and, therefore, tries to optimize his control to achieve the best possible level of output. The purpose of these models is usually decision making rather than prediction, where prediction, a necessary input, is often taken as a deterministic exogenous variable in the model.

Unlike the mathematical models in which the condition of the system at each time can be expressed, simulation models contain a set of equations which describe how the system changes. These changes accumulate step-by-step to map the behavior pattern of the system (Forrester, 1968). The equations in a simulation model do not express the state of the system at one particular time. The model imitates, kinematically, the dynamic behavior of the actual system.

What we discussed at the beginning of this chapter concerning criticisms of forecasting can be summarized as follows: Our failures with forecasting occur when we try to answer rigidly the question "what will happen." Our successes with forecasting occur when we ask "why is x happening" and "how will x change." Consequently, the main purpose of forming a system model should not be to produce an accurate end result but should be a mechanism to organize the effort for a better understanding of cause and effect within the system. And for this purpose simulation offers a better alternative than forecasting.

Without the aid of a simulator, learning can occur only when we actually experience the behavior of the system. However, with a model we may generate patterns of the system's behavior using different assumptions and thereby learn much about the system before actually experiencing its processes.

Limits of a Model

Since we defined "model" as an abstract representation of a real system, the boundaries of the model should represent the boundaries of the system of concern.

A network is perhaps one of the most useful ways to represent a system. In it, nodes symbolize the entities, and lines or arrows, connecting the nodes, represent the relationships. An entity may be a thing, an attribute, a concept, or even a system. Thus, in general, each system contains other subsystems and, at the same time, is contained in a larger system. In this context, every entity we touch we find hitched to everything else in the universe. But because of limited interest, limited resources and limited abilities, we always have to content ourselves to a restricted number of entities and only the most important relationships. Still such limitations should not mean that we have to look at the system in isolation from the rest of the environment. Suppose we are interested in the behavior of Y_1 and Y_2 (see Figure II-2). Consider also x_i's, $i=1,\ldots 5$, as other important entities of the system affecting the behavior of Y_1 and Y_2.

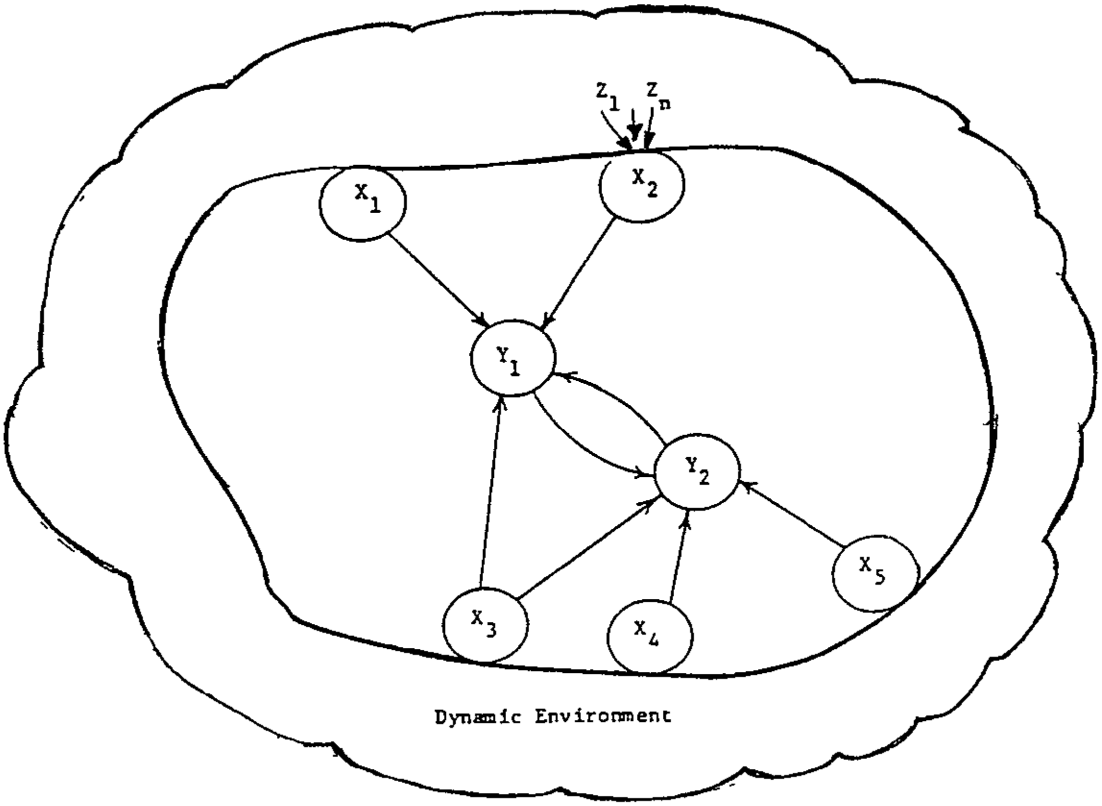


Figure II-2. A System in its Dynamic Environment.

Each of these, x_i, is perhaps linked to other entities like z_i, $i=1,\ldots n$, and z_i is linked to other entities and so on. Because of limited ability, interest and resources, we may have to stop expanding the system under study to the first seven entities in Figure II-2. Still, we must consider the dynamic behavior of the system inside the dynamic environment surrounding it.

It is useful, at this point, to define two types of variables in our example. First, those variables whose value is determined by the other variables in the system, such as Y_1 and Y_2, are called "endogenous." Second, variables whose values are determined by forces outside the system are called "exogenous."

Horizon, Forecast, Prediction and Scenarios

Forecasts have often been made by looking at an entity in isolation and on the basis of what has happened in the past.

Thus, assuming that the trend continues in the future, the state of the entity is predicted. Fluctuation of past data confuses the analyst, so he must argue for the possible and plausible range of outcomes. Then the variance of possible future outcomes widens quickly as we go further into the future. For longer range forecasts, the level of confidence drops, almost, to zero (Figure II-3). Therefore, in predicting longer range objectives, direct use of knowledge observations must be abandoned.

A scenario approach has been suggested as a viable alternative (English, 1978).

> "A scenario is a hypothesized situation that represents a plausible description of what could occur within specified social, technical, and economic constraints. Because the scenario is perceived as occurring beyond a horizon that necessarily limits visibility of the future, it cannot be construed as a valid prediction. A scenario, therefore, gives rise to this question: What if the future unfolded in some supposed way, what then might the consequences be? In the absence of clairvoyance, this is the only reasonable approach that can be taken".

It is recognized that societal aspirations underpinning predicted outcomes may change as events unfold, but aspirations over time are likely to be of a more permanent nature, having much less variance, than the variance of a forecast of any one entity of that future environment. Figure II-3 depicts these characteristics (Ayati, 1980).

With a defined scenario we can make projections on the behavior of surrounding dynamic environment (Figure II-2) in terms of the behavior of the exogenous entities of the system. In Chapter V we develop scenarios for the general socio-economic environment in which the aviation industry behaves. Then, numerical implications of these scenarios, in terms of the behavior of the exogenous variables, will be demonstrated. Since the model is, in fact, imbedded in the scenario, some relationships among entities may also vary according to different scenarios.

Large vs. Aggregated Model

Aside from the limitations of resources needed to develop and operate a large complex model which include many variables, such an expansion may not be even useful. Errors in estimations may accumulate unchecked and so distort results. Too many details may tend to develop a deceptive confidence and eventually harm the purpose of the model as an aid for planning. One must acknowledge some degree of validity in this

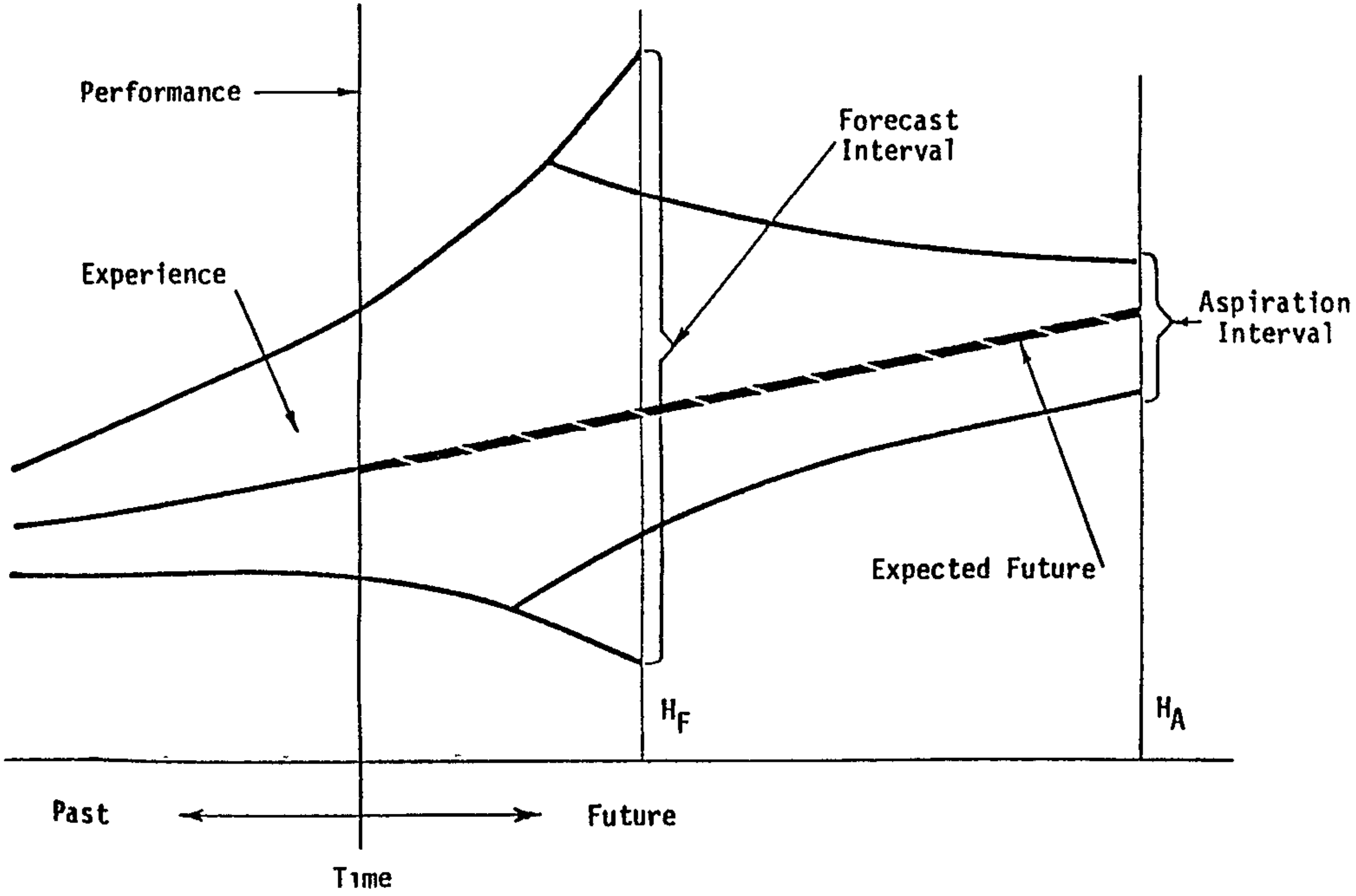


Figure II-3 Prediction and Aspiration Level argument, since verification tests cannot eliminate all possible error when many assumptions are needed. The greater danger of a large model, however, is the deception that can happen when the model builder takes the model as the system itself instead of a crude abstraction of the system. In other words, he may take the model as a substitute for human intelligence and not merely as an aid for the decision maker.

We emphasize the point that the purpose of the model development and use is basically educational rather than crystal-ball reading. With this view, the argument of "Large vs. Aggregated Model" takes another dimension. When the number of variables in a model increases, the complexity of the model, in terms in taking many things into consideration, increases the confusions and the possiblity of unchecked error accumulation. In this regard it should not be forgotten that the essence of modeling is to lose some details to gain clarity and understanding. However, having more variables in the model increases the reliability of incorporating the most important variables and relationships.

On the other hand, crudity of the analysis decreases when more variables are considered in the system. In particular, when establishing relationships among entities are made by experts' opinion, these opinions are more accurate and perhaps more reliable when the entities are at a more detailed and practical level. For example, in predicting the operating costs of the airline industry, it would be more clarifying if we break down the overall cost into its items and try to predict, with the help of lower echelon experts in each area, the more probable future of each cost item. It is the art and skill of the model builder to optimize, perhaps instinctively, the appropriateness of his model size with his objectives. Of course, the optimization is subject to constraints of his resources.

The Requirements of Modeling

The art of model building recognizes the relative importance of the model objective in choosing the right set of variables with the right degree of aggregation, and in finding reasonable relationships. The quality of what the modeling produces depends fundamentally on the extent of the perception of the real system. Knowledge of past performance of the system is the main ingredient of this perception. In particular, in formulating the relationships and parameter identification, historical data plays the crucial role. Finally, reliable historical data are, often, necessary to validate the model by matching performance.

Model Validation

Modeling authorities have repeatedly suggested the absence of any absolute criteria for providing validity (in the sense of proof) for a model. All that is necessary and desirable is to increase confidence in a model's utility (Forrester, 1975).

The validity of a model should be judged in the context of its objectives. We cannot say a model is good or bad in an absolute sense. It is either appropriate or inappropriate in the context of some use.

To increse confidence in a model, the users should be able to test its validity in the following dimensions:

1) Structure and parameters of the model shold be verifiable through a clear and carefully done documentation of model development;

2) the model should generate a time series of endogenous variables consistent with actual historical data; and

3) the parameters to which the level of endogenous variables are sensitive should be identified.

The existence of reliable historical data is a necessary condition for the testing of a model.

CHAPTER III
DIGRAPH AS A SIMULATION METHODOLOGY

A projective model is essentially an explicit expression of 'cause' and 'effect' relationship among a set of variables. Knowing this causes and effects relationship with some degree of approximation, and assuming the future course of certain causes, one can make projections of the system. To construct such a model, certain parts of graph theory, in particular, digraph theory--the theory of directed graphs--has a natural appeal.

Digraph has been suggested as a "structural analysis" tool under the category of geometric models. "If mathematical models are classified into two types, geometric and arithmetic, digraph theory gives rise to geometric models. A geometric model deals with the shape and structure of a system, while an arithmetic model deals with specific numerical value and makes precise and time-specific predictions" (Roberts, 1974).

Digraph as a structural analysis tool applied to socio-economic models has shown limited success. When arithmetic results in terms of reliable estimation of value of certain variables at certain times are needed, digraph, at its present development, cannot produce any satisfying answers (Roberts, 1974). However, with some improvement and extension, the methodology can be used as a simulator to generate numerical value and time-specific prediction as well as a geometric model to represent the shape and structure of a system.

In this chapter the fundamentals of digraph, as it is suggested and applied by Roberts (Roberts, 1972; 1974) for structural analysis of a socio-economic systems will be reviewed. Then the limitations of this methodology will be addressed, and suggestions for a more comprehensive methodology will be presented. In Chapter VI application of the extended version of digraph to an air transportation demand model will be presented in detail.

Digraph Methodology

A digraph is a collection of nodes and arrows in which nodes are used to symbolize variables and arrows symbolize the relationship between variables. Construction purpose of digraph models involve the following steps:

--Identifying the variables

--Establishing the relationships
among variables.

Variable Identification

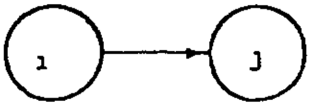
Engineering studies of physical systems often involve a relatively small set of variables which are clearly identifiable. Moreover, relationships among them are precisely measurable. Conversely, in systems involving social and economic factors, variables are often only vaguely identifiable, if they are known at all, and many factors may be obscured from analytical observation. Not only may the number of variables be large but the variables themselves sometimes may seem to be capricious, changing value in an unpredictable way. An example is for variables which measure consumer preference for certain discretionary goods such as air traffic demand for pleasure purposes.

Where accurately measured data are not available, the best available would be a collection of opinions from experts since the other alternative is a pure speculation. The Delphi method may be chosen to systematically collect experts' opinions on the relevant socio-economic variables. The Delphi method, unlike conventional meetings and conferences, emphasizes avoiding face to face interactions (Dalkey, 1969).

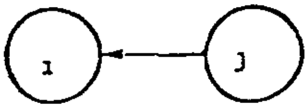
Roberts (1972) shows a detailed example of a research effort to identify a minimum sufficient set of variables to be considered in a "Transportation Energy Demand" model.

Identifying the Relationships Among Variables

A relationship, in digraph methodology, refers to the change stimulated in variable j as the *direct* result of changes occuring in variable i.

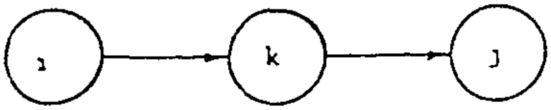


(a)



(b)

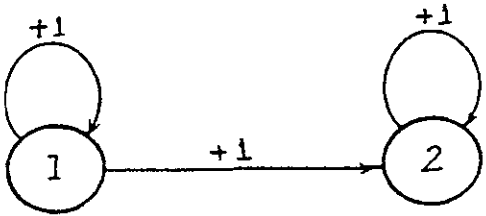
Note that (a) and (b) describe two different relationships. Also, it is important that only direct effects be considered. If, for example, in graph (a) a change in the level of variable i causes changes in some intermediary variable k and k, in turn, causes changes in variable j, then the graph should be corrected as:



To establish the relationship among variables, three questions need to be addressed. First, is there any significant direct cause and effect relationship between the two variables under consideration? Second, if there is such a relationship, is it positive or negative? That is, does a positive increment in variable i cause a positive or negative increment in variable j? Third, how strongly amplifying is this casual relationship? That is, if variable i goes up by 1 unit, how many units will variable j increase or decrease? This number is called the "arc weight" in digraph terminology. Roberts (1972/2; 1974) shows the details of a Delphi Study on establishing relationships among the variables of a "Transportation Energy Demand" model.

Analysis of a Digraph

Once the major variables (nodes) are chosen and the main relationship among variables (arrows) are established, the model is ready for analysis. Analysis of a digraph, basically, refers to perturbing the system by applying an autonomous pulse on one or more of the variables and then assessing the propagation of changes into the network (system). This is, in fact, a structural analysis which enhances the knowledge of the analyst about the behavioral nature of interacting parts of the system. In particular, the analyst wants to detect the stability or instability of the level of some variables. For example, if we apply a pulse of magnitude one to node i in network (a) above, after passage of one period, nodes 1 and 2 will each increase by one unit and the increase will stimulate another change in both nodes.



(a)

	Time	New Pulse to 1	Level of Variable 1	New Pulse to 2	Level of 2
	0	0	v_1	0	v_2
Start →	0^+	1*	v_1+1	0	v_2
	1	1	v_1+2	1	v_2+1
	2	1	v_1+3	2**	v_2+3
	3	1	v_1+4	2	v_2+5
	.	.	.	.	.
	.	.	.	.	.
	.	.	.	.	.
	n	1	v_1+n	2	v_2+n+2

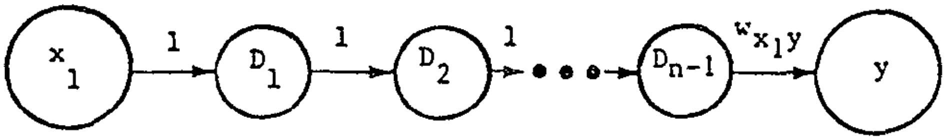
* The Autonomous Exogenous Pulse.

** One Pulse from 1 and another from itself 2.

Table III - 1. Values and Pulse Processes on Graph (a)

As time passes, the level of nodes 1 and 2 grows unboundedly. Therefore, systems (a) is considered to be unstable. (See Table III - 1 above).

Note that the basic assumption of digraph theory is that the effect of change in 1 and 2 is realized after passage of one period of time. If the causal effect requires a time lag of n periods, the only solution (though the solution looks trivial) is to assume n-1 dummy variables among the two. The weight, w_{12} must be given to the first or last arc. And the other arcs will be given a weight of +1:

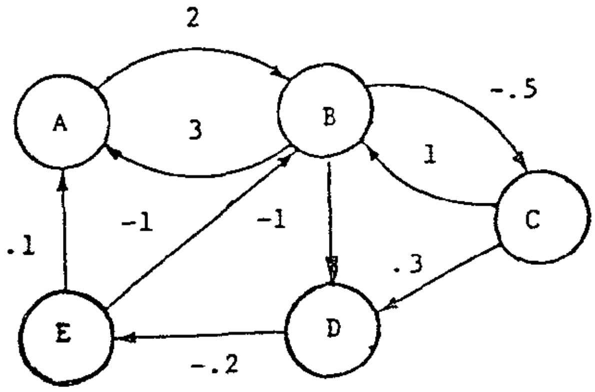


Mathematical Analysis of a Digraph

The technique for analyzing a digraph starts with constructing a cross-impact matrix in which the elements, w_{ij}, are the weights on arc ij. The arc weights represent the magnitude of the causal relation between two nodes (variables).

$$A = \begin{array}{c|ccccccccc|} & 1 & 2 & \circ & \circ & j & \circ & \circ & \circ & n \\ \hline 1 & & & & & & & & & \\ 2 & & & & & & & & & \\ \circ & & & & & w_{ij} & & & & \\ i & & & & & & & & & \\ \circ & & & & & & & & & \\ \circ & & & & & & & & & \\ \circ & & & & & & & & & \\ \circ & & & & & & & & & \\ n & & & & & & & & & \end{array}$$

An example of a weighted digraph and the associated cross-impact matrix as shown below in Figure III-1.



$$\begin{array}{c|ccccc|} & A & B & C & D & E \\ \hline A & 0 & 3 & 0 & 0 & 1 \\ B & 2 & 0 & 1 & 0 & -1 \\ C & 0 & -\,5 & 0 & 0 & 0 \\ D & 0 & -1 & .3 & 0 & 0 \\ E & 0 & 0 & 0 & -.2 & 0 \end{array}$$

Figure III - 1. A Weighted Digraph and Its Weighted Cross-Impact Matrix

A cross-impact matrix is essential in assessing the response and stability of the system. The analysis of a digraph (Roberts, 1976) shows how the stability of the system can be established by studying the eigen values of the cross-impact matrix.

However, when arithmetic results in terms of reliable estimation of value of certain variables at a certain time are needed, digraph, at its present stage of development, can not produce any satisfying answers. The next section of this chapter contains suggestions for improvement of digraph methodology to a systematic technique by which prediction of the value of system variable would be possible.

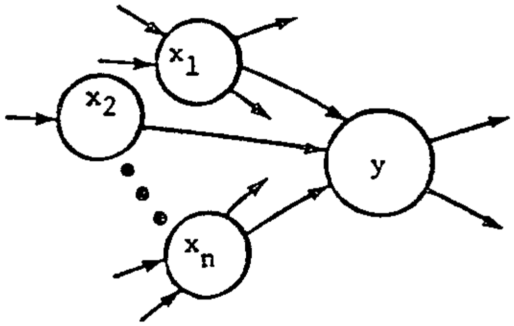
A Methodology for Simulation with Digraph

Development of a reliable projection method for a complex system of variables requires two considerations. First, assumptions about the interacting nature of system components (relationships among endogenous and exogenous variables) must be realistic; and second, pulses applied to the system should replicate outside forces affecting the system as closely as possible (i.e., changes occurring to the real world system variables result from policy changes or other forces). The first consideration is involved with the model of the system itself (nodes and arcs) while the second is involved with forces which are external to the system. The prediction methodology being developed is based on three fundamental modifications of the current digraph approach. Two of these deal with the system model in terms of the cross-impact matrix and time lags in the system. The third modification deals with repeated exogenous pulses applied to the digraph model and their validity as realistic surrogates for the real world effects.

1. Estimation of Cross-Impact Matrix Weights

Currently, the estimated weights in the cross-impact matrix are constant and independent of the level of the variables and also independent from the changing environment under which the observed system operates. In other words, there is no capability for reflecting changes which occur to the environment external to the system being modeled.

Mathematically, constant weights in the cross-impact matrix imply that the relationships between variables are linear as illustrated below:



$$\Delta y=f(\Delta x_1,\ \Delta x_2 .\,.\,.\,.\ \Delta x_n)$$
$$=w_1\Delta x_1+w_2\Delta x_2+.\,.\,.\,.\ w_r\Delta x_n$$

In many instances in the real world this linear approximation is not satisfactory. In general, the causuality relationship between variables may be non-linear; it may be time-dependent or value-dependent or both (i.e., it may depend on the state of the system). Introducing nonlinearity into digraph methodology involves two problems: first -- how to assess the nonlinear relationship; and second -- how to incorporate nonlinearities into the methodology. Assessment of a relationship may be accomplished by utilizing results of previous or current studies. Otherwise, expert opinion may be the best substitution in lieu of scientific research. In any case, we are looking for a function such as the following one illustrated in Figure III-2. Assume that the value of variables x_1 and y are known to be at R. We shift the horizontal and vertical axes to R in order to reflect these current values. If variable x_1 increases (decreases) by 1 unit (or by Δx), we want to know what the corresponding increase or decrease of y (Δy) will be. The ratio of $\frac{\Delta y}{\Delta x} = w$,

and this is the same as the weight in the cross-impact matrix. This ratio may be assessed as an algebraic function or just a table resulting from a gathering of expert opinion.

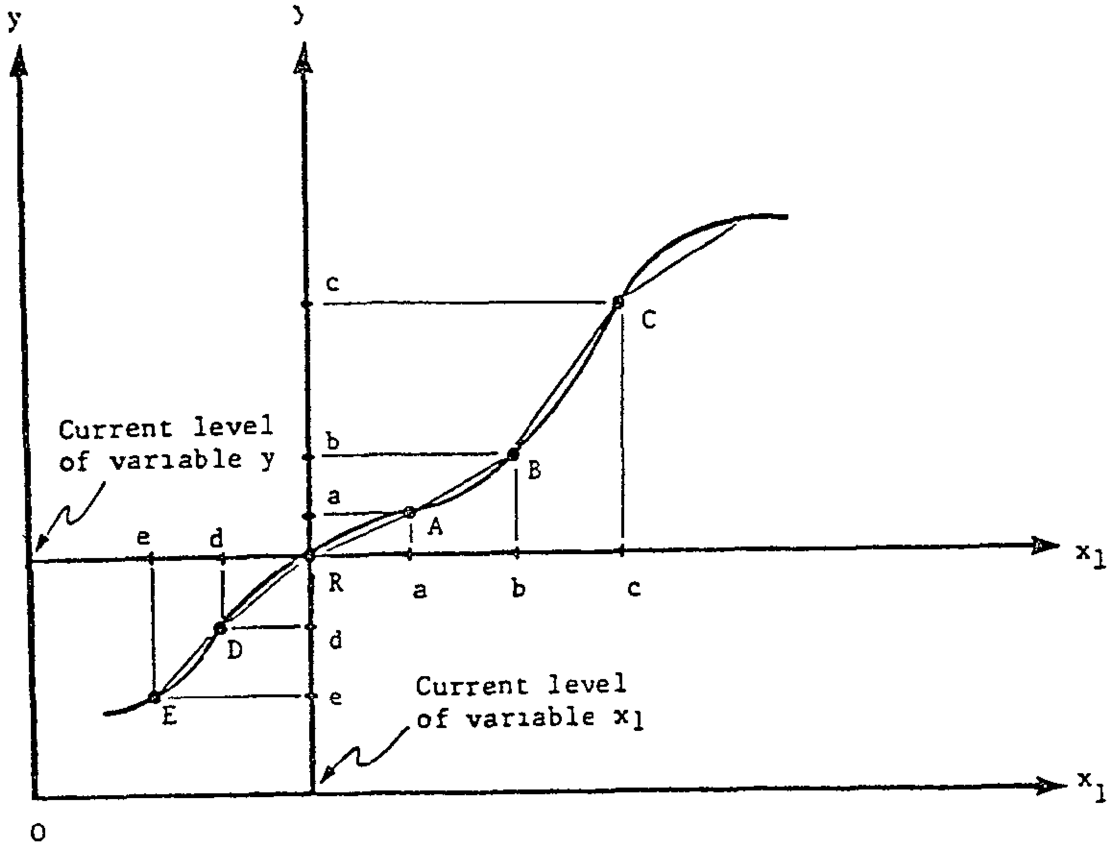
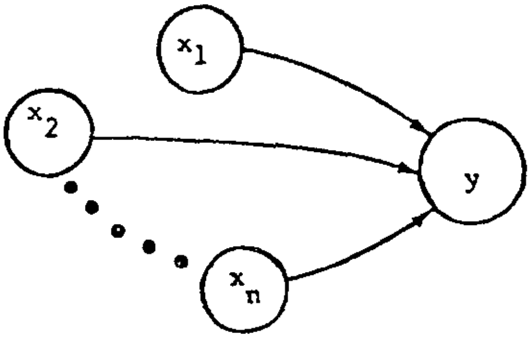


Figure III - 2. Causal Effect of Change in x_1 on y

It is important to recognize that the relationship depicted in Figure III-2 is quite different from the relationship that would be determined by historical data or its extrapolation. Consider the following figure:



$$\Delta y=f(\Delta x_1,\ \Delta x_2 \ldots\ \Delta x_n)$$

In the past, it is assumed that the level of y has been changing due to the combination of changes taking place in $x_1, x_2 \ldots x_n$. Historical data can be valuable information in examining the possibility of a causal relationship between variables as depicted above.

Once the relationship $\Delta y = f(\Delta x_1, x_1, x_2 \ldots x_n)$ is established as in Figure III-2, then the linear approximation, $\Delta y/\Delta x$ can be utilized instead of a constant w. Thus, the cross-impact matrix of the system turns into a dynamic one. (In fact, the word "kinematic" should be used instead of "dynamic" since the essential elements of a dynamic system, force and mass, are not being used here. But it is a common mistake and changing dynamic to kinematic may cause more confusion.) The computer can be instructed so that at each new value of one or more variables in the program will refer to a related table (or algebraic function) to calculate a new weight, w_1, for the next step.

The estimation of $\Delta y/\Delta x_1$ by expert judgment can be done more accurately at the current value of any two variables (like point R in Figure III-2), than for significantly different variable values (points B or C). It is clear that as the values of the two variables change, the uncertainty of expert opinion increases. Therefore, when the variables are assumed to have changed value, it may be appropriate to ask the experts to provide more input based on new consideration of the new variable values. In other words, let the panel of experts get the feeling of being in the next period (e.g., five, ten or twenty years from now) with all concerned variables at their new values. By placing the experts in a new time period, working assumptions of an accompanying scenario can, perhaps, Some applications may require one to consider a gradual realization of change in dependent variables. Consider a situation where the realized change in y, as affected by a change in x, will be 10% of the connecting weight, $W_{x,y}$, in the first period, 0.25 $W_{x,y}$ in the second period and .65 $W_{x,y}$ in the third period. To model such a time lag into a digraph, we suggest a more general structure of dummy nodes as depicted in Figure III-4.

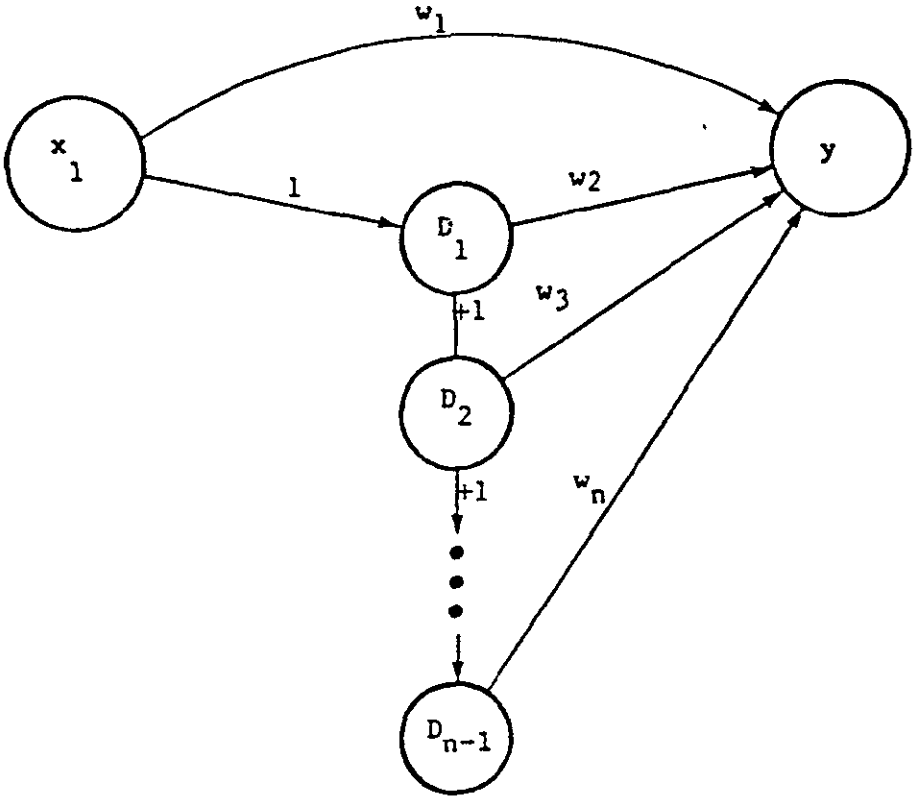


Figure III-4. Digraph Structure for Gradual Response

Suppose the maximum time lag is n periods. We can introduce n-1 dummy nodes, D_1, $D_2 \ldots D_{n-1}$, as in Figure III-4. If a pulse of magnitude one is exercised upon x_1 at time zero, the level of y at time 1 goes up by w_1; and D_1 goes up by 1; at time 2, y goes up by w_2; and D_2 goes up by 1; at time 3, y goes up by w_3; and D_3 goes up by 1, and so on. Therefore, after passage of n periods, y has increased by $\sum_{i=1}^{n-1} w_i$.

The corresponding matrix for this structure will be:

$$TL = \begin{array}{c|cccccccc|}
 & X_1 & D_1 & D_2 & \cdot & \cdot & \cdot & D_{n-1} & Y \\
\hline
X_1 & 0 & 1 & & & & & & w_1 \\
D_1 & & 0 & 1 & & & & & w_2 \\
D_2 & & & 0 & 1 & & & & w_3 \\
 & & & & \cdot & & & & \\
 & & & & & \cdot & & & \\
 & & & & & & \cdot & & \\
 & & & & & & & 1 & \\
D_{n-1} & & & & & & & 0 & w_n \\
Y & & & & & & & & 0 \\
\hline
\end{array}$$

With this structure, time lags of any kind (e.g., a step function like Figure III-3, a dependent function of the state of the system, or a pulse dependent function) can be constructed.

Note that Figure III-4 is a general structure of dummy nodes. With this structure the constant (sudden) time lag can be presented as well. All one has to do is to give all the weights $W_{x,y}$ to the first arc, W_1; and make all the rest, $W_2 \ldots W_n$, zero.

Adding dummy nodes makes the adjacency matrix very large and sparse, which may create computational problems. There are two ways to economize in use of dummy nodes. First, take the time period longer (e.g., a year instead of a week or a day). Of course the trade-off is that the model may lose the required degree of precision. Second, for all relationships (arcs) originating from a particular node, the same set of dummy nodes can be used. For instance, if time lag of response between x_1 and y is n periods and between x_1 and z is 3 periods, the first three dummy nodes can be shared.

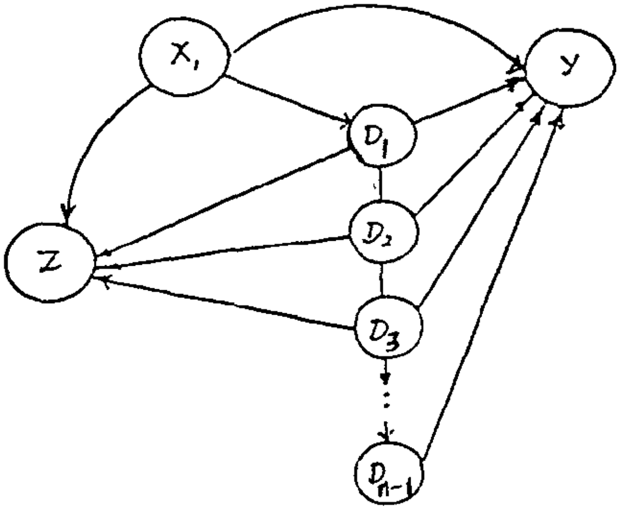


Figure III-5 Sharing Dummy Nodes Originating from x_1

The second suggestion for reducing the number of dummy nodes becomes more effective when the time interval (period) is small and, therefore, many arcs originating from the same variables require large numbers of nodes. For example, in Figure III-5, if the time of each period is a year, time lag between x_1 and y is n years and between x_1 and z is three years. If we decide to take a shorter time, say a month for each period, then the number of dummy nodes required between x_1 and y increases to 12 x n and between x_1 and z increases to 12 x 3. By sharing the dummy nodes we save 36 dummy nodes for each node in the digraph with characteristic similar to x_1.

3. Value Estimation Incorporating Repeated Pulses

Pulses cause changes which occur to the system between two periods. These changes can result from a pulse originating outside the system or from a pulse inside the system from the endogenous variables due to the cause and effect relationship among variables. In modeling a socio-economic system, new policies initiate outside pulses. These exogenous pulses can also originate from uncontrollable circumstances such as oil price changes, political perturbations or natural occurrences. Internal pulses always initially result from the effect of an exogenous pulse and are simply the manifestation of the interacting components of the system. For example, if the external price of energy is increased, this will cause changes in system variables such as demand and consumption at later time periods which in turn may affect airline fare structure.

In a real world situation, pulses are seldom just a single perturbation. Rather, due to the dynamism of the surrounding environment, exogenous pulses repeatedly impact the system from several sources (Figure II-2). The current status of digraph methodology does not provide the capability for analyzing a system subject to repeated pulses. Therefore, certain changes in digraph theory are proposed in the following discussion.

In the structural analysis of a digraph, two theorems, presented by Roberts (1974) deal with pulses which are exercised upon the system and the resulting value of each node at each period.

1. Theorem 4.5:

$$P_j\ (t) = P_j\ (a)\ A^t \text{ or } P_j\ (t+1) = P_j\ (t)\ A \qquad \text{Eq. (1)}$$

where: $P\ (t)$ is the pulse generated by the system, as the result of $P_j\ (o)$, the autonomous pulse at time zero, and applied to node j at time t

A is the cross-impact square matrix

A^t is the cross-impact square matrix to the power t

2. Theorem 4.4:

$$V_j\ (t) = (\text{start}) + \text{the } ij \text{ entry of } (I + A + A^2 + .. + A^t) \qquad \text{Eq. (2)}$$

where: $V_j\ (t)$ is the value of node j at time t

In order to model a real world complex system, two differential changes in the above theorems are required to adapt them for our purposes. First, as it is suggested in this chapter, the cross-impact matrix, A, should be a kinematic one, changing value from one period to the next. Therefore, a modification in this respect is necessary to both theorems. This modification can be accomplished by substituting the following relationships for A where each individual matrix A(t) may be different to reflect the kinematic nature of the analysis.

The second modification needs to reflect two basic kinds of pulses, external and internal, which interact with the system:

1) Outside forces which perturb the system now and then, $p^x(t)$ (In structural analysis only the first perturbation is considered, as "autonomous pulse.")

2) The system itself, as the result of outside perturbation, through feedback loops and cycles, generates changes in value of some variables, $p^1(t)$. Therefore, a realistic formulation of pulse process should incorporate both types of changes.

Suppose the system is at starting period and the state of the system is V(start). Simulation of pulse starts with first exogenous pulse, p^x(start), to be applied to the system and results in an internally generated pulse p^1:

$$p^x \text{ (start) } \times w \text{ (start) } = p^1 \text{ (1)} \qquad \text{Eq. (3)}$$

$$v \text{ (o) } = v \text{ (start) } + p^x \text{ (start)} \qquad \text{Eq. (4)}$$

where: p^x, p^1 are defined above, V(t) is the vector of values of all nodes at time t.

Next period, this internally generated pulse, p^1 (1), plus the external pulse at new period, p^x (1), construct a pulse vector, p^o, which impacts the system now.

$$\left| p^x \text{ (1)} \right| + \left| p^1 \text{ (1)} \right| = \left| p^o \text{ (1)} \right|$$

$$\left| p^o \text{ (1)} \right| \times w \text{ (1)} = \left| p^i \text{ (2)} \right|$$

$$\left| v \text{ (1)} \right| = \left| p^o \text{ (1)} \right| + \left| v \text{ (o)} \right|$$

The process continues for the next periods, and in general:

$$\left| p^x \text{ (t)} \right| + \left| p^1 \text{ (t)} \right| = \left| p^o \text{ (t)} \right| \qquad \text{Eq. (5)}$$

$$\left| p^o \text{ (t)} \right| \times W \text{ (t)} = \left| p^i \text{ (t)} \right| \qquad \text{Eq. (6)}$$

$$\left| v \text{ (t)} \right| = \left| v \text{ (t-1)} \right| + \left| p^o \text{ (t)} \right| \qquad \text{Eq. (7)}$$

Consequently, pulse on variable j at period t will be:

$$p_j\ (t) = \quad p_j^x\ (t-1) + p_j^1\ (t-1) \quad x\ A\ (t-1)$$

As the result of pulse, p_j (t), the value of the variable j, V_j (t), at time t will be:

$$V_j\ (t) = V_j\ (\text{start}) + p_j\ (o) + p_j\ (1) + \ldots + p_j\ (t)$$

V_j (t), as calculated above, is a projected value of variable j at time t. It incorporates the modifications to digraph methodology discussed above. These three changes have included the kinematic cross-impact matrix, the gradual realization of time lag effects and, finally, incorporation of repeated pulses in the computation of system variables.

CHAPTER IV

HISTORICAL PERSPECTIVE

Our knowledge of the past and our anticipation of the future have at least one thing in common: both are interpretations of existing data and information. History is, in fact, the interpretation of events and environments of the past inferred by historians from often crude and inaccurate data available to them. Although future data have not yet materialized, present and past data become the basis for futurists' inference. As we discussed in Chapter II, in the subject of scenario approach, the futurist tries to predict the future course of events, with one eye looking for social aspirations as the direction of change, while the other eye looks for both possibilities and limitations. In this sense, the past and present become the mirror of the future:

> One way of evaluating future forecasts is to look at historical precedents to gain at least some perspective-no matter how flawed the past might be as a mirror of the future." (O'Toole, 1978).

This chapter presents a historical data bank of the aviation industry, required for all stages of model development:

- to enhance understanding of the system,
- to help identify important parameters and relationships, and
- to validate the model (See Chapter II).

Before presenting description of the aviation databank, it is appropriate to review the historical events of the organization of the industry as well as the technological development which shaped the industry into its present form.

The Growth of Air Transportation

The path to maturity, common for most industry, has a slow start, as only a few people, perhaps rich, can afford to demand the product. Then, if the product becomes more generally recognized as being useful, acceptance grows exponentially. The increased demand permits reduction of costs which again causes more demand. In this stage, demand is running ahead of supply capability. Eventually, the market becomes saturated, and supply and demand approaches equilibrium and demand growth slows down. This pattern is depicted in the typical growth curve, an S-shape or logistic curve.

Although the first air passenger service in the U.S. began in 1914, it lasted only four months. The real development of commercial air transportation started after World War I.* However, the generous contracts due to the Air Mail Act of 1925 provided a big impetus to the industry. The Act was passed after a number of aircraft operators had tried to provide scheduled passenger and cargo flights, only to find not enough revenue to cover costs.

Technical advancement in aircraft facilitated the rapid growth in air service in the early 1930's. There was growth each year, despite the general economic downturn.

The Air Mail Act of 1934 provided the industry Federal aid and protection from "excessive competition." The Civil Aeronautics Authority was established by Congress in 1938, which later in 1940 evolved in today's Civil Aeronautics Board (CAB). As an independent regulatory agency, the CAB was given the authority to issue new entries into the industry, to regulate fares and set the standards for air safety. Later in 1958, after two tragic mid-air collisions, Congress passed an Act setting up the Federal Aviation Agency (FAA). Under this Act, Federal airport-airway support functions were also transferred from the Department of Commerce to the new agency. The Federal Aviation Agency was renamed the Federal Aviation Administration, when in 1966, Congress established the Department of Transportation (DOT) with FAA becoming a part of DOT.

After World War II, from 1949 until the recession year of 1958, when passenger traffic fell by 0.6 percent, the industry enjoyed a relatively vigorous annual rate of growth, ranging from 12 to 25 percent. In 1958, the jet aircraft was introduced but unanticipatedly the market declined, causing financial problems for many carriers. In the 1960's, traffic revived and rose to an annual rate of over 20 percent over the period 1965-1968. The growth was partly due to lower costs, discount fares and improved services, made possible by turbine-powered aircraft. In 1970, the growth again stopped for a short period (due to general economic recession) and rose again until the 1973 energy crisis, after which the demand underwent another dip.

Technological Evolution of Aircraft

Technological progress of aircraft has shown a similar S-shape growth path. The speed of transport aircraft, as it is shown in Figures IV-1 and IV-2, increased about five times between 1928 and 1958, but has shown little change in the past

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*The discussion on the air transportation history is abstracted for the "Handbook of Airline Statistics," published by the Civil Aeronautic Board (CAB), 1973.

20 years. There was a steady growth in speed due to increased specific thrust of power up to the limiting propeller capability. It stopped there until the jet came in with a step increase in speed to Mach limits. The next step will be a multiple increase only if we can break through the M1 barrier (economically).

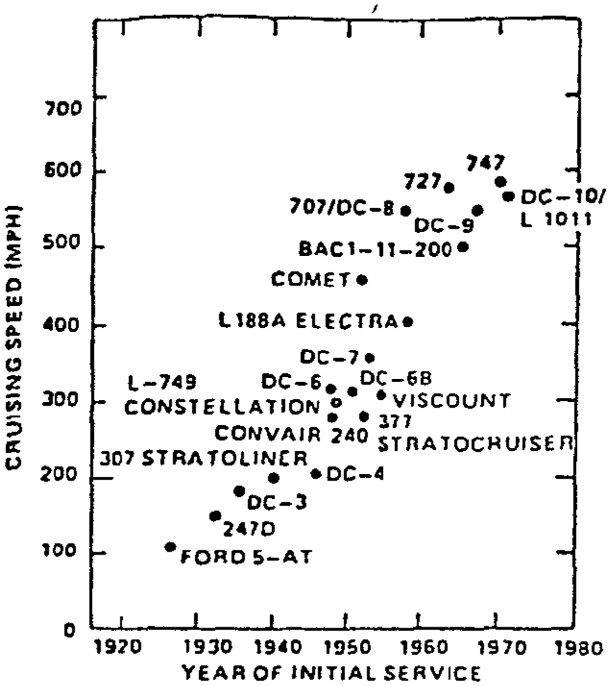


Figure IV-1 Speed History of Transport Aircraft

Source: TAOPTS Vol. 3, 1976.

In another dimension of technological progress, the passenger and cargo capacity of new aircraft, and consequently, the average capacity of the fleet, show similar S-shape behavior. (See Figures IV-3 and IV-4.)

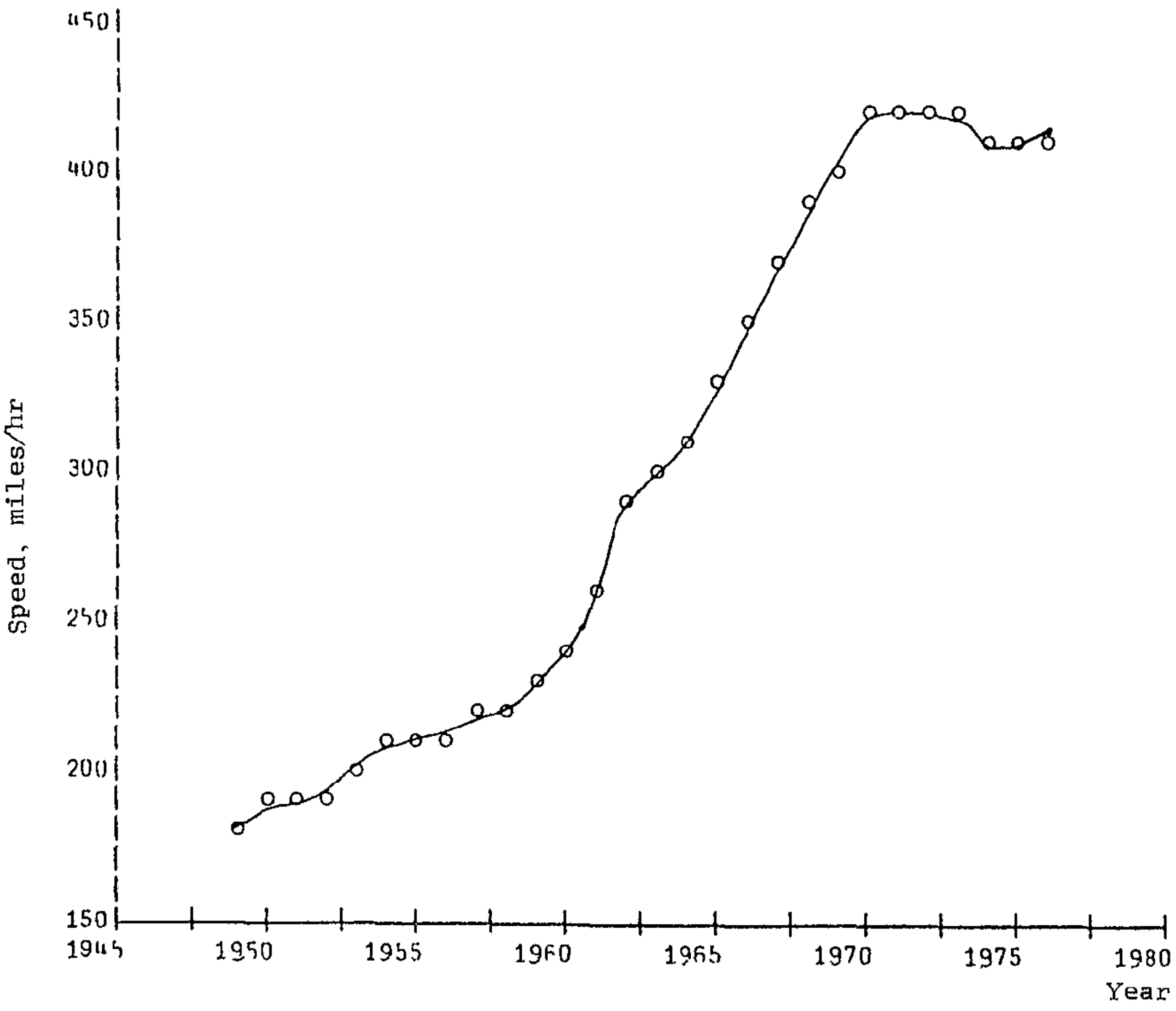


Figure IV-2 , Average Airborn Speed for U.S. Fleet of Commercial Aircraft.

Year	Average Airborne, Speed Miles/hr
1949	184
1950	187
1951	189
1952	195
1953	201
1954	206
1955	213
1956	216
1957	220
1958	224
1959	229
1960	244
1961	265
1962	289
1963	304
1964	315
1965	332
1966	350
1967	372
1968	389
1969	405
1970	415
1971	415
1972	415
1973	415
1974	412
1975	413
1976	415

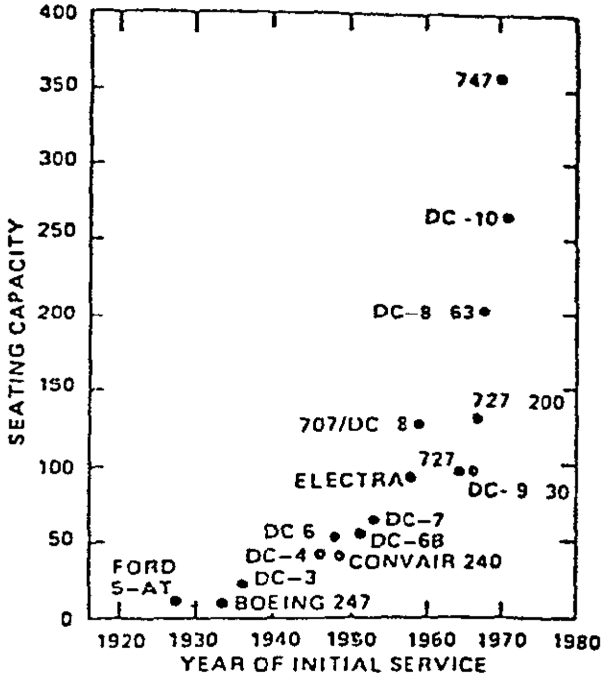
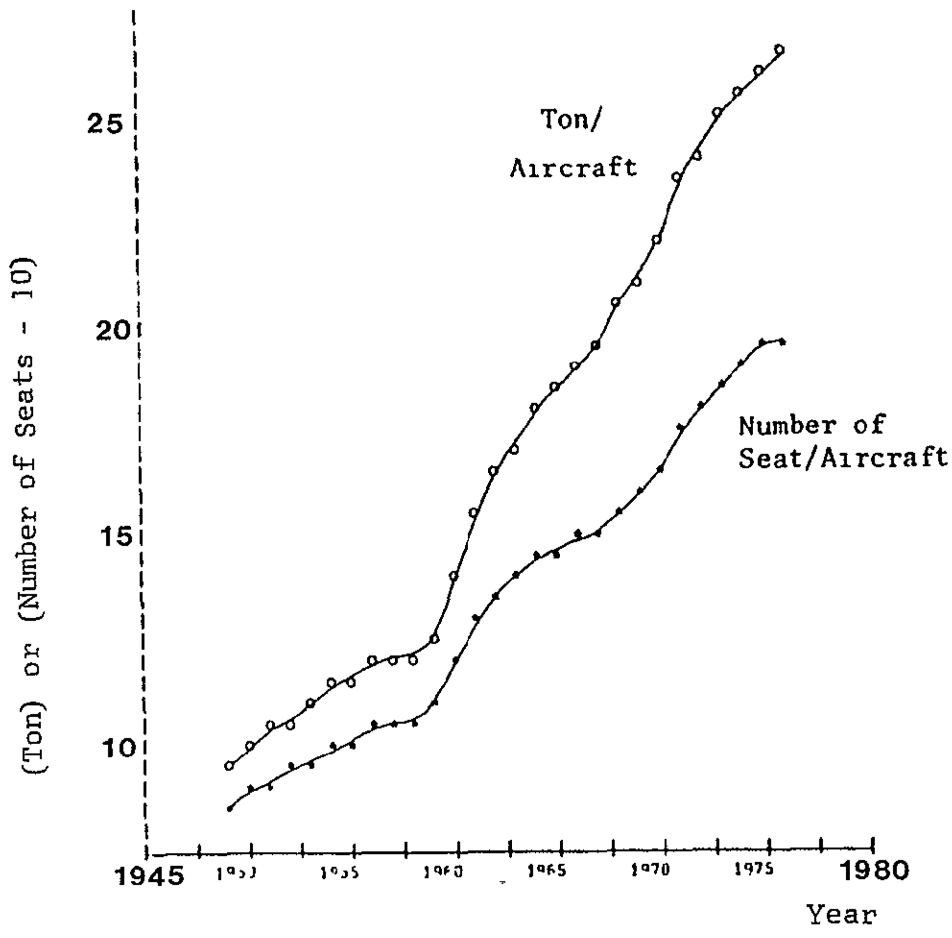


Figure IV-3
Growth of Passenger Capacity of New Transport Aircraft

Most important of all, cost performance has shown the same characteristics. Figure IV-5 shows the relative direct operating cost per seat mile. The standard B707 and DC-8 are taken as benchmarks. The curve has been constructed on an approximate constant dollar basis by raising the cost ratios between one aircraft and the standard 707/DC-8 at the time of aircraft entering the market. The decrease in operating costs has been more attributed to technological betterment than the increase in the size of aircraft, (e.g., a smaller aircraft such as the DC-9-30 designed for short range shows operating cost comparable to operating costs of larger aircraft witrh the same technology). However, increasing size decreases seat-miles up to 350-400 passengers and after that the trend flattens.



Year	Average Cap'y of the Fleet, ton per A/C	Average No. of Seats per Pass A/C
1949	4.572	35.100
1950	4.950	37,000
1951	5 257	40,500
1952	5.620	43,400
1953	5.941	46,700
1954	6.462	50,800
1955	6.612	52 100
1956	6.787	53,200
1957	7.029	54.900
1958	7.146	57.000
1959	7.681	60.200
1960	9.019	69.300
1961	10.061	78.500
1962	11.354	85.900
1963	12.107	90.600
1964	13.048	93.400
1965	13.605	96.200
1966	14.119	98.200
1967	14.712	101.200
1968	15 480	107.100
1969	16.211	111.000
1970	17.186	117.000
1971	18.561	125,000
1972	19.185	128.500
1973	20.016	134.000
1974	20.748	139.600
1975	21.096	142.600
1976	21.261	145 700

Figure IV - 4 Average Capacity of Aircraft.

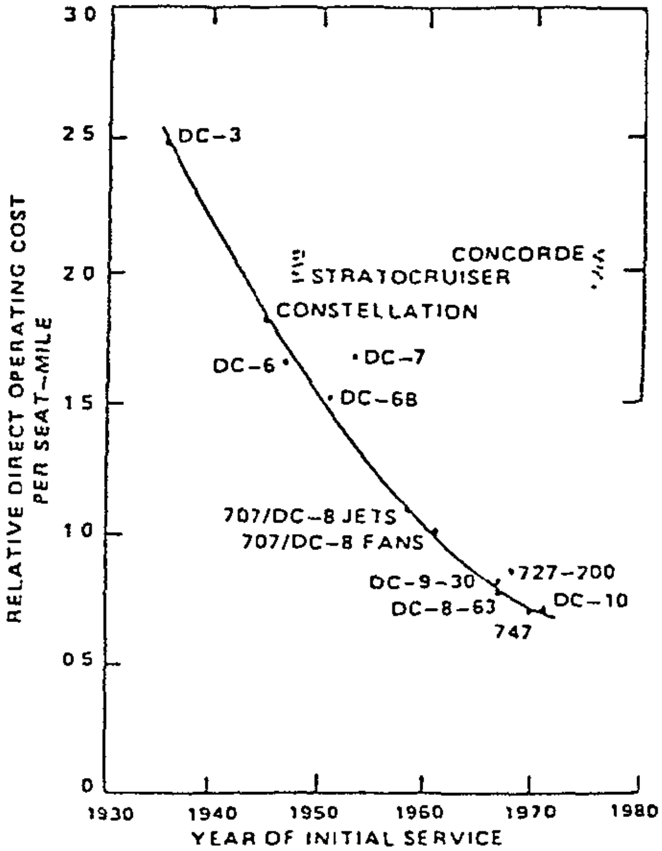


Figure IV-5
Direct Operating Cost of New Aircraft from DC-3 to DC-10

The three Figures IV-1, IV-3, and IV-5, displaying the fifty years of technological history of aircraft, show that almost always, successful aircraft have had equal or lower cost compared with their predecessors while offering service improvement in either speed, range, comfort or a combination of them. These service improvements and cost decreases led to huge growth in air travel (in some periods in the range of 15-25 percent per year.)

In the pre-jet era before 1958, the industry experienced rapid technical progress. Significant improvements in airfoil design, flap systems, structural materials and other types of design and manufacturing were achieved. The great contributions of avionics made the navigation (including the take-off and landing) much safer. As a result of these improvements, technological obsolescence was fast. Within two to seven years, a succeeding aircraft could force the preceding one out of service.

The jet transport of the B-707 and DC-8 class increased the speed to the threshold of the tran-sonic region (Figure IV-1); greatly reduced operating costs (Figure IV-5); virtually eliminated vibration; reduced internal noise; and especially eliminated the roughness of most high altitude and bad weather flights. Twenty years later, these aircraft are still in service on major routes. Although the current wide-body generation of aircraft contains some additional improvements, such as high by-pass ratio turbo-fan engines, improvements in aerodynamic components (airfoils, flaps, and slats) and structural improvements in construction and material, their functional benefits are primarily due to large size.

One cause of the aircraft production decrease in the early and mid-seventies was that the expected phasing out of B-707's and DC-8's due to functional obsolescence did not occur. These aircraft, some approaching the age of twenty-five years, will fe forced out of service by 1985 only because of community noise requirements and the high fuel costs.

How further technological progress in aircraft will proceed in the future is a subject to be discussed in the next chapter.

Air Transportation Data

While manipulating numbers with a bad model leads to confusion and error, a potentially good model cannot be validated without reliable numbers. Moreover, extensive information is acquired from past data to establish relationships among interfacing system variables. In particular, when the outcome of the model is sensitive to certain parameters, the quality of the results depends on the assumed relationship which, in turn, often depends on the accuracy of available historical data.

Being a regulated industry, air transportation has enjoyed an affluence of copious historical data. However, the reliability and completeness of data vary. Scheduled services of certificated carriers, and in particular, domestic trunks have the most complete set of data, while supplemental carriers have the least. Traffic-related data are usually ample and reliable. However, data relating to investments, expenditures, profits and flying equipment which are less a concern of regulatory agencies are not as readily available. Some cross-reference study of data may help in getting more accurate data.

The search into various sources of aviation historical data may run into many categories of data. Some dimensions of these categories will be as follows:

Type of Load:	(Passenger):	First Class, Coach.
	(Cargo)	Freight, Mail, Express.
Supplier of Service:		Certificated route air carriers. Supplemental air carriers.

Type of Service:	Scheduled, Non-scheduled.
Market: (Domestic):	Nationwide, Inter-regional (Hawaii, Alaska) local, commuter.
(International)	
Accounts and Measurements:	Traffic, capacity, revenue.
Expense:	Direct aircraft operating expenditures. Flying operations. Crew. Fuel and oil. Insurance and others. Direct maintenance, flight equipment. Ground and indirect operating expenditures. Indirect maintenance. Maintenance of ground equipment. Passenger service. Traffic service. Investment: Aircraft, parts, ground, building and equipment. Depreciation.

Aircraft:
- Type: Piston, Jet, Turboprop, Turbofan, Two, Three, or Four engines.
- Number on order.
- Number in the fleet.
- Number of new aircraft entering U.S. fleet.
- Average price.
- Average capacity (seat or ton per aircraft).
- Average speed.

Although data for all categories mentioned above have not been included in the databank, the classification from which the databank is compiled has been inspired by model objectives. Like the process of model building, compiling data is also an iterative process. Some of the collected data may not seem as crucial, while some necessary data may be hard to find. However, most of what has been included in the databank, and presented here, has been used in the modeling process. This will be seen in the next chapters. Few other charts are informative enough to give a broader view of the industry. For example, in Figures IV-6 through IV-8, the volume of traffic is broken down to the relative share of various sections of the industry, as well as the type of service, market, and type of load.

Although corresponding data for capacity, revenue, et cetera were available, presentation of so much data seemed to be excessive.

In most literature and statistical publications, conclusions are drawn based on the data related only to a section of the industry (such as trunk carriers or domestic carriers), while the purpose of this research is to model the industry as a whole. Therefore, the aggregated data related to the whole industry have been used whenever such data have been available.

As will be discussed in later chapters, the simulation model often uses the rate of change or percentage-wise rate of change; therefore, these two measures are shown along with the historical data of some more important variables.

In addition to the aviation historical data, few socio-economic variables affecting the aviation economic system, as it is modeled in this research, are included. These include: GNP, disposable income, personal consumption, population and so on.

One of the reasons for presentation of all historical data in this chapter is to eliminate repetition of charts and tables throughout the report as well as ease of references to these data. For consistency, the figures and tables use the units as reported in the literature, common to the aviation and energy industries. For convenience, conversion multipliers to S.I. units are shown below.

Miles (passenger-miles, etc.) X 1.609 = kilometers (km)
Ton X .9072 = tonne (1000 kg)
Ton-mile X 1.460 = tonne-km
Gallon X 3.785 = liter
Gallon/ton-mile X 2.593 = liter/tonne-km
Quad (10^{15}) BTU X 1.055 = EJ (10^{18} joule)

For reference, charts and tables are categorized according to the following table:

TRAFFIC DATA

Passenger and Cargo (including mail express, excess baggage, et cetera), Share of Transportation, Figure IV-6.

International and Domestic Share of U.S. Commercial Air Transportation, Figure IV-7.

Scheduled and Non-Scheduled Air Transportation, Figure IV-8, Figure IV-9, Figure IV-10.

FLEET PERFORMANCE, CAPACITY AND TRAFFIC

Speed History of Transport Aircraft (New), Figure IV-1.
Average Airborn Speed of the Fleet, Figure IV-2.
Growth of Passenger Capacity of New Transport Aircraft, Figure IV-3.

Average Capacity of Aircraft, in Ton and in Number of Passengers in the Fleet, Figure IV-4.
Number of Aircraft in the Fleet, Table IV-1, Figure IV-11.
Number of Aircraft Departures, Figure IV-12.
Average Utilization of Aircraft, Figure IV-13.
Over-all Aircraft-Miles Flown, Figure IV-14.
Over-all Aircraft-Hours Flown, Figure IV-15.
Average Passenger Trip Length and Flight Stage Length, Figure IV-16.

SYSTEM CAPACITY

Passenger and Cargo Capacity, Figure IV-17.
Passenger and Cargo Load Factor, Figure IV-18.
Over-all Load Factor, Annual Change, Figure IV-19.
Excess Capacity: Load Factor if Average Utilization Were 10 Hours per Pay, Figure IV-20.

REVENUE

Passenger and Cargo Share of Overall Transport Revenue, Figure IV-21.
Average Revenue per Ton-Mile (All Services), the Rate of Annual Change, Figure IV-22.
Average Passenger and Cargo Revenue per Ton-Mile in Current Dollar, Figure IV-23; in Constant Dollar, Figure IV-24.

EXPENSES

Direct Operation Costs (DOC) per Ton-Mile Available Capacity and its Annual Change, Figure IV-25.
DOC of New Aircraft from DC-3 to DC-10, Figure IV-5.
Fuel Consumption Total, Figure IV-26.
Fuel Consumption per Ton-Mile Available Capacity, Figure IV-27.
Fuel Price, Average, $/Gal., Figure IV-29; per Ton-Mile, Figure IV-28
Ratio of Aviation Fuel Price to the Average Price of Crude Oil, Figure IV-30; to Fossil Fuel Price, Figure IV-31.
Fuel Costs as Percentage of DOC, Figure IV-32.
Fuel Costs as Percentage of All Costs, Figure IV-33.
Crew Costs per Ton-Mile Available Capacity, Figure IV-34.
Maintenance Costs: Direct, Indirect, Total, Figure IV-35.
  Insurance and Miscellaneous Costs, Total (Certificated Air Carriers), Figure IV-36.
  Insurance and Miscellaneous Direct Costs per Ton-Mile Available Capacity, Figures IV-37 to IV-39.

Indirect Costs and Its Annual Change, Figure IV-40.
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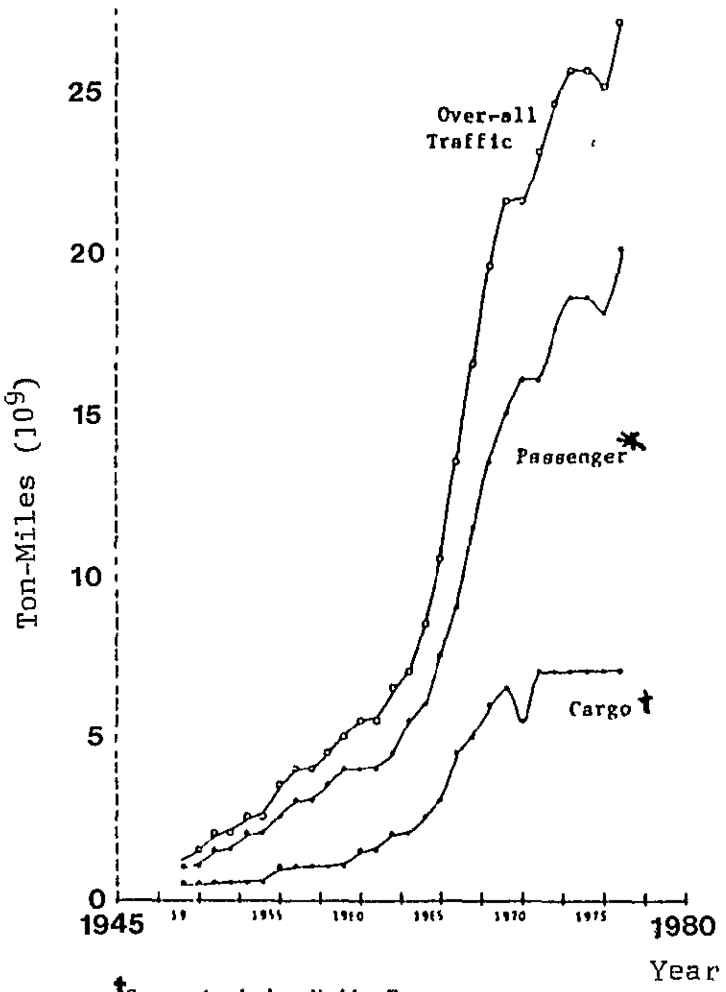


†Cargo includes Mail, Express, etc.

Figure IV - 6 Passenger and Cargo Shares of Air Transportation

Year	Over-all Traffic Ton-Miles MM	Passenger Traffic Ton-Miles* MM	 %	Cargo Traffic Ton-Miles† MM	 %
1949	1226	948	77.3	278	22.7
1950	1506	1116	74 1	390	25 9
1951	1928	1416	73.4	512	26.6
1952	2206	1670	75 7	536	24 3
1953	2498	1936	77.5	562	22 5
1954	2744	2170	79 1	574	20.9
1955	3338	2580	77.3	758	22.7
1956	3823	2883	75.4	940	24.6
1957	4243	3225	76.0	1018	24.0
1958	4324	3283	75.9	1041	24.1
1959	4973	3786	76.1	1187	23 9
1960	5353	4059	75.8	1294	24.2
1961	5717	4185	73.2	1532	26 8
1962	6642	4647	70.0	1995	30.0
1963	7232	5257	72.7	1975	27 3
1964	8431	6106	72 4	2325	27.6
1965	10439	7334	70.3	3105	29.7
1966	13275	8988	67.7	4287	32.3
1967	16714	11512	68.9	5202	31.1
1968	19437	13572	69.8	5865	30.2
1969	21574	15111	70.0	6463	30 0
1970	21606	15868	73 4	5738	26.6
1971	22765	15999	70.3	6766	29 7
1972	24267	17407	71.7	6860	28.3
1973	25511	18451	72.3	7060	27.7
1974	25353	18307	72.2	7047	27.8
1975	24771	18021	72.7	6750	27.3
1976	26915	19849	73.7	7066	26.3

*Each Passenger Ton-Mile is equivalent to 10 Passenger Mile

MM = million

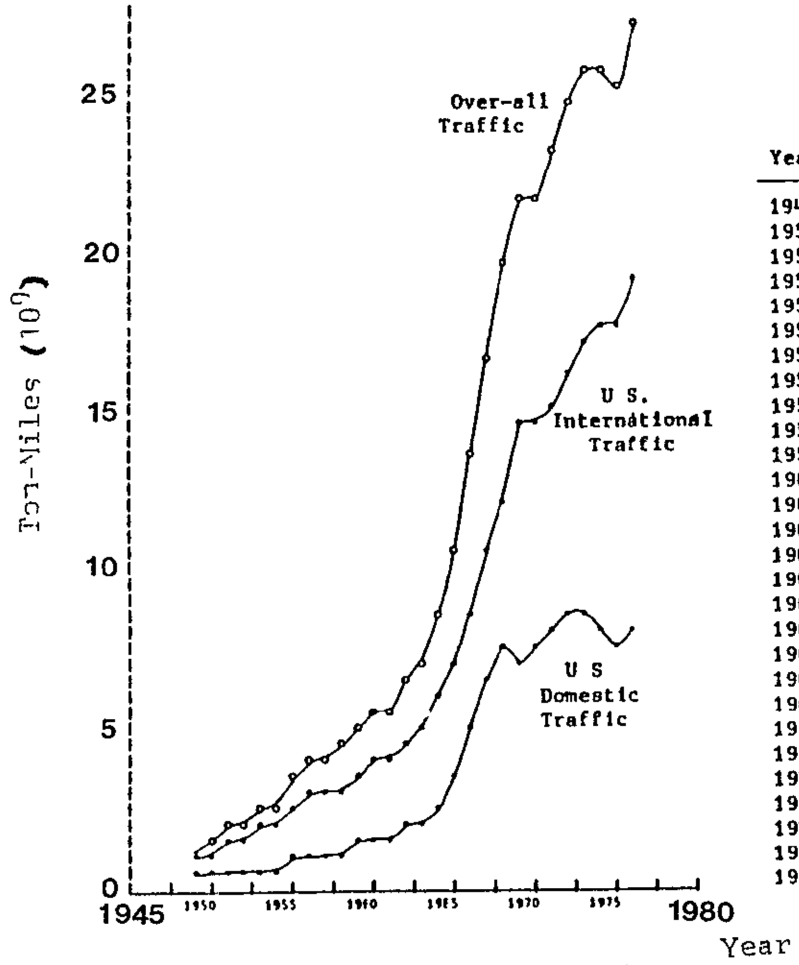


Figure IV - 7 **International and Domestic Share of U.S Commercial Air Transportation.**

Year	Over-all Traffic Ton-Miles MM	U S. Domestic Traffic Ton-Miles MM	%	U S International Traffic Ton-Miles MM	%
1949	1226	900	73.4	326	26.6
1950	1506	1142	75.9	364	24.1
1951	1928	1443	74.8	485	25.2
1952	2206	1654	75.0	552	25.0
1953	2498	1901	76.1	597	23.9
1954	2744	2107	76.8	637	23.2
1955	3338	2540	76.1	798	23.9
1956	3823	2857	74.7	966	25.3
1957	4243	3228	76.1	1015	23.9
1958	4324	3237	74.9	1087	25.1
1959	4973	3699	74.4	1274	25.6
1960	5353	3904	72.9	1449	27.1
1961	5717	4081	71.4	1636	28.6
1962	6642	4607	69.4	2035	30.6
1963	7232	5035	69.6	2197	30.4
1964	8431	5826	69.1	2605	30.9
1965	10439	7041	67.4	3398	32.6
1966	13275	8365	63.0	4910	37.0
1967	16714	10317	61.7	6397	38.3
1968	19437	11922	61.3	7515	38.7
1969	21574	14378	66.6	7197	33.4
1970	21606	14268	66.0	7338	34.0
1971	22765	14839	65.2	7926	34.8
1972	24267	15972	65.8	8295	34.2
1973	25511	17200	67.4	8311	32.6
1974	25353	17460	68.9	7893	31.1
1975	24771	17424	70.3	7347	29.7
1976	26915	19132	71.1	7783	28.9

MM = million

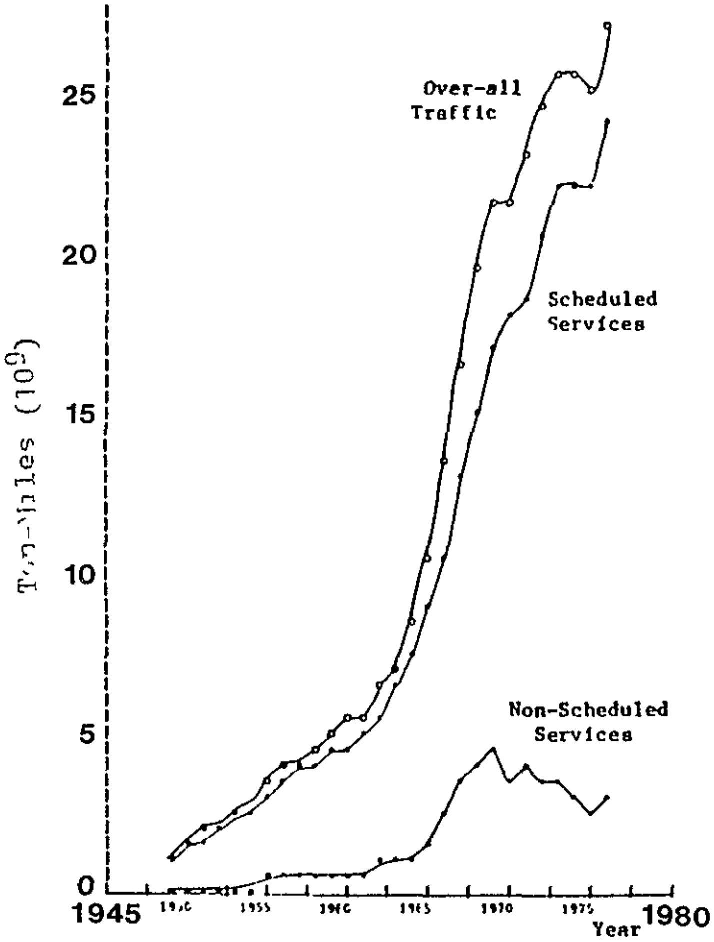
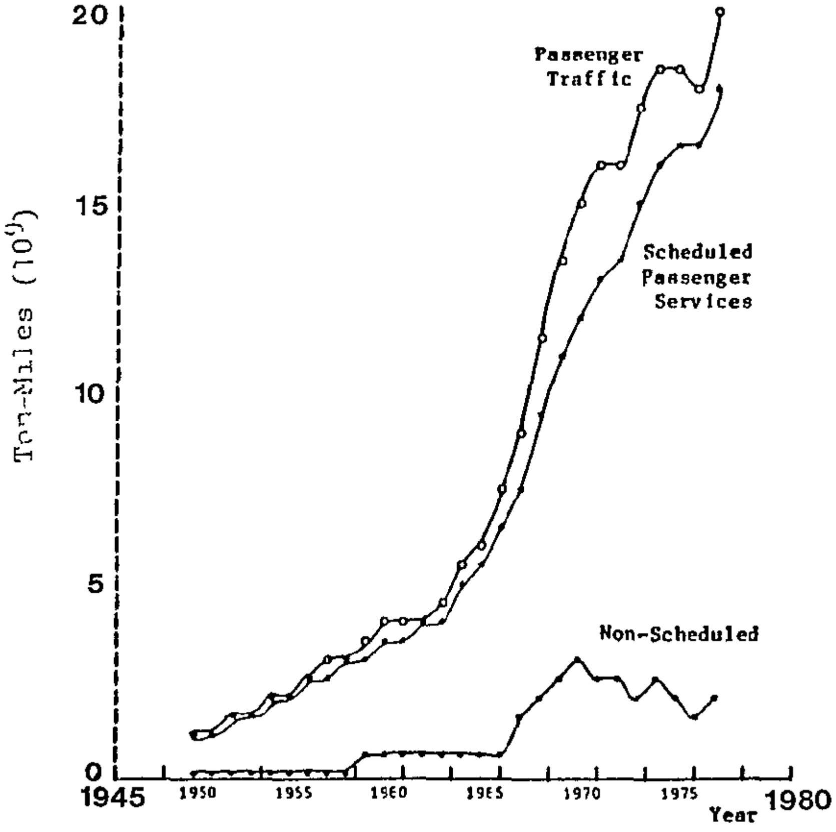


Figure IV - 8 Scheduled and Non-Scheduled Share of Traffic

Year	Over-all Services Ton-Mile MM	Scheduled Services Ton-Mile MM	Scheduled Services %	Non-Scheduled Services Ton-Mile MM	Non-Scheduled Services %
1949	1226	1131	92.3	95	7.7
1950	1506	1359	90.2	147	9.8
1951	1928	1690	87.7	238	12.3
1952	2206	1972	89.4	234	10.6
1953	2498	2252	90.2	246	9.8
1954	2744	2512	91.5	232	8.5
1955	3338	2982	89.3	356	10.7
1956	3823	3386	88.6	437	11.4
1957	4243	3763	88.7	480	11.3
1958	4324	3799	87.9	525	12.1
1959	4973	4388	88.2	585	11.8
1960	5353	4729	88.3	624	11.7
1961	5717	4971	87.0	746	13.0
1962	6642	5570	83.9	1072	16.1
1963	7232	6346	87.7	886	12.3
1964	8431	7434	88.2	997	11.8
1965	10439	8986	86.1	1453	13.9
1966	13275	10686	80.5	2589	19.5
1967	16714	13036	78.0	3678	22.0
1968	19437	15249	78.5	4188	21.5
1969	21574	16898	78.3	4676	21.7
1970	21606	18166	84.1	3440	15.9
1971	22765	18685	82.1	4080	17.9
1972	24267	20746	85.5	3521	14.5
1973	25511	22242	87.2	3269	12.8
1974	25353	22245	87.7	3108	12.3
1975	24771	22185	89.6	2586	10.4
1976	26915	24121	89.6	2794	10.4

MM = million



SOURCE OF DATA : CAB 1975 ; 1975 ,1977

Figure IV - 9 Scheduled and Non-Scheduled Share of Passenger Traffic,

	Total Passenger Traffic	Schedule Passenger Services		Non-Schedule Passenger Services	
	Ton-Miles†	Ton-Miles †		Ton-Miles†	
Year	MM	MM	%	MM	%
1949	948	863	91.0	85	9.0
1950	1116	1001	89.7	115	10 3
1951	1416	1287	90.9	129	9.1
1952	1670	1524	91.3	146	8.7
1953	1936	1777	91 8	159	8 2
1954	2170	2007	92.5	163	7 5
1955	2580	2368	91 8	212	8 2
1956	2883	2686	93 2	197	6.8
1957	3225	2999	93 0	226	7.0
1958	3283	3023	92.1	260	7.9
1959	3786	3490	92 2	296	7.8
1960	4059	3733	92 0	326	8 0
1961	4185	3827	91.4	358	8.6
1962	4647	4210	90 6	437	9.4
1963	5257	4839	92.0	418	8.0
1964	6106	5630	92.2	476	7.8
1965	7334	6629	90 4	705	9.6
1966	8988	7736	86.1	1252	13.9
1967	11512	9561	83 1	1951	16.9
1968	13572	11023	81.2	2549	18.8
1969	15111	12197	80.7	2914	19 3
1970	15868	13171	83.0	2697	17.0
1971	15999	13565	84.8	2434	15.2
1972	17407	15241	87.6	2166	12.4
1973	18451	16196	87.8	2255	12.2
1974	18307	16292	89.0	2015	11.0
1975	18021	16281	90.3	1740	9 7
1976	19849	17899	90 2	1950	9.8

†Each Passenger Ton-Mile is equivalent to *10 Passenger Mile.*

MM = million

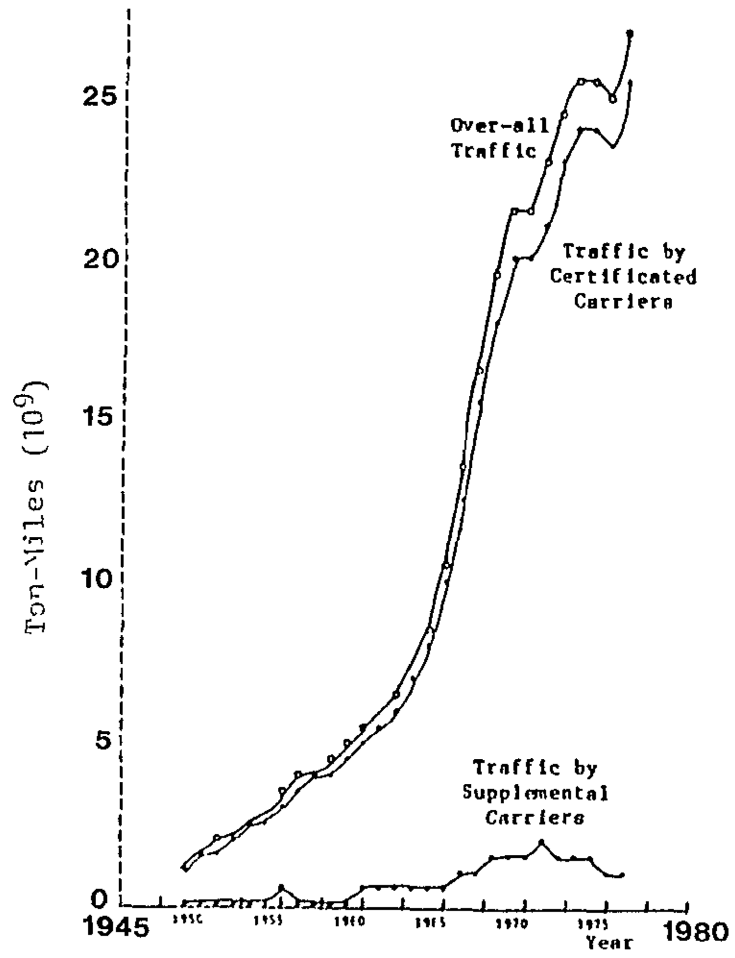


Figure IV - 10 Shares of Traffic Carried by Certificated Carriers and Supplemental Carriers

Year	Over-all Traffic Ton-Miles MM	Traffic Carried by Certificated Air Carriers Ton-Miles MM	%	Traffic Carried by Supplemental Air Carriers Ton-Miles MM	%
1949	1226	1152	94.0	74	6.0
1950	1506	1398	92.8	108	7.2
1951	1928	1743	90.4	185	9.6
1952	2206	2005	90.9	201	9.1
1953	2498	2288	91.6	210	8.4
1954	2744	2564	93.4	180	6.6
1955	3338	3088	92.5	250	7.5
1956	3823	3619	94.7	204	5.3
1957	4243	4082	96.2	161	3.8
1958	4324	4120	95.3	204	4.7
1959	4973	4734	95.2	239	4.8
1960	5353	5024	93.9	329	6.1
1961	5717	5395	94.4	322	5.6
1962	6642	6238	93.9	404	6.1
1963	7232	6860	94.9	372	5.1
1964	8431	8016	95.1	415	4.9
1965	10439	9895	94.8	544	5.2
1966	13275	12441	93.7	834	6.3
1967	16714	15684	93.8	1030	6.2
1968	19437	18114	93.2	1323	6.8
1969	21574	19989	92.7	1585	7.3
1970	21606	20186	93.4	1420	6.6
1971	22765	20906	91.8	1859	8.2
1972	24267	22805	94.0	1462	6.0
1973	25511	23928	93.8	1583	6.2
1974	25353	23900	94.3	1453	5.7
1975	24771	23533	95.0	1238	5.0
1976	26915	25709	95.5	1206	4.5

M = million

		Number of Aircraft in the U.S. Commercial Fleet		
Year	Airline Statistics[1]	Statistical Abstract[2]	Aerospace Fact and Figures[3]	UCLA[4]
1949		1090	1090	1274
1950		1120	1120	1395
1951		1121	1121	1469
1952		1227	1227	1543
1953		1300	1300	1588
1954		1336	1336	1610
1955		1359	1359	1697
1956		1543	1543	1794
1957		1664	1664	1893
1958		1731	1731	1947
1959		1769	1895	2070
1960	2011	1768	1850	2104
1961	2012	1867	1867	2027
1962	1926	1831	2104	2020
1963	1832	1832	2047	1907
1964	1872	1863	2079	1905
1965		1896	2081	1991
1966	2055	2027	2125	2181
1967		2194	2274	2380
1968	2381	2317	2452	2546
1969		2363	2586	2587
1970	2564	2390	2690	2520
1971			2642	2593
1972	2518		2642	2496
1973	2464	2361	2599	2512
1974	2412	2244	2472	2448
1975		2267	2672	2406
1976	2420	2271	2707	2449

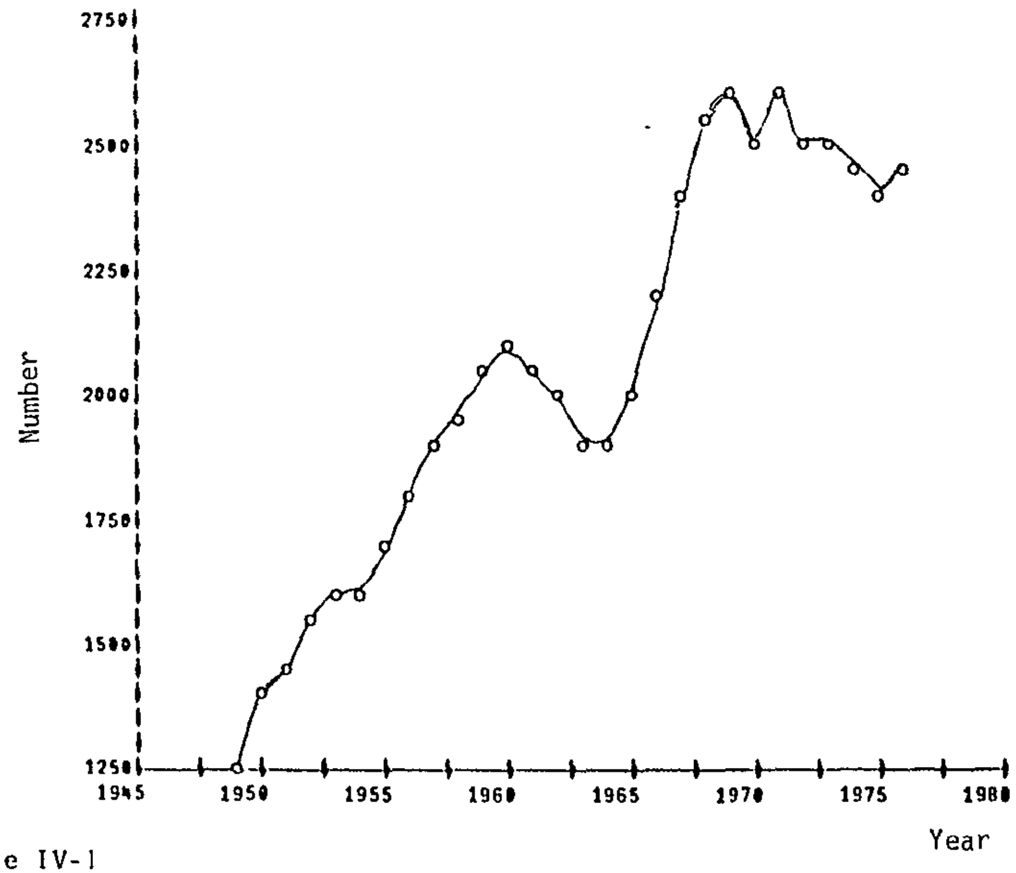
Table IV - 1 U. S. Commercial Fleet

[1] Number of aircraft in certificated air carriers reported by Handbook of Airline Statistics CAB 1973, 1975 1977

[2] Number of aircraft in scheduled service reported by U. S. Historical Statistics, Statistical Abstracts 1970, 1977

[3] Reported by Aerospace Industries Association ot America, 1949 through 1977

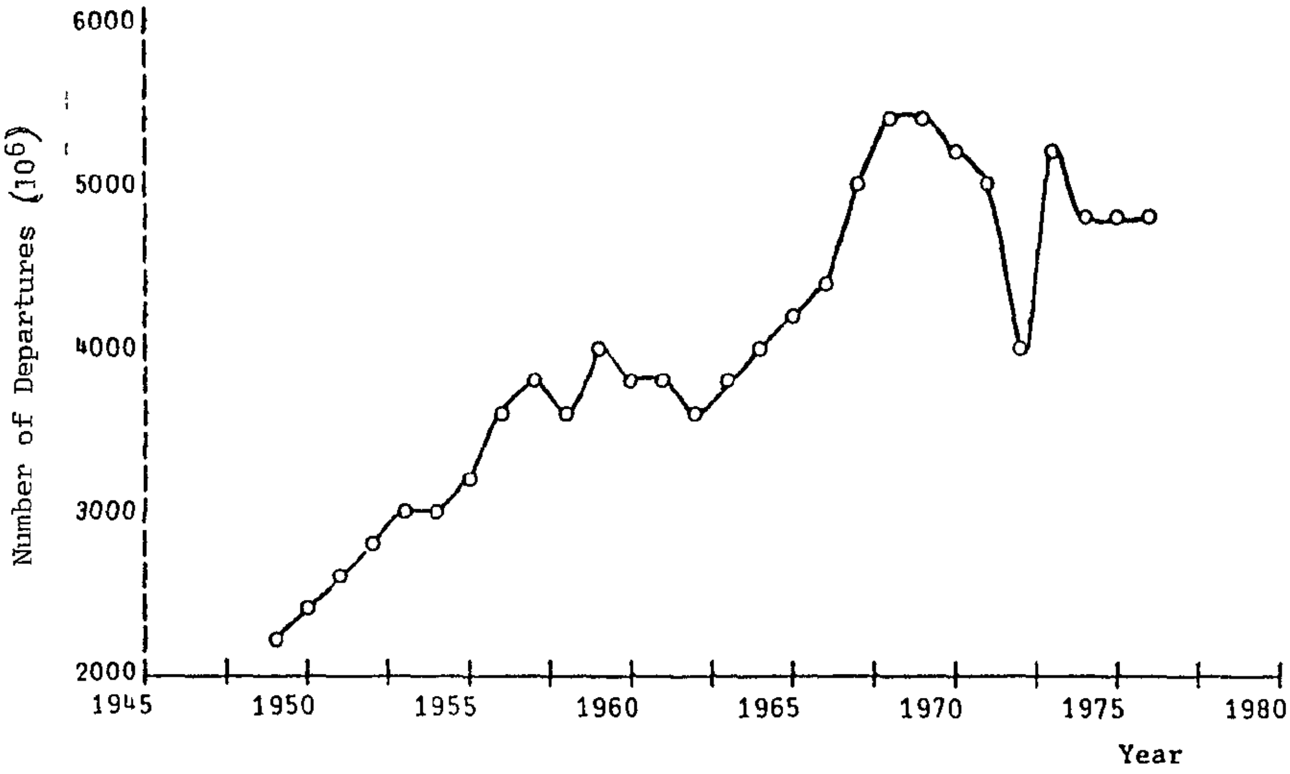
[4] Number of representative aircraft in U. S. commercial fleet calculated from overall aircraft-hours flown, Figure IV - 15, divided by total capacity of industry



Year	Number of Aircraft UCLA Estimate*
1949	1274
1950	1395
1951	1468
1952	1542
1953	1588
1954	1609
1955	1697
1956	1793
1957	1882
1958	1947
1959	2069
1960	2103
1961	2027
1962	2020
1963	1906
1964	1904
1965	1991
1966	2180
1967	2379
1968	2546
1969	2586
1970	2520
1971	2593
1972	2496
1973	2511
1974	2447
1975	2406
1976	2448

*See Table IV-1

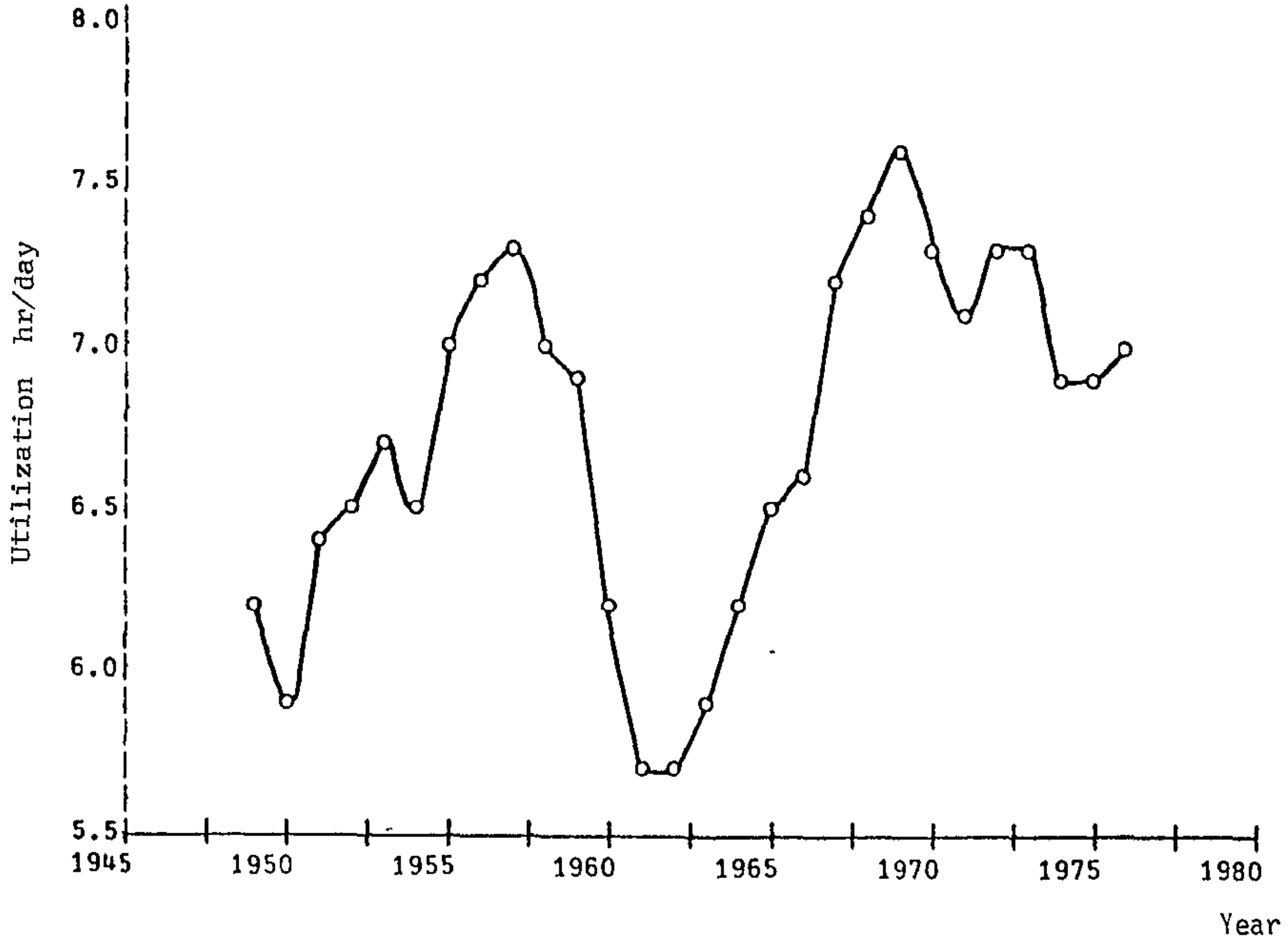
Figure IV - 11 Number of Aircraft in the U S Commercial Airlines



* *SOURCE OF DATA : CAB* 1975 ; 1975 ;1977

Year	Number of Aircraft Departures In Year x 1000
1949	2262
1950	2457
1951	2596
1952	2737
1953	2960
1954	3002
1955	3281
1956	3503
1957	3771
1958	3634
1959	3910
1960	3853
1961	3750
1962	3660
1963	3788
1964	3955
1965	4198
1966	4373
1967	4946
1968	5348
1969	5379
1970	5119
1971	4999
1972	4056
1973	5134
1974	4726
1975	4705
1976	4833

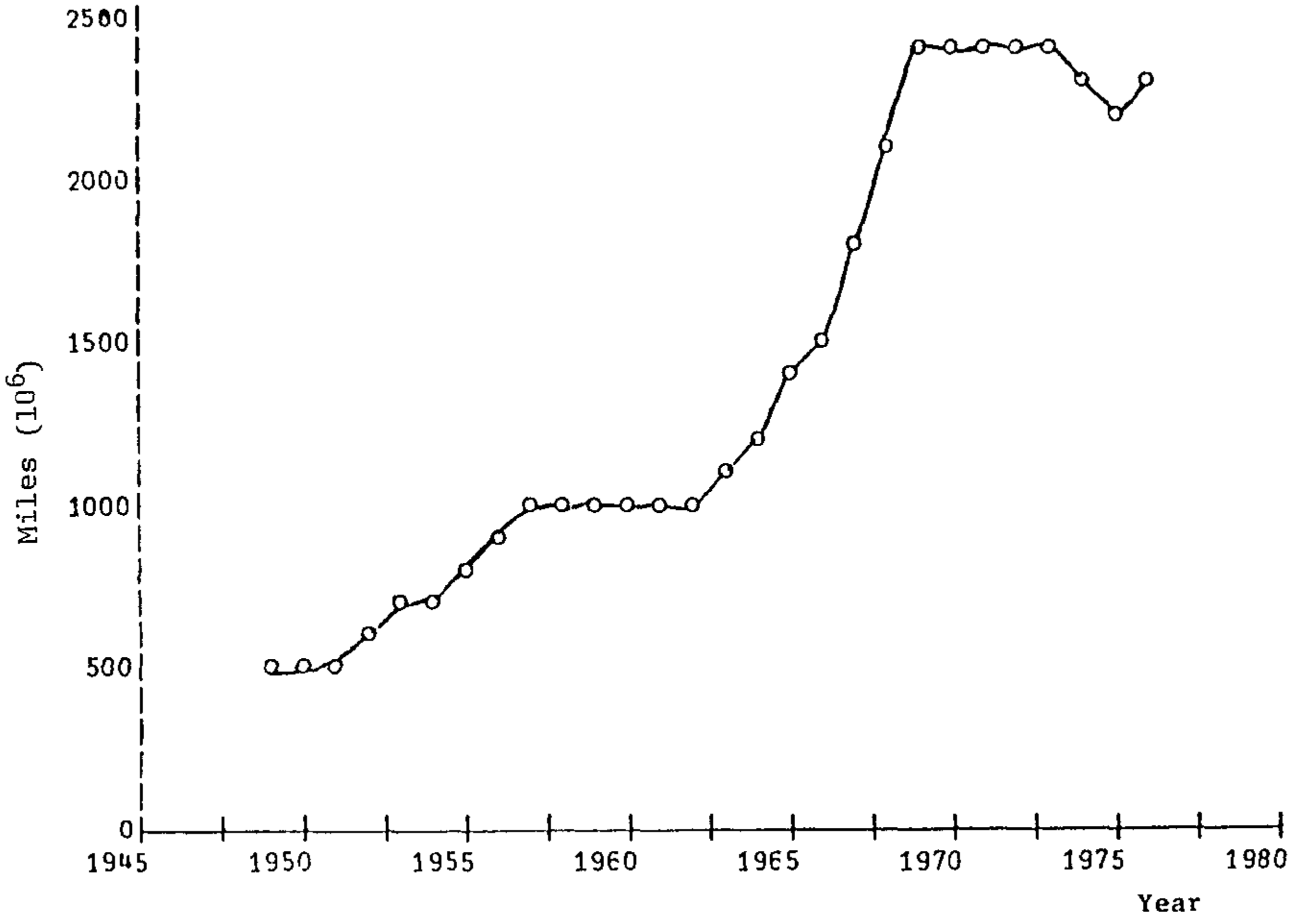
Figure IV - **12** Number of Aircraft Departures (Certificated Air Carriers).



Year	Average Aircraft Utilization Hrs/day
1949	6.2
1950	5.9
1951	6.4
1952	6.5
1953	6.6
1954	6.5
1955	7.0
1956	7.2
1957	7.3
1958	7.0
1959	6.9
1960	6.2
1961	5.7
1962	5.7
1963	5.9
1964	6.1
1965	6.5
1966	6.6
1967	7.2
1968	7.4
1969	7.6
1970	7.3
1971	7.1
1972	7.3
1973	7.3
1974	6.9
1975	6.9
1976	7.0

* *SOURCE OF DATA : CAB* 1975 ; 1975 ;1977

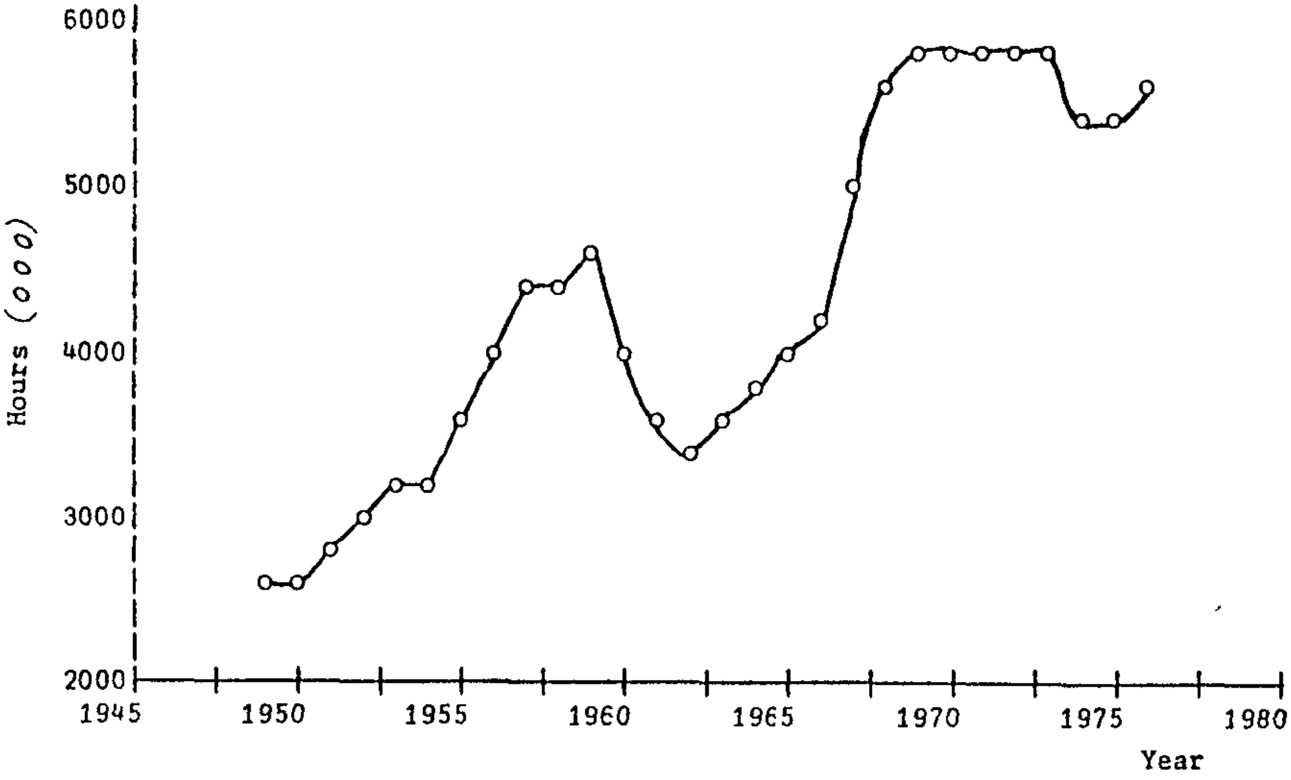
Figure IV - 13 Average Aircraft Utilization (Certificated Air Carriers)



Year	Million Aircraft Miles Flown in Year
1949	463
1950	478
1951	526
1952	590
1953	657
1954	680
1955	780
1956	869
1957	976
1958	973
1959	1030
1960	998
1961	969
1962	1010
1963	1095
1964	1189
1965	1353
1966	1483
1967	1833
1968	2146
1969	2385
1970	2426
1971	2378
1972	2376
1973	2449
1974	2258
1975	2240
1976	2320

* *SOURCE OF DATA : CAB* 1975 ; 1975 ;1977

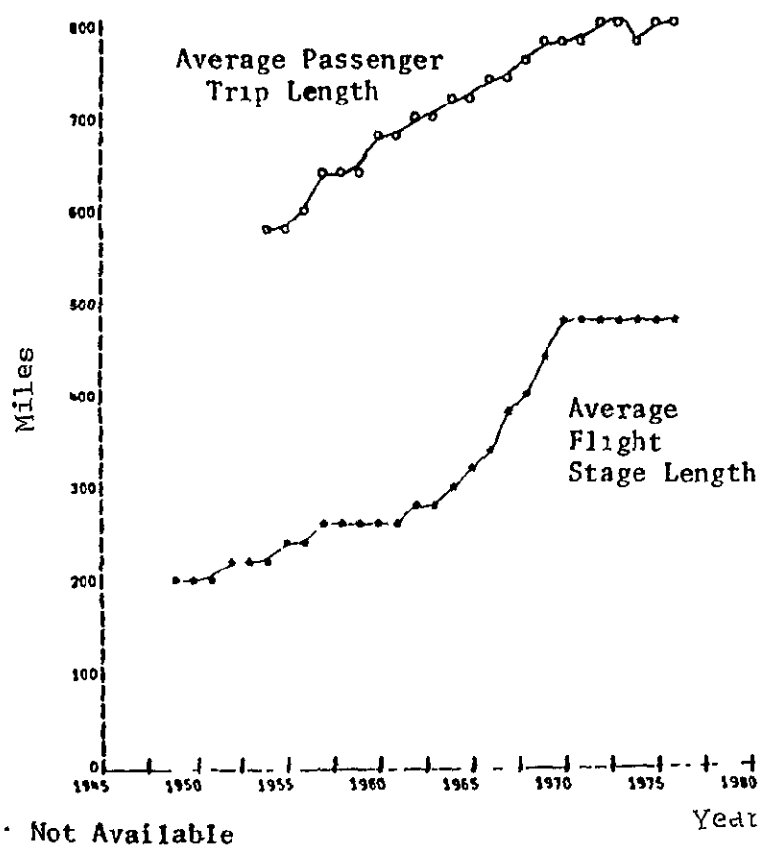
Figure IV - 14 Overall Aircraft-Miles Flown (Certificated Air Carriers)



Year	Aircraft Hours (000) Flown In Year
1949	2520
1950	2562
1951	2780
1952	3031
1953	3272
1954	3294
1955	3658
1956	4032
1957	4438
1958	4339
1959	4503
1960	4088
1961	3655
1962	3491
1963	3607
1964	3774
1965	4072
1966	4233
1967	4924
1968	5521
1969	5895
1970	5846
1971	5725
1972	5728
1973	5899
1974	5474
1975	5422
1976	5588

* *SOURCE OF DATA : CAB* 1975 ; 1975 ;1977

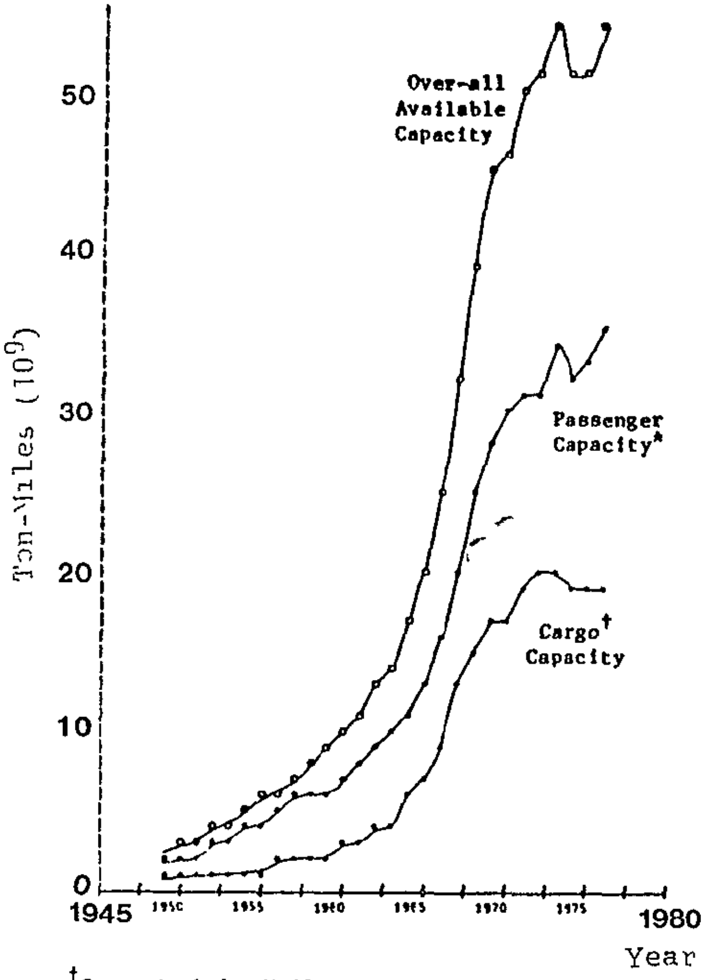
Figure IV - 15 Overall Aircraft-Hours Flown (Certificated Air Carriers)



Year	Passenger Trip Length Miles	Flight Stage Length Miles
1949	NA	203
1950		192
1951		203
1952		215
1953		222
1954	582	230
1955	584	238
1956	601	248
1957	632	259
1958	641	268
1959	650	264
1960	672	259
1961	682	259
1962	699	276
1963	707	289
1964	715	301
1965	726	322
1966	730	339
1967	748	371
1968	759	401
1969	788	443
1970	775	473
1971	781	476
1972	796	471
1973	801	477
1974	785	478
1975	794	476
1976	801	480

NA: Not Available
Source of Data. CAB 1973; 1975; 1977

Figure IV - 16 Average Passenger Trip Length, Average Flight Stage Length, Certificated Air Carriers.



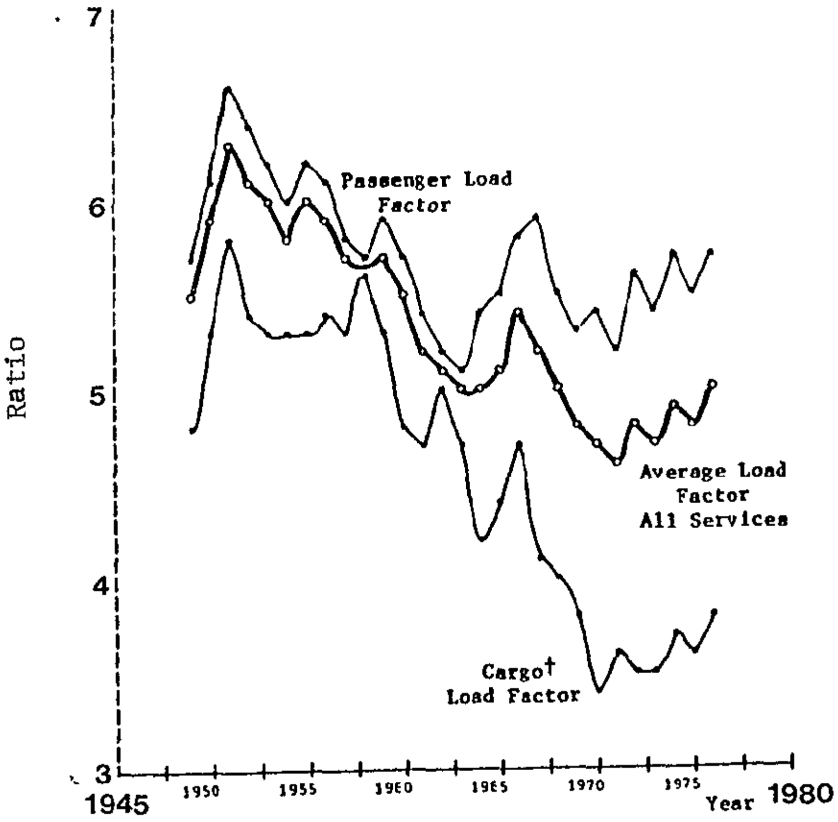
Year	Over-all Capacity Ton-Miles MM	Passenger Capacity Seat-Mile MM	 %	Cargo Capacity Ton-Miles MM	 %
1949	2241	16579	74.0	583	26.0
1950	2556	18189	71.2	737	28.8
1951	3038	21583	71 0	880	29.0
1952	3597	26055	72 4	992	27.6
1953	4195	31279	74.6	1067	25.4
1954	4694	36047	76.8	1089	23.2
1955	5597	41660	74.4	1431	25.6
1956	6455	47168	73.1	1738	26.9
1957	7447	55144	74.0	1933	26.0
1958	7589	57364	75.6	1853	24.4
1959	8655	63987	73 9	2256	26.1
1960	9796	70812	72.3	2714	27.7
1961	11023	77606	70.4	3262	29.6
1962	12915	89221	69.1	3992	30 9
1963	14473	102433	70.8	4230	29.2
1964	16884	113782	67.4	5506	32.6
1965	20471	134446	65.7	7026	34 3
1966	24721	156098	63.1	9111	36.9
1967	32373	196309	60.6	12742	39 4
1968	39240	245010	62.4	14739	37.6
1969	45258	283647	62.7	16893	37.3
1970	46273	295148	63.8	16758	36.2
1971	49585	307800	62 1	18805	37.9
1972	50874	312758	61.5	19598	38.5
1973	53967	338707	62.8	20096	37 2
1974	51297	322547	62.9	19042	37.1
1975	51216	325779	63.6	18638	36 4
1976	53522	347613	64.9	18761	35 1

MM = million

†Cargo includes Mail, Express, etc.

*Each Passenger Ton-Mile is equivalent to 10 Passenger-Miles.

Figure IV - 17 Passenger and Cargo Share of Capacity

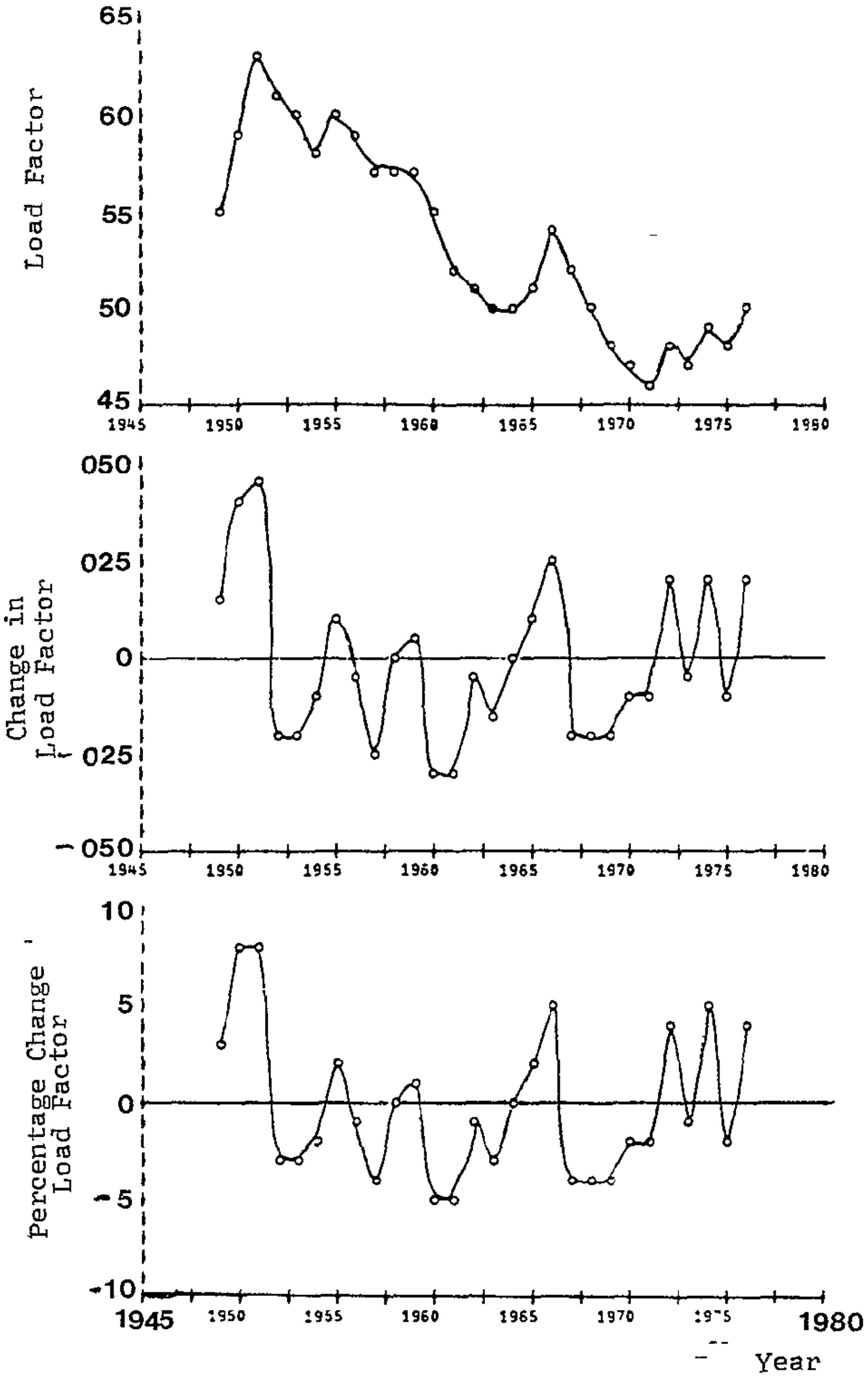


SOURCE OF DATA : CAB 1975 ; 1975 ;1977

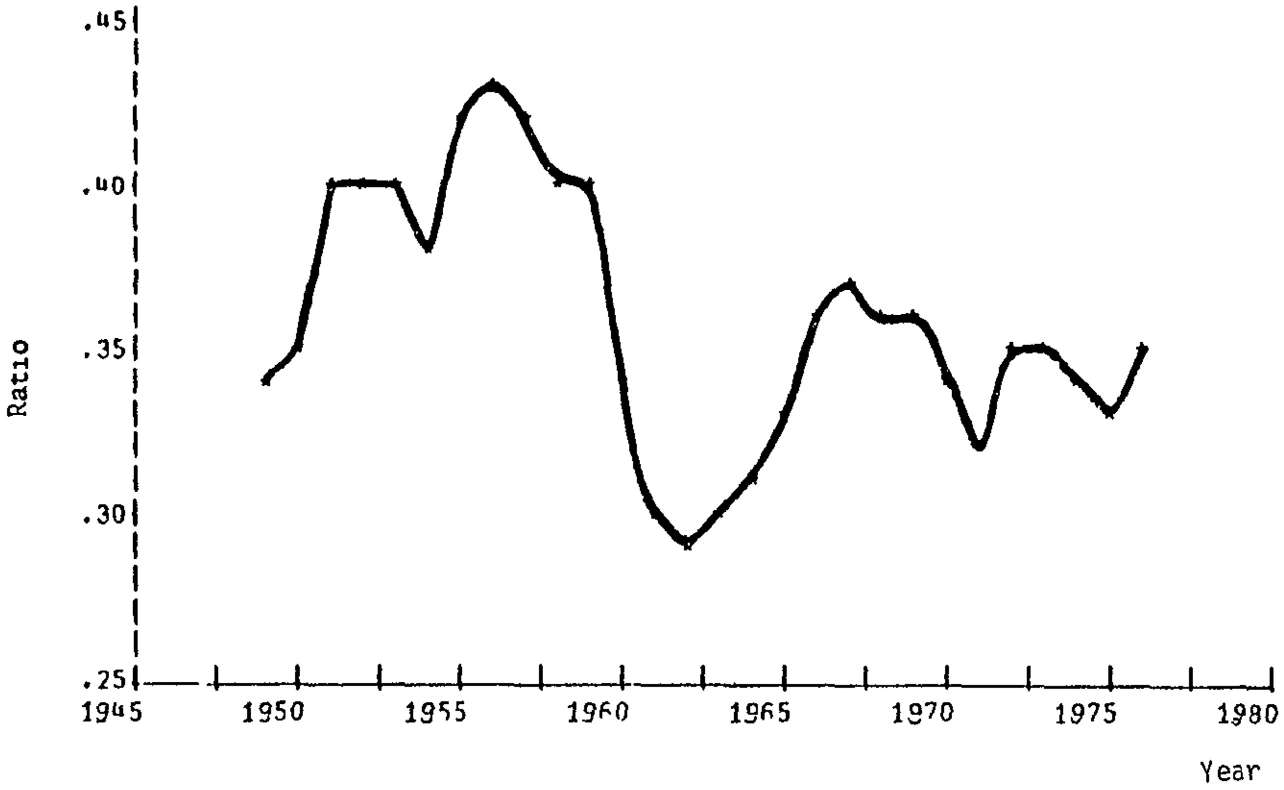
†Cargo includes Mail, Express, etc.

Figure IV - 18 Historical Load Factor

Year	Average Load Factor		
	Over-all	Passenger	Cargo
1949	0.55	0.57	0.48
1950	0.59	0.61	0.53
1951	0.63	0.66	0.58
1952	0.61	0.64	0.54
1953	0.60	0.62	0.53
1954	0.58	0.60	0.53
1955	0.60	0.62	0.53
1956	0.59	0.61	0.54
1957	0.57	0.58	0.53
1958	0.57	0.57	0.56
1959	0.57	0.59	0.53
1960	0.55	0.57	0.48
1961	0.52	0.54	0.47
1962	0.51	0.52	0.50
1963	0.50	0.51	0.47
1964	0.50	0.54	0.42
1965	0.51	0.55	0.44
1966	0.54	0.58	0.47
1967	0.52	0.59	0.41
1968	0.50	0.55	0.40
1969	0.48	0.53	0.38
1970	0.47	0.54	0.34
1971	0.46	0.52	0.36
1972	0.48	0.56	0.35
1973	0.47	0.54	0.35
1974	0.49	0.57	0.37
1975	0.48	0.55	0.36
1976	0.50	0.57	0.38

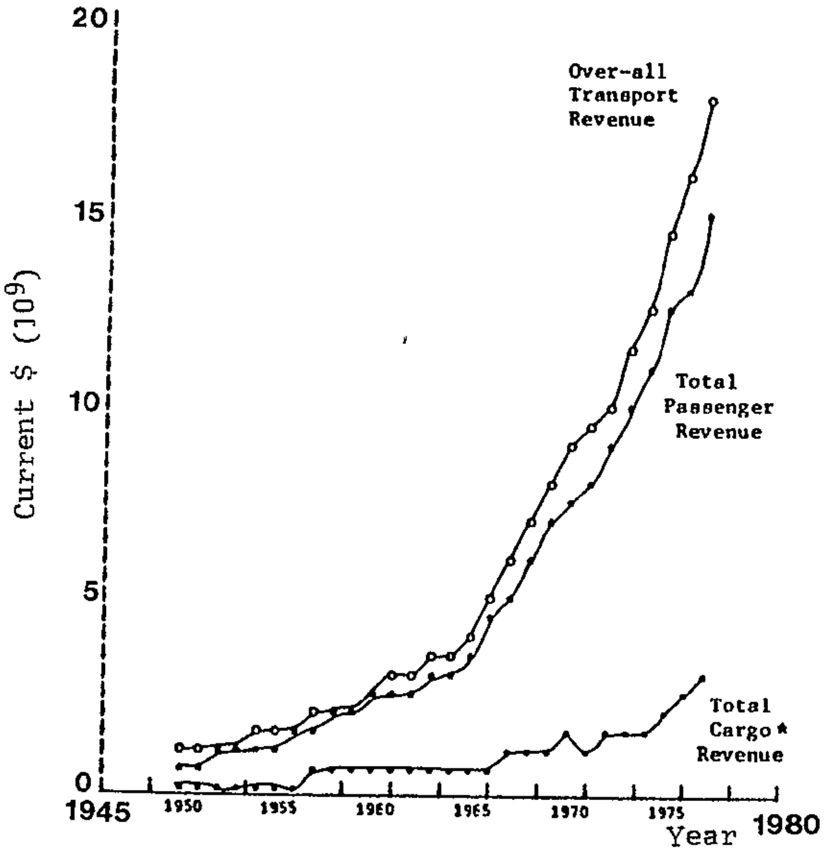


gure IV - 19 U S. Commercial Air Transportation Load Factor and Its Rate of Change



Year	Ratio
1949	0.337
1950	0.350
1951	0.404
1952	0.398
1953	0.396
1954	0.378
1955	0.416
1956	0.427
1957	0.418
1958	0.401
1959	0.396
1960	0.337
1961	0.297
1962	0.291
1963	0.296
1964	0.307
1965	0.331
1966	0.355
1967	0.371
1968	0.365
1969	0.364
1970	0.341
1971	0.324
1972	0.347
1973	0.347
1974	0.343
1975	0.333
1976	0.350

Figure IV - 20 Excess Capacity: Load Factor If Average Utilization Were 10 Hours Per Day.



SOURCE OF DATA : CAB 1975 ; 1975 ;1977

*Cargo includes Mails, Express, etc.

Year	Over-all Revenue	Passenger Revenue		Cargo* Revenue	
	$ MM	$ MM	%	$ MM	%
1949	796	595	74.7	201	25.3
1950	866	660	76.2	206	23.8
1951	1069	855	80.0	214	20.0
1952	1186	1001	84.4	185	15.6
1953	1367	1133	82.8	234	17.2
1954	1418	1247	87.9	171	12.1
1955	1661	1463	88.1	198	11.9
1956	1897	1643	86.6	254	13.4
1957	2111	1828	86.6	283	13.4
1958	2236	1938	86.7	298	13.3
1959	2612	2294	87.8	318	12.2
1960	2873	2532	88.1	341	11.9
1961	3037	2632	86.7	405	13.3
1962	3476	2940	85.6	496	14.4
1963	3746	3246	86.6	500	13.4
1964	4243	3661	86.3	582	13.7
1965	4980	4263	85.6	717	14.4
1966	5837	4890	83.8	947	16.2
1967	6999	5875	83.9	1124	16.1
1968	7955	6784	85.3	1172	14.7
1969	9028	7748	85.8	1280	14.2
1970	9476	8236	86.9	1240	13.1
1971	10211	8834	86.5	1377	13.5
1972	11311	9835	87.0	1476	13.0
1973	12582	10919	86.8	1663	13.2
1974	14509	12584	86.7	1925	13.3
1975	15767	13081	83.0	2686	17.0
1976	17905	15061	84.1	2845	15.9

MM = million

Figure IV - 21 **Share of Passenger and Cargo Revenue of U.S. Commercial Air Transportation.**

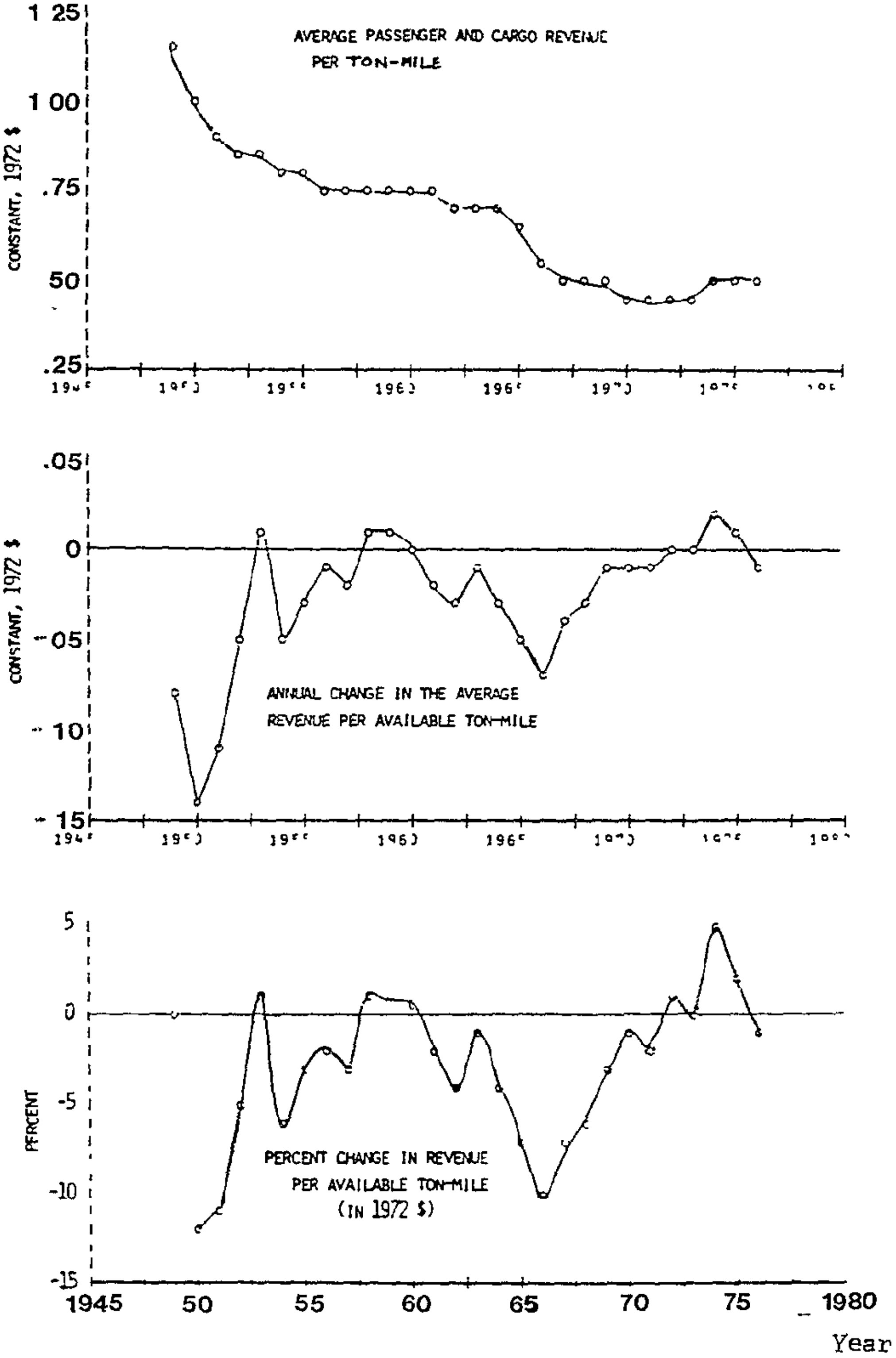
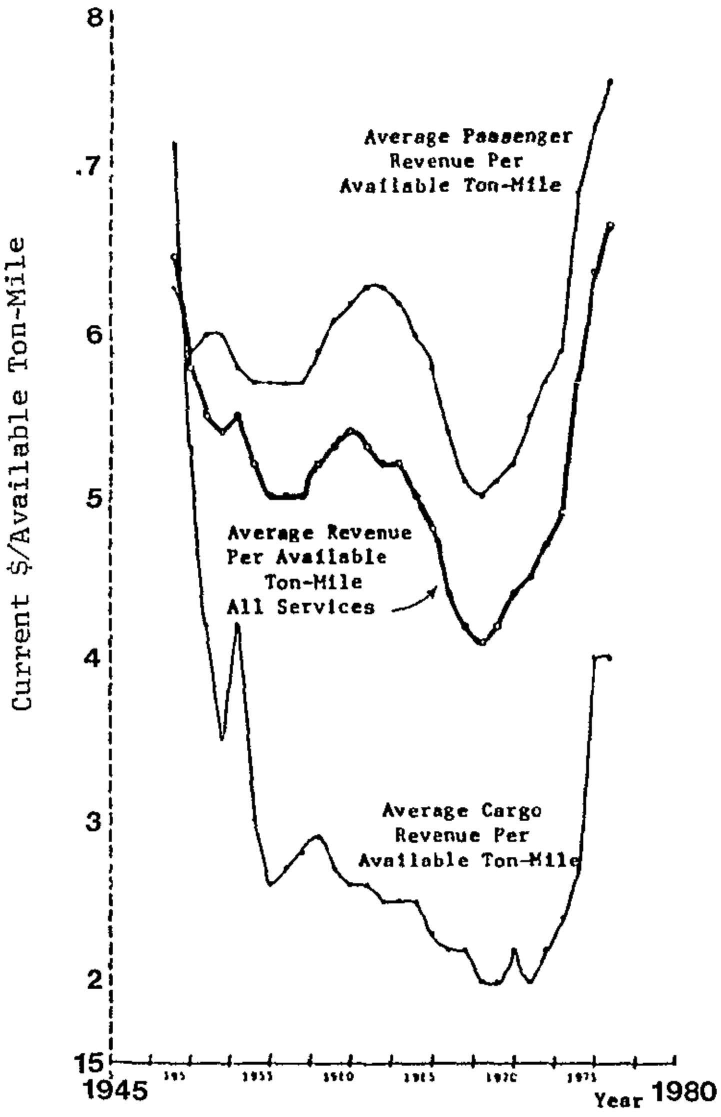
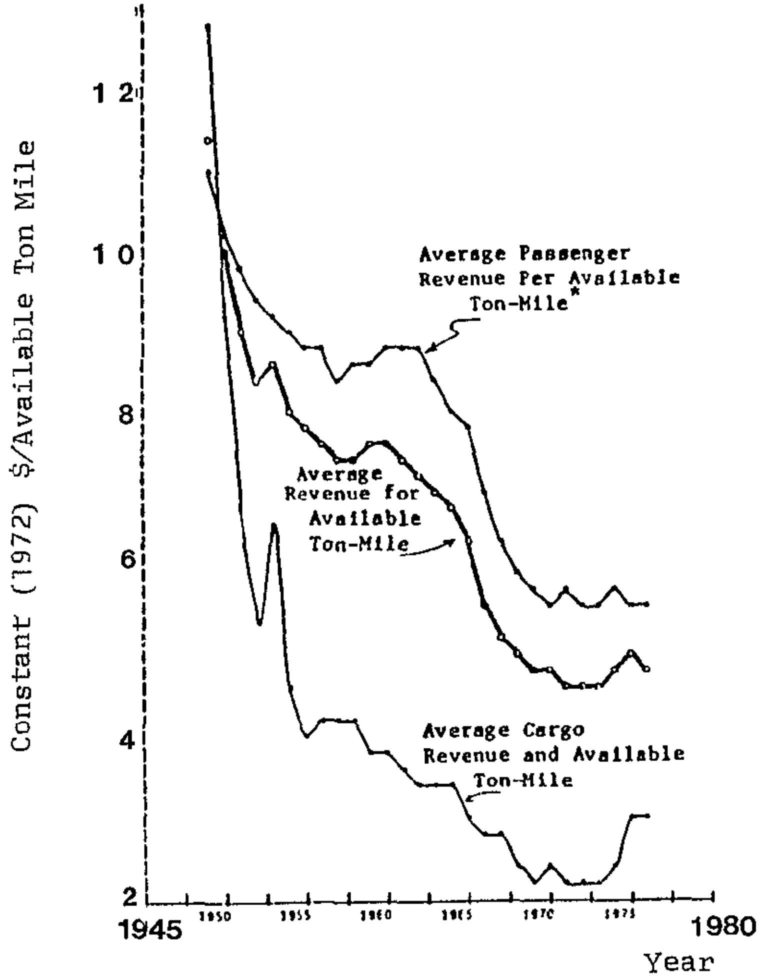


Figure IV - 22 U.S. Commercial Air Transportation Average Revenue Per Ton-Mile All Services.



Year	Average Revenue in Current Dollar Per Ton-Mile		
	All Services	Passenger	Cargo
1949	0.65	0.63	0.72
1950	0.58	0.59	0.53
1951	0.55	0.60	0.42
1952	0.54	0.60	0.35
1953	0.55	0.58	0.42
1954	0.52	0.57	0.30
1955	0.50	0.57	0.26
1956	0.50	0.57	0.27
1957	0.50	0.57	0.28
1958	0.52	0.59	0.29
1959	0.53	0.61	0.27
1960	0.54	0.62	0.26
1961	0.53	0.63	0.26
1962	0.52	0.63	0.25
1963	0.52	0.62	0.25
1964	0.50	0.60	0.25
1965	0.48	0.58	0.23
1966	0.44	0.54	0.22
1967	0.42	0.51	0.22
1968	0.41	0.50	0.20
1969	0.42	0.51	0.20
1970	0.44	0.52	0.22
1971	0.45	0.55	0.20
1972	0.47	0.57	0.22
1973	0.49	0.59	0.24
1974	0.57	0.69	0.27
1975	0.64	0.73	0.40
1976	0.67	0.76	0.40

Figure IV - 23 Average Passenger and Cargo Fare (Current Dollar)



*Each Passenger Ton-Mile is equivalent to 10 Passenger Mile

Average Revenue in Constant (1972) $

Year	Per Ton-Mile All Services	Passenger*	Cargo
1949	1.14	1.10	1.27
1950	1.00	1.03	0.92
1951	0.89	0.97	0.67
1952	0.85	0.94	0.54
1953	0.86	0.91	0.65
1954	0.80	0.89	0.46
1955	0.78	0.89	0.41
1956	0.76	0.88	0.42
1957	0.74	0.84	0.41
1958	0.75	0.85	0.41
1959	0.75	0.87	0.38
1960	0.76	0.88	0.37
1961	0.74	0.88	0.37
1962	0.72	0.88	0.34
1963	0.71	0.84	0.35
1964	0.68	0.81	0.34
1965	0.63	0.77	0.31
1966	0.57	0.70	0.28
1967	0.52	0.64	0.27
1968	0.49	0.60	0.24
1969	0.48	0.59	0.23
1970	0.47	0.56	0.23
1971	0.46	0.57	0.21
1972	0.47	0.57	0.22
1973	0.46	0.56	0.22
1974	0.49	0.58	0.23
1975	0.50	0.56	0.31
1976	0.49	0.56	0.30

Figure IV - 24 Average Passenger and Cargo Fare (Constant Dollar)

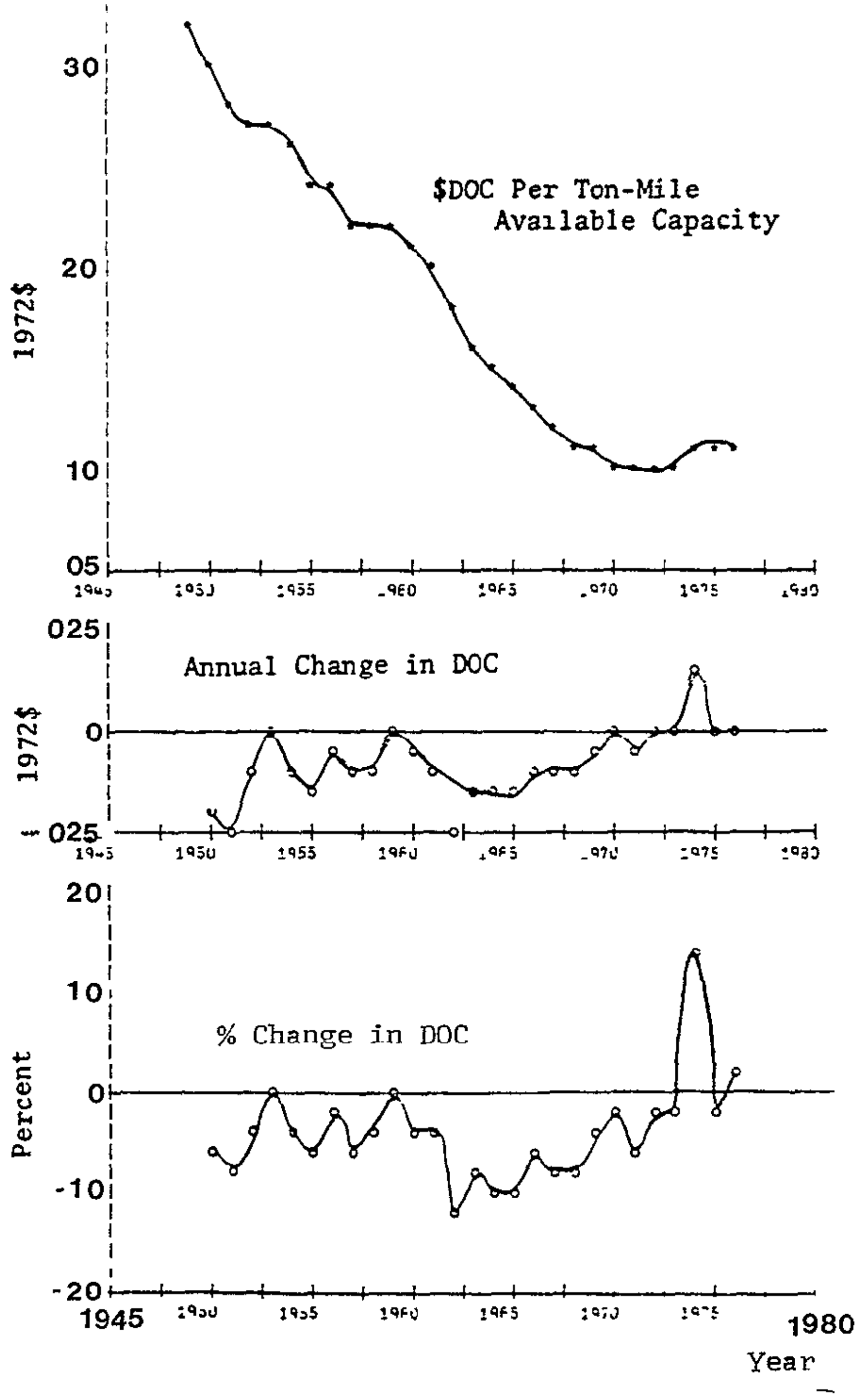
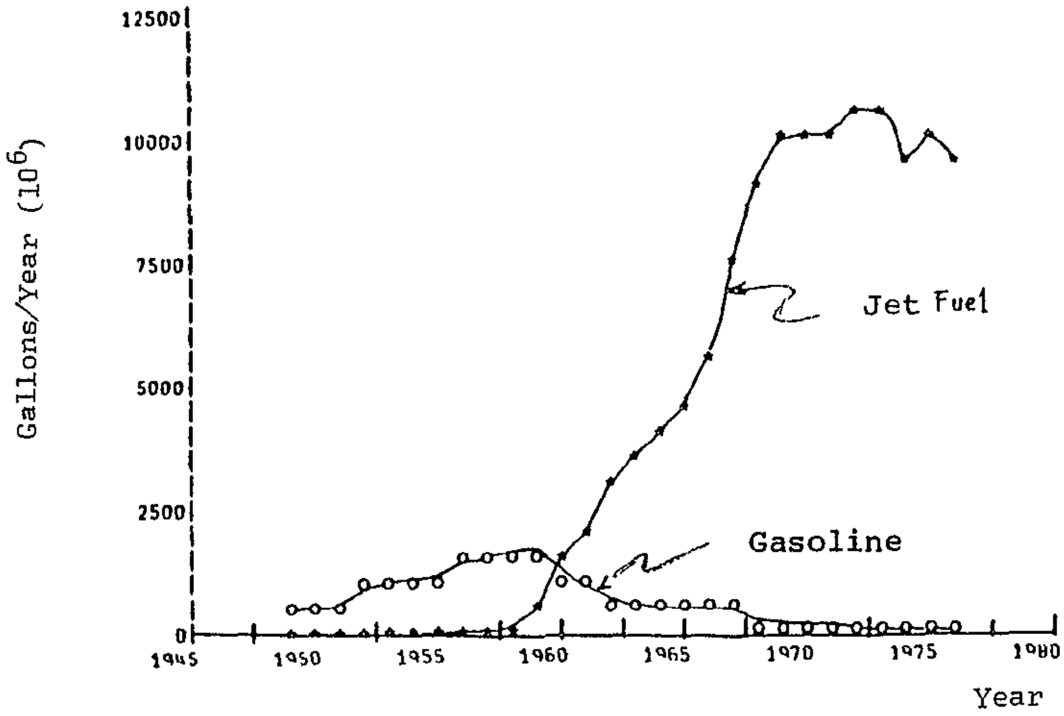


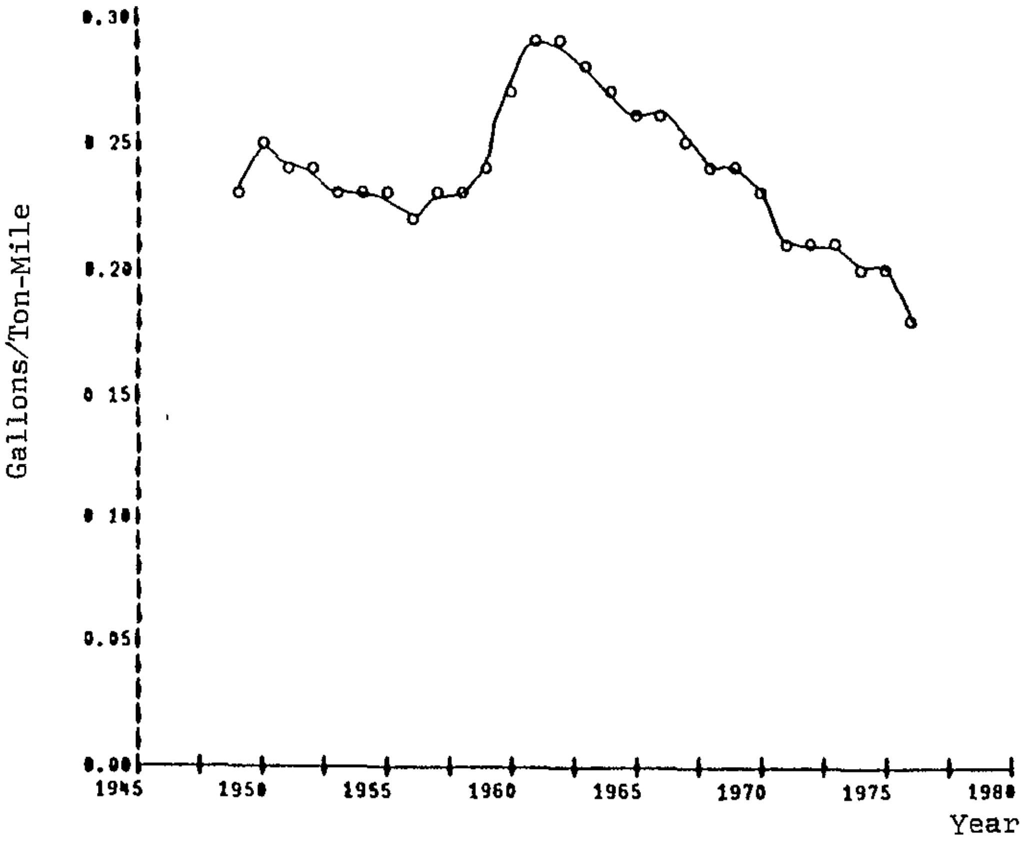
Figure IV - 25 Historical Direct Operating Costs (DOC) for Certified Air Carriers and Its Rate of Change



Fuel Consumption gal/year (10^6)

Year	Gasoline	Jet Fuel
1949	500.0	0.0
1950	600.0	0.0
1951	683.0	0.0
1952	797.0	0.0
1953	907.0	0.0
1954	1018.0	0.0
1955	1195.0	2.0
1956	1354.0	34.0
1957	1557.0	81.0
1958	1602.0	95.0
1959	1540.0	477.0
1960	1189.0	1331.0
1961	951.0	2073.0
1962	738.0	2800.0
1963	651.0	3291.0
1964	589.0	3870.0
1965	519.0	4650.0
1966	398.0	5669.0
1967	268.0	7523.0
1968	128.0	8981.0
1969	33.0	10113.0
1970	14.0	10085.0
1971	12.0	10140.0
1972	13.0	10302.0
1973	10.0	10700.0
1974	8.0	9554.0
1975	6.0	9832.0
1976	4.0	9507.0

Figure IV - 26 U.S Certificated Air Carriers' Fuel Consumption.



Year	Gallons/ Ton-Mile
1949	0.232
1950	0.247
1951	0.241
1952	0.237
1953	0.229
1954	0.228
1955	0.226
1956	0.225
1957	0.227
1958	0.232
1959	0.242
1960	0.269
1961	0.286
1962	0.288
1963	0.283
1964	0.271
1965	0.263
1966	0.258
1967	0.253
1968	0.245
1969	0.237
1970	0.228
1971	0.215
1972	0.212
1973	0.208
1974	0.195
1975	0.200
1976	0.184

Figure IV - 27 Average Fuel Consumption, Gallon per Ton-Mile available capacity. All services in the U.S. certificated air carriers.

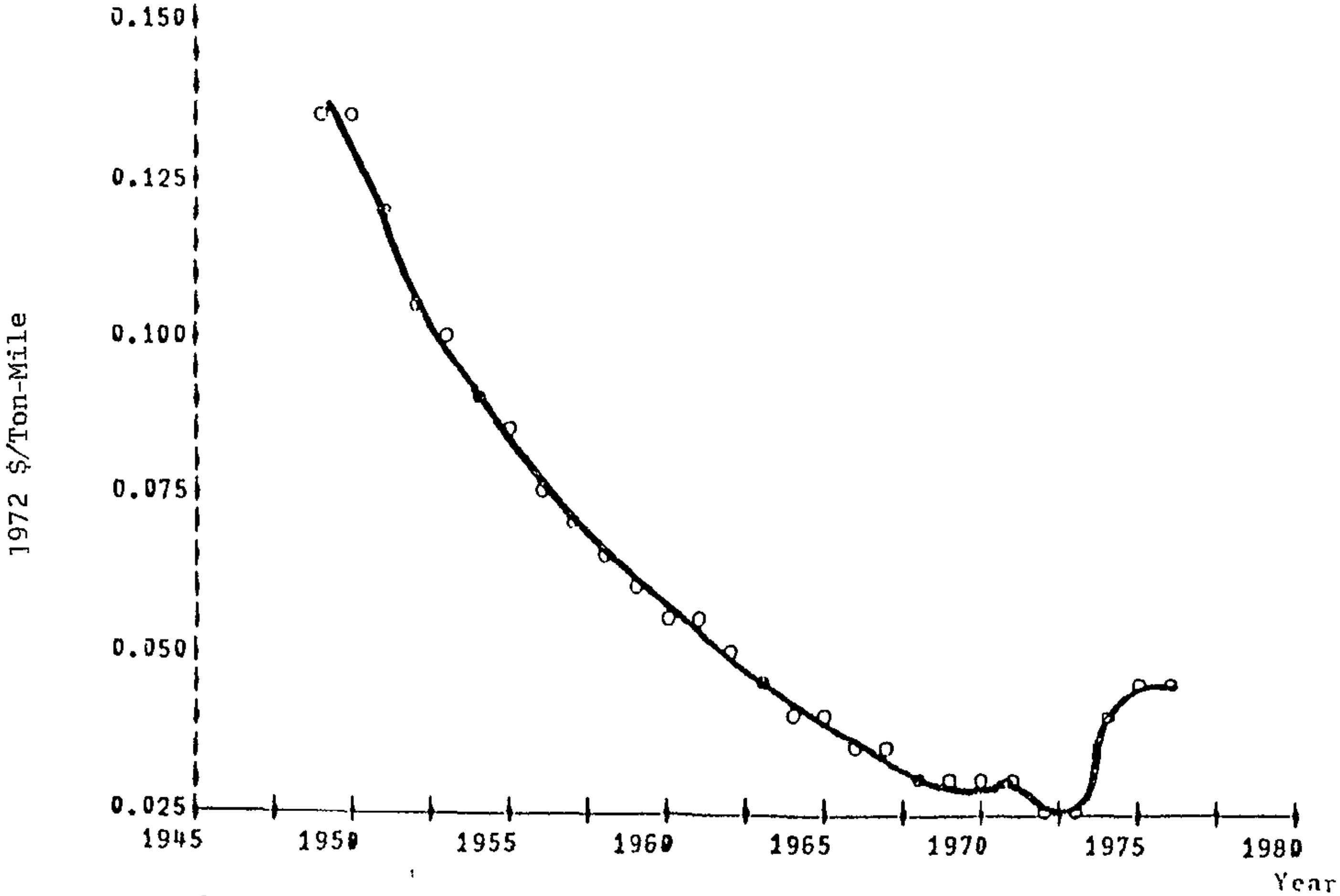
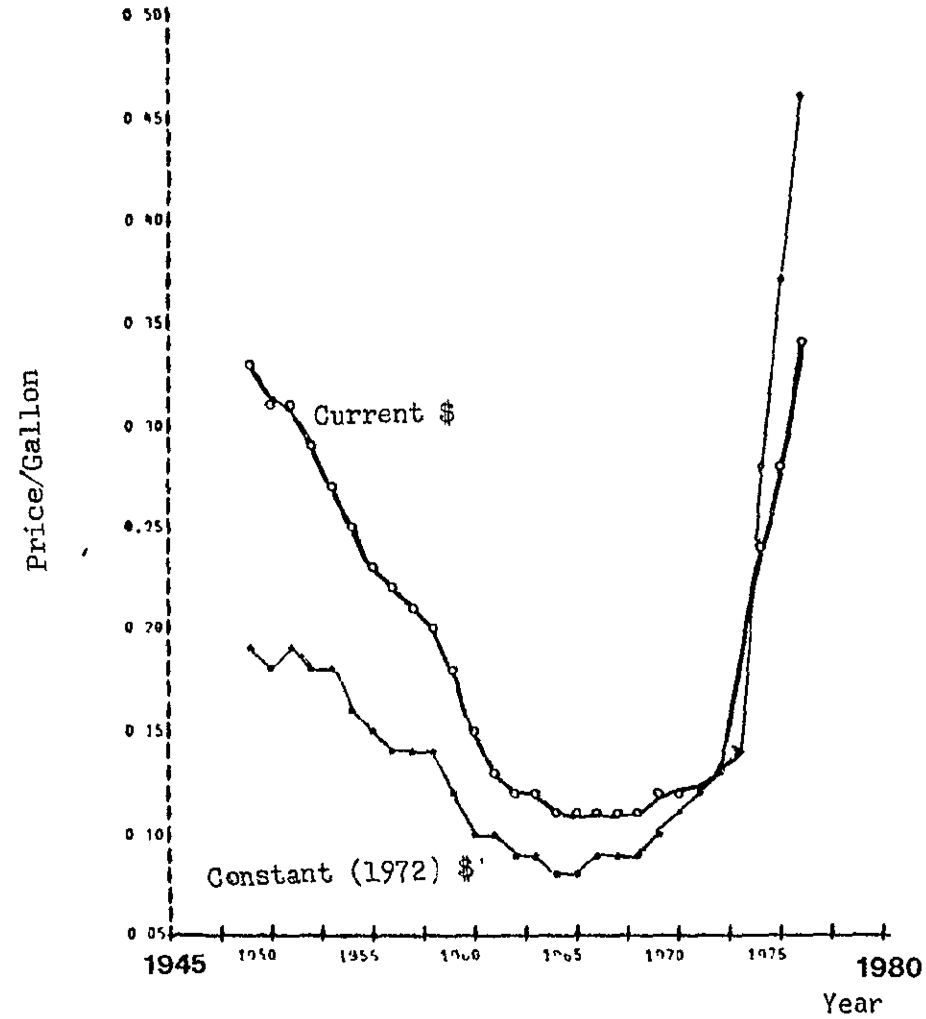


Figure IV - 28 Fuel cost per Ton-Mile Available Capacity

Year	1972 $
1949	0.134
1950	0.133
1951	0.119
1952	0.107
1953	0.098
1954	0.089
1955	0.083
1956	0.077
1957	0.069
1958	0.066
1959	0.062
1960	0.056
1961	0.053
1962	0.050
1963	0.046
1964	0.041
1965	0.039
1966	0.037
1967	0.035
1968	0.032
1969	0.031
1970	0.028
1971	0.028
1972	0.027
1973	0.027
1974	0.039
1975	0.044
1976	0.046



Aviation Fuel Price $/Gal

Year	1972 $	Current $
1949	0.188	0.329
1950	0.178	0.310
1951	0.190	0.306
1952	0.182	0.287
1953	0.175	0.274
1954	0.161	0.250
1955	0.150	0.234
1956	0.144	0.222
1957	0.139	0.206
1958	0.137	0.198
1959	0.124	0.178
1960	0.105	0.148
1961	0.095	0.133
1962	0.090	0.124
1963	0.087	0.119
1964	0.084	0.113
1965	0.084	0.111
1966	0.085	0.110
1967	0.088	0.110
1968	0.091	0.110
1969	0.101	0.115
1970	0.107	0.116
1971	0.121	0.125
1972	0.126	0.126
1973	0.145	0.136
1974	0.280	0.237
1975	0.365	0.284
1976	0.460	0.338

Figure IV - 29 Average Aviation Fuel Price

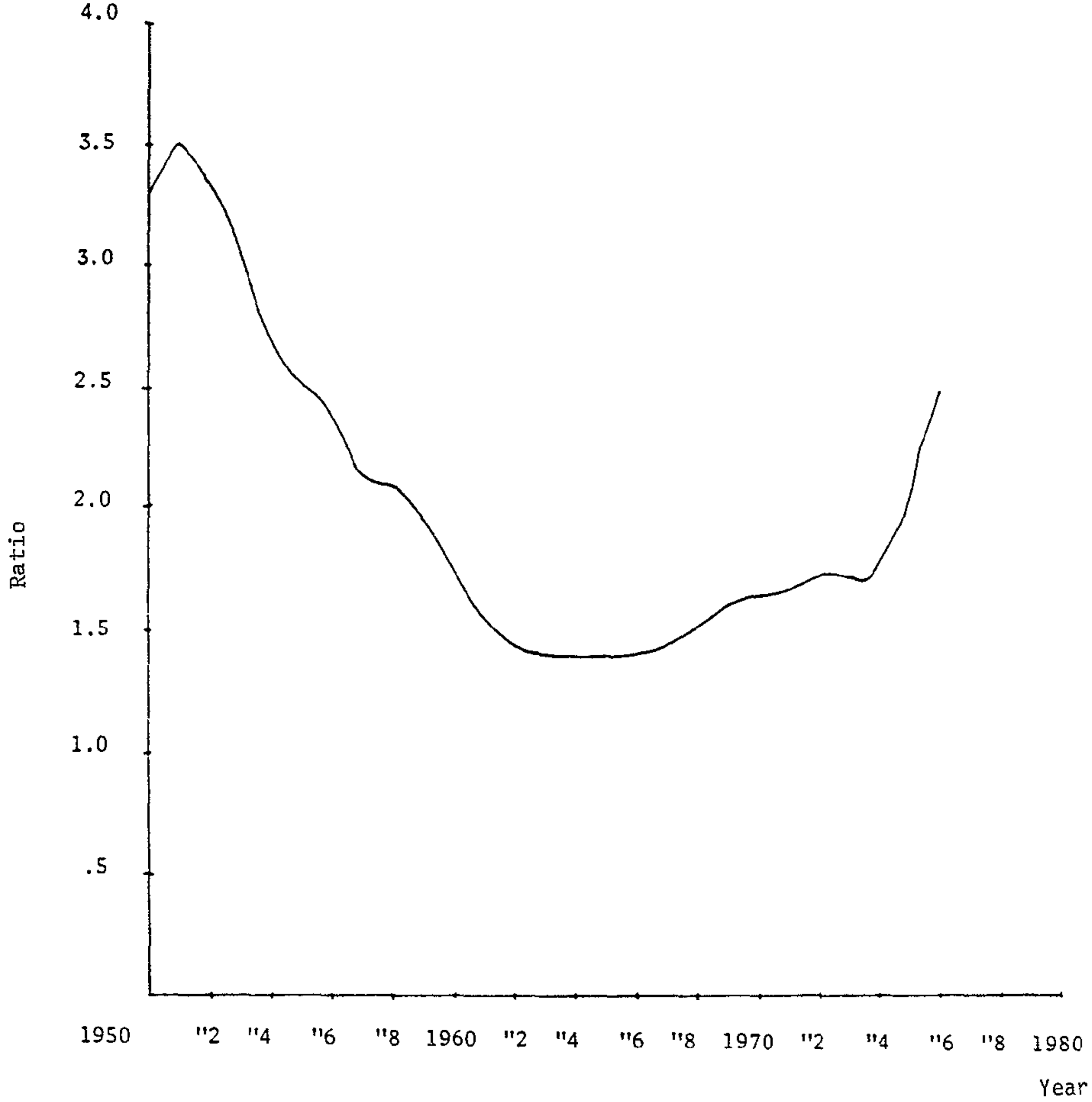


Figure IV-30 Ratio of Aviation Fuel Price/Crude Oil Price

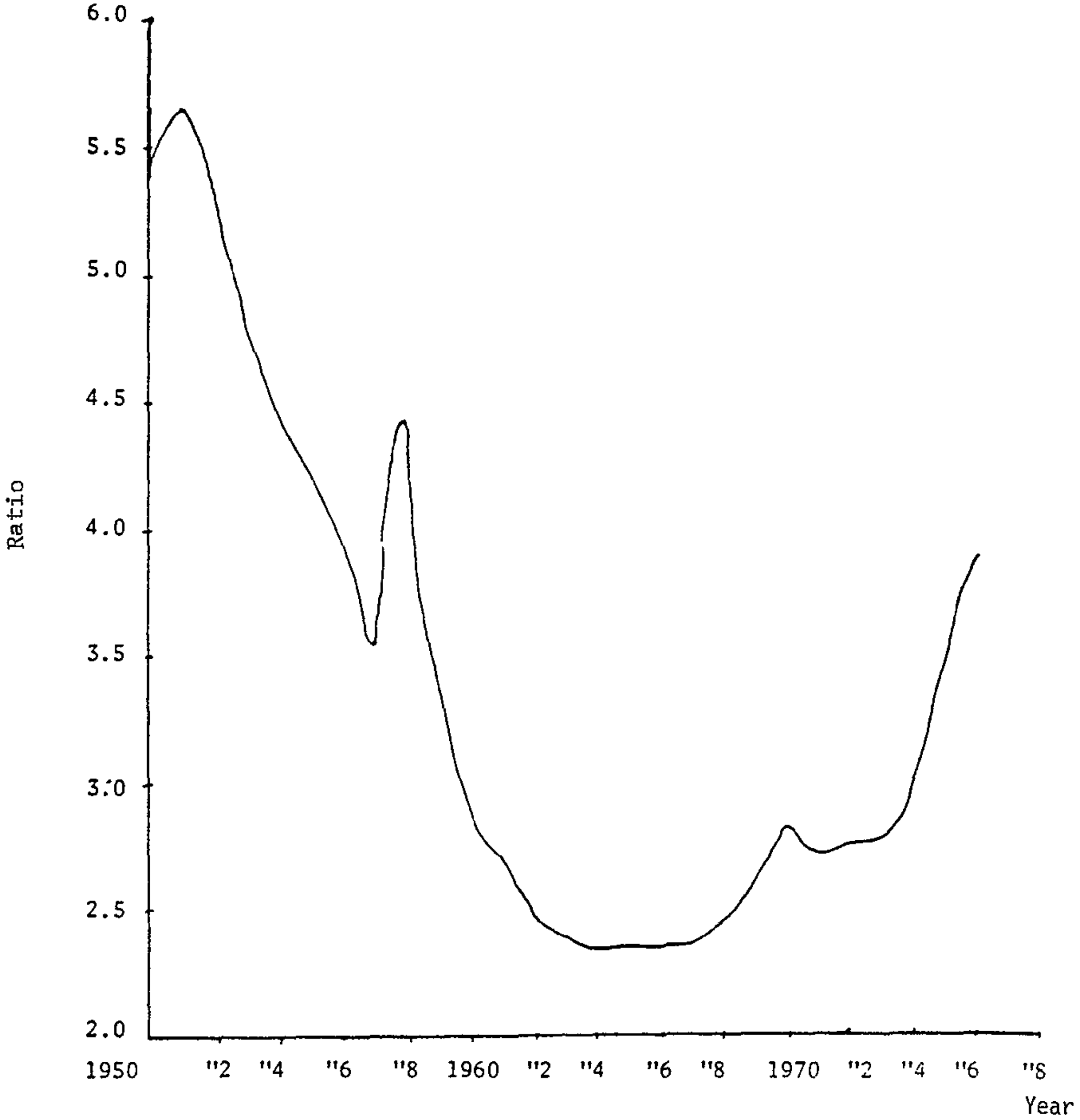
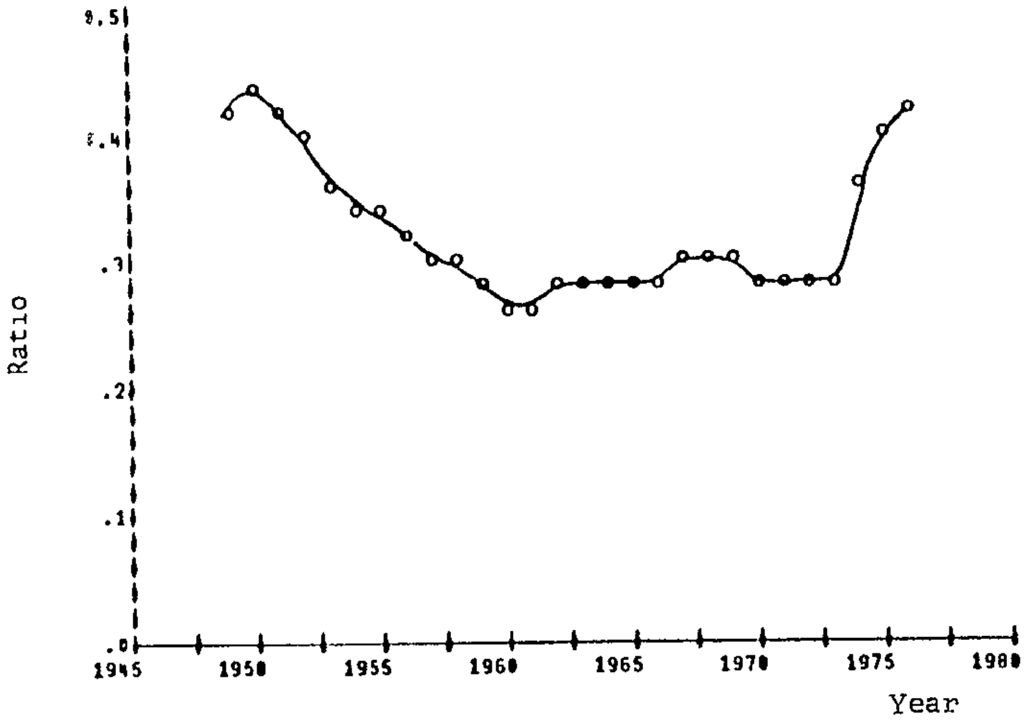
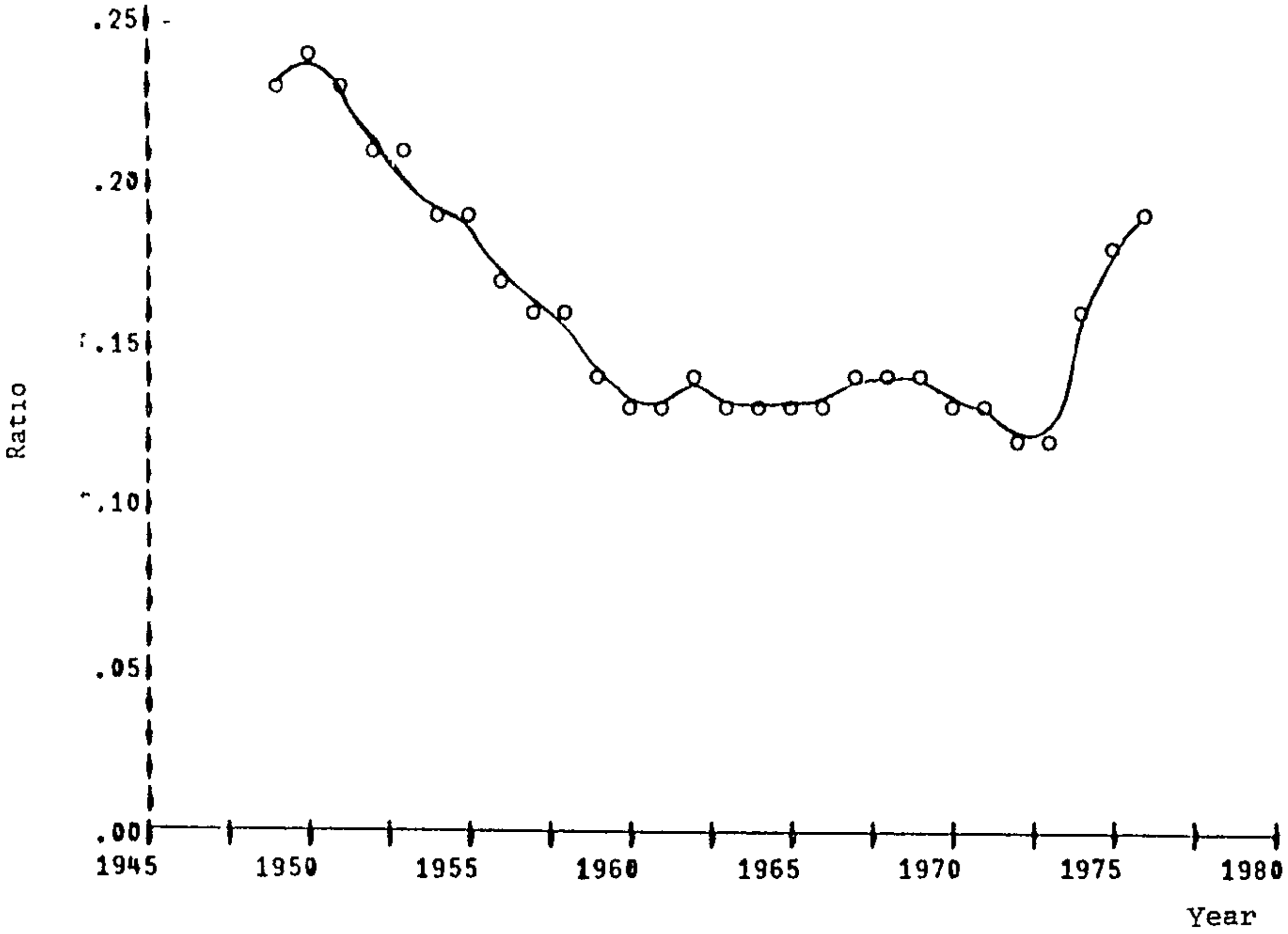


Figure IV-31 Ratio of Aviation Fuel Price/Avg Tot. Fossil Fuels Price



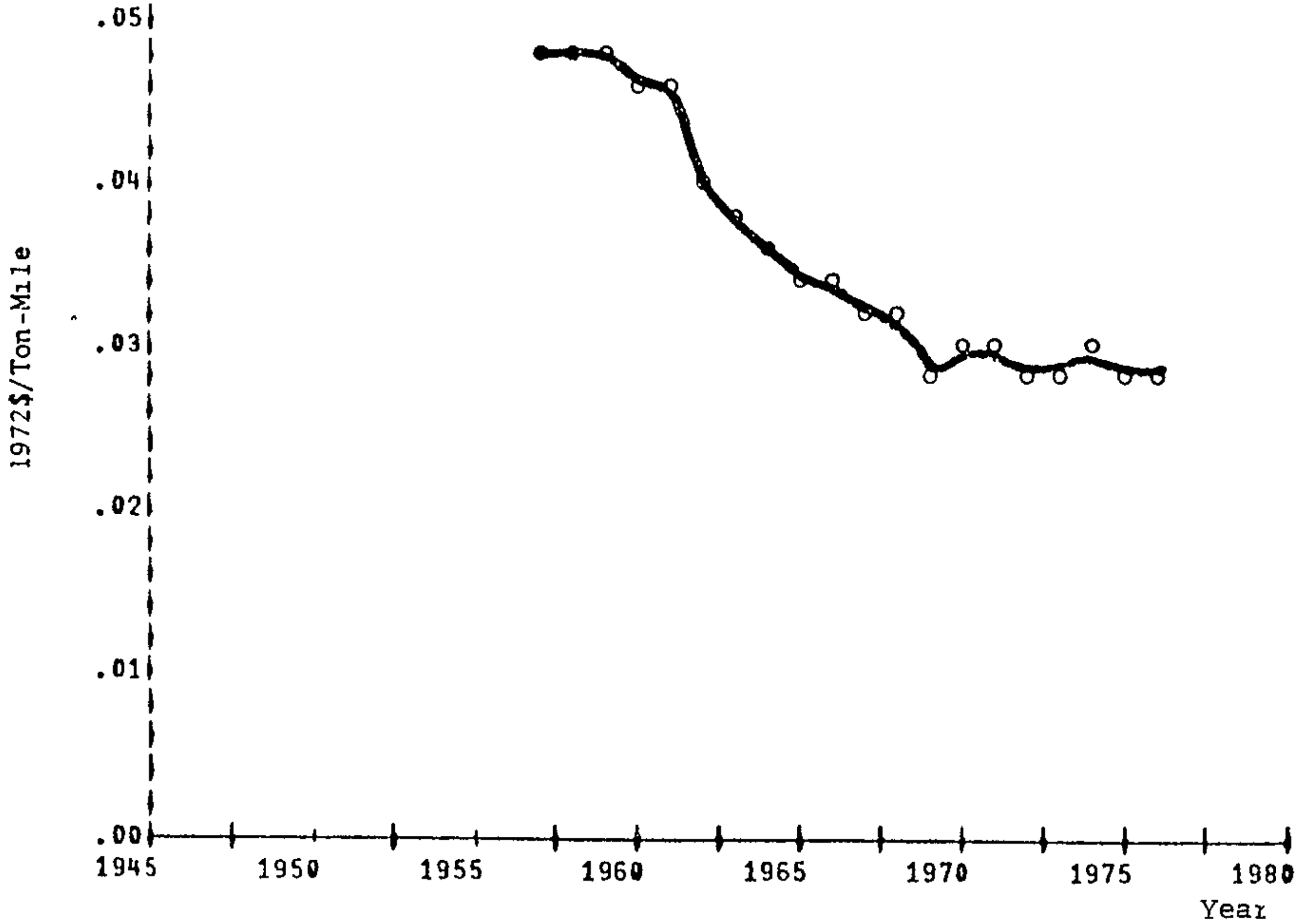
Year	
1949	41
1950	43
1951	42
1952	40
1953	36
1954	34
1955	34
1956	32
1957	30
1958	30
1959	26
1960	26
1961	26
1962	27
1963	28
1964	27
1965	28
1966	28
1967	29
1968	29
1969	29
1970	27
1971	28
1972	27
1973	28
1974	35
1975	40
1976	41

Figure IV - 32 Ratio of Fuel Cost to Direct Operating Costs, Certificated Air Carriers



Year	Ratio
1949	0.226
1950	0.243
1951	0.233
1952	0.215
1953	0.205
1954	0.193
1955	0.187
1956	0.175
1957	0.164
1958	0.157
1959	0.144
1960	0.133
1961	0.132
1962	0.136
1963	0.135
1964	0.132
1965	0.134
1966	0.134
1967	0.139
1968	0.138
1969	0.139
1970	0.126
1971	0.130
1972	0.123
1973	0.123
1974	0.162
1975	0.184
1976	0.192

Figure IV-33 Ratio of Fuel Cost to Total Cost, Certificated Air Carriers.



Year	1972$ Per Ton-Mile Capacity
1957	0.047
1958	0.048
1959	0.049
1960	0.046
1961	0.045
1962	0.040
1963	0.038
1964	0.036
1965	0.034
1966	0.034
1967	0.032
1968	0.031
1969	0.029
1970	0.029
1971	0.029
1972	0.029
1973	0.029
1974	0.029
1975	0.029
1976	0.029

Figure IV-34 Crew Costs Per Ton-Mile Available Capacity, As Domestic Operation of Domestic Trunk

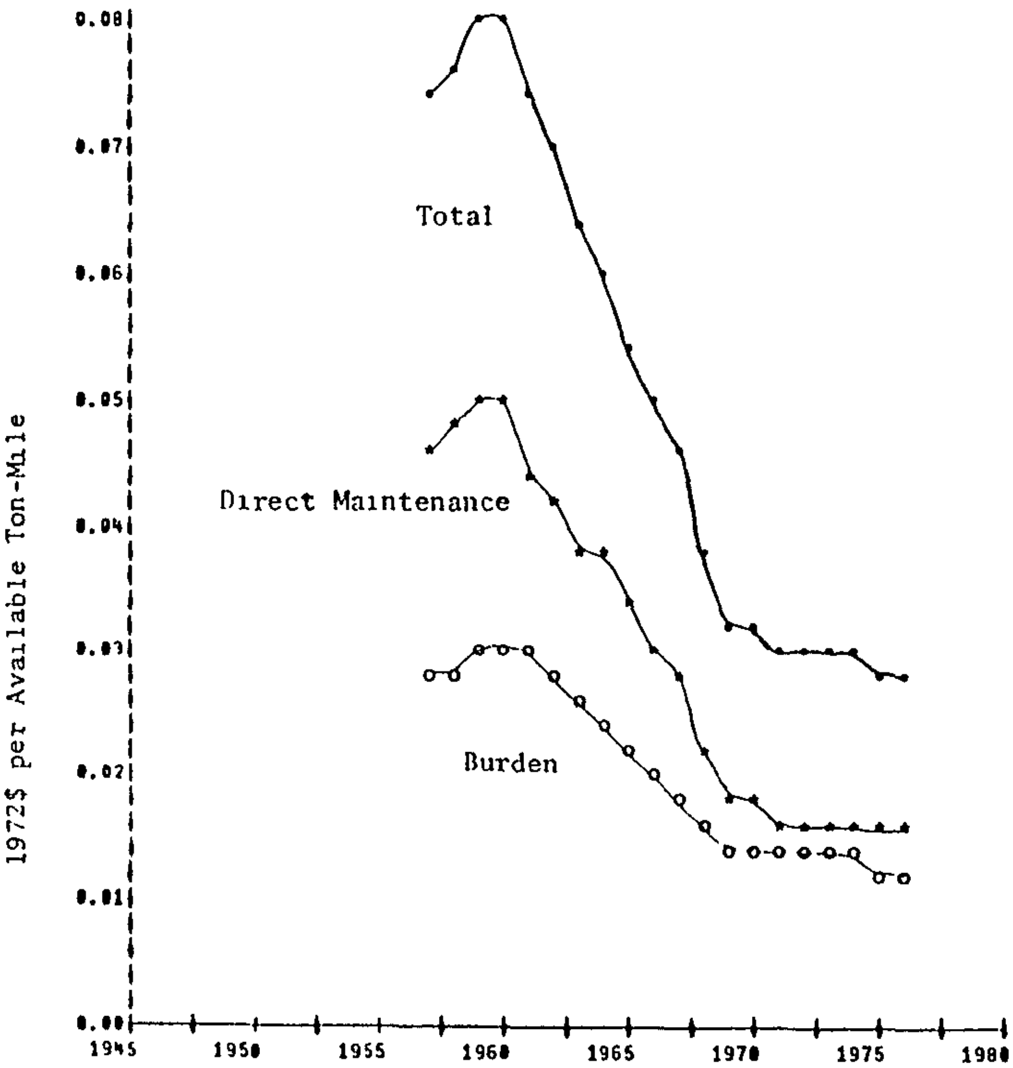


Figure IV-35 Maintenance Costs.

Maintenance Costs
1972$ per Available Ton-Mile Capacity

Year	Direct	Burden	Total
1957	0.04652	0.02749	0.07401
1958	0.04776	0.02808	0.07584
1959	0.05051	0.02913	0.07963
1960	0.04957	0.03093	0.08050
1961	0.04335	0.02965	0.07300
1962	0.04233	0.02850	0.07083
1963	0.03883	0.02557	0.06439
1964	0.03701	0.02324	0.06025
1965	0.03315	0.02121	0.05436
1966	0.02940	0.01999	0.04939
1967	0.02744	0.01767	0.04511
1968	0.02250	0.01552	0.03802
1969	0.01895	0.01404	0.03299
1970	0.01735	0.01412	0.03147
1971	0.01570	0.01332	0.02902
1972	0.01610	0.01320	0.02930
1973	0.01649	0.01300	0.02950
1974	0.01665	0.01308	0.02974
1975	0.01595	0.01230	0.02825
1976	0.01596	0.01251	0.02847

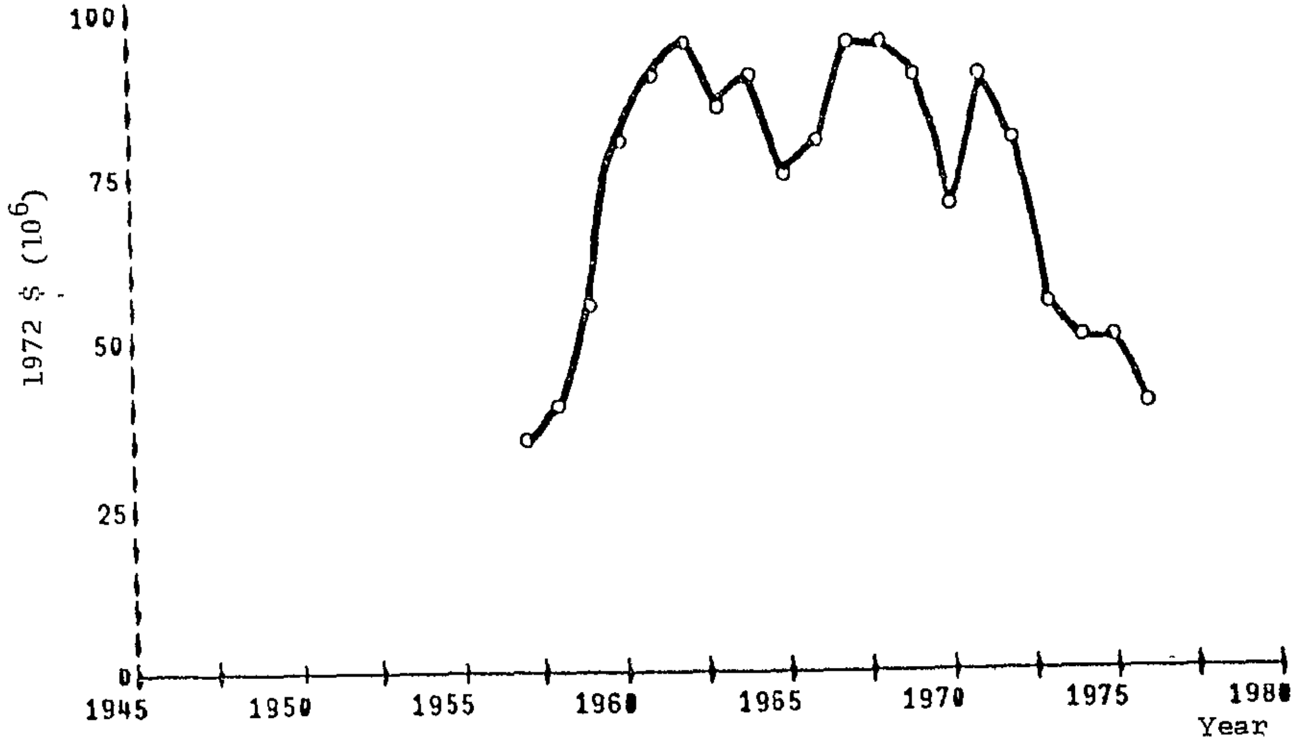


Figure IV - 36 Total Insurance Cost
(Certificated Air Carriers)

Year	1972 $ (10^6)
1957	34.390
1958	38.172
1959	57.419
1960	78.183
1961	91.718
1962	97.199
1963	83.802
1964	92.492
1965	72.987
1966	78.804
1967	96.444
1968	94.037
1969	87.906
1970	71.610
1971	87.832
1972	77.891
1973	53.326
1974	49.898
1975	49.863
1976	38.037

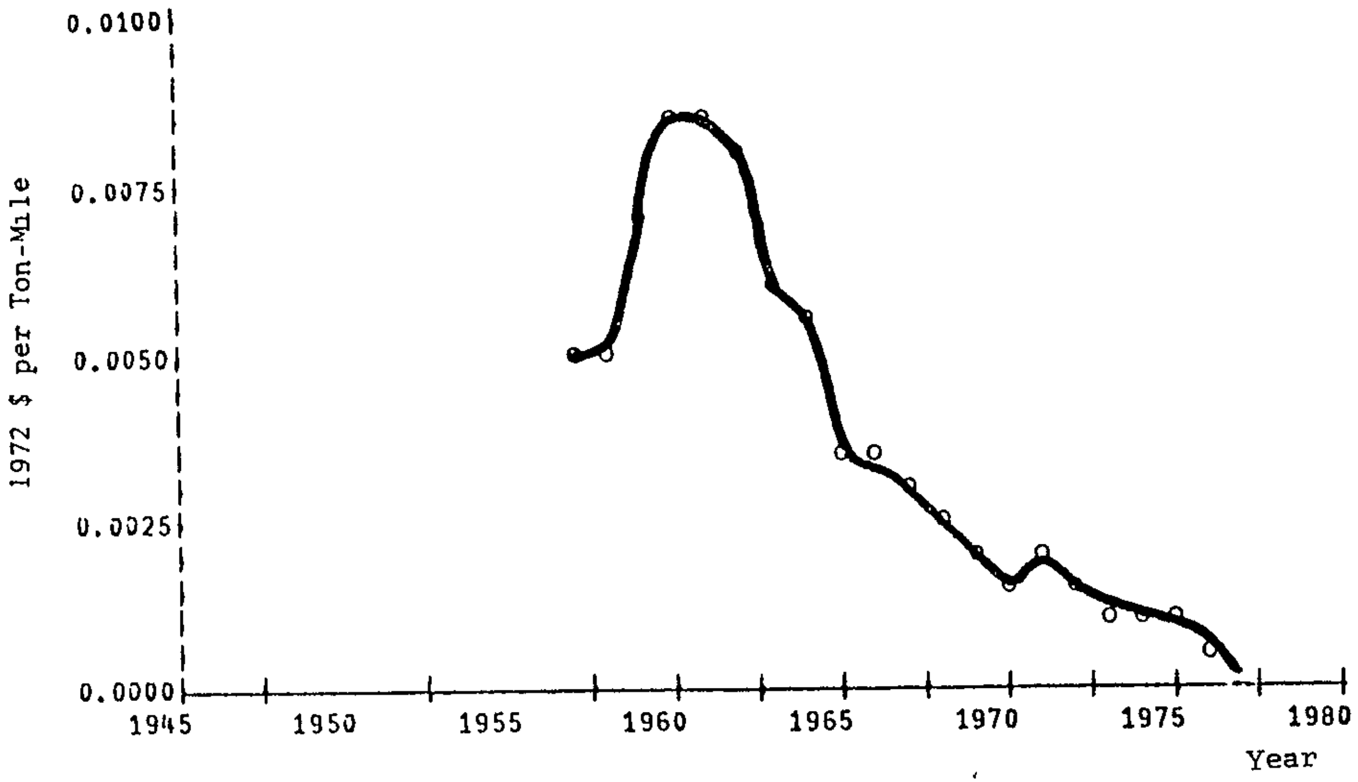


Figure IV-37 Cost of Insurance per Ton-Mile Available Capacity.

Year	1972 $ per Ton-Mile
1957	0.00476
1958	0.00521
1959	0.00689
1960	0.00833
1961	0.00867
1962	0.00789
1963	0.00602
1964	0.00567
1965	0.00371
1966	0.00335
1967	0.00313
1968	0.00253
1969	0.00205
1970	0.00162
1971	0.00186
1972	0.00160
1973	0.00104
1974	0.00102
1975	0.00101
1976	0.00074

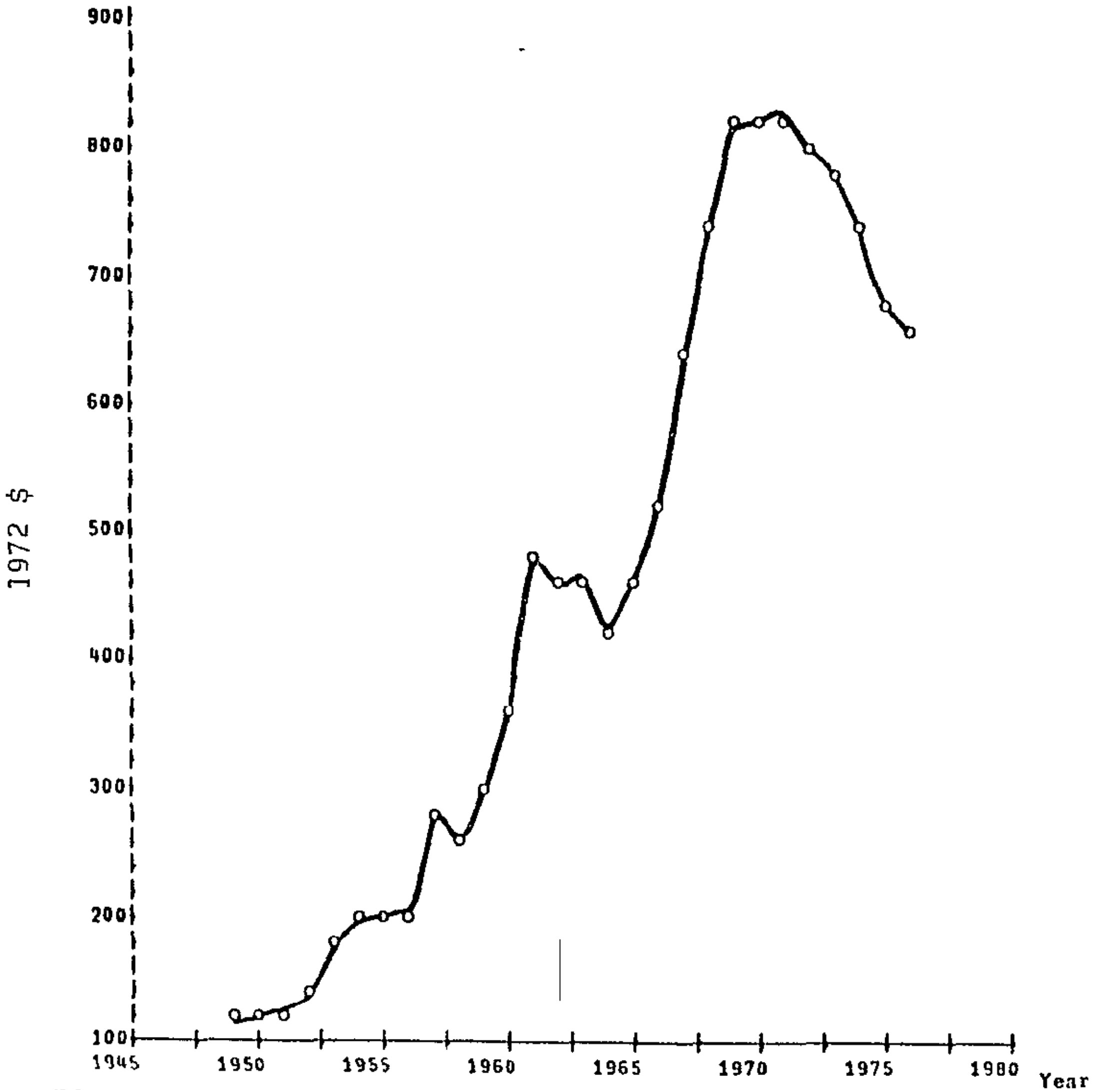


Figure IV - 38 Depreciation Costs (Certificated Air Carriers)

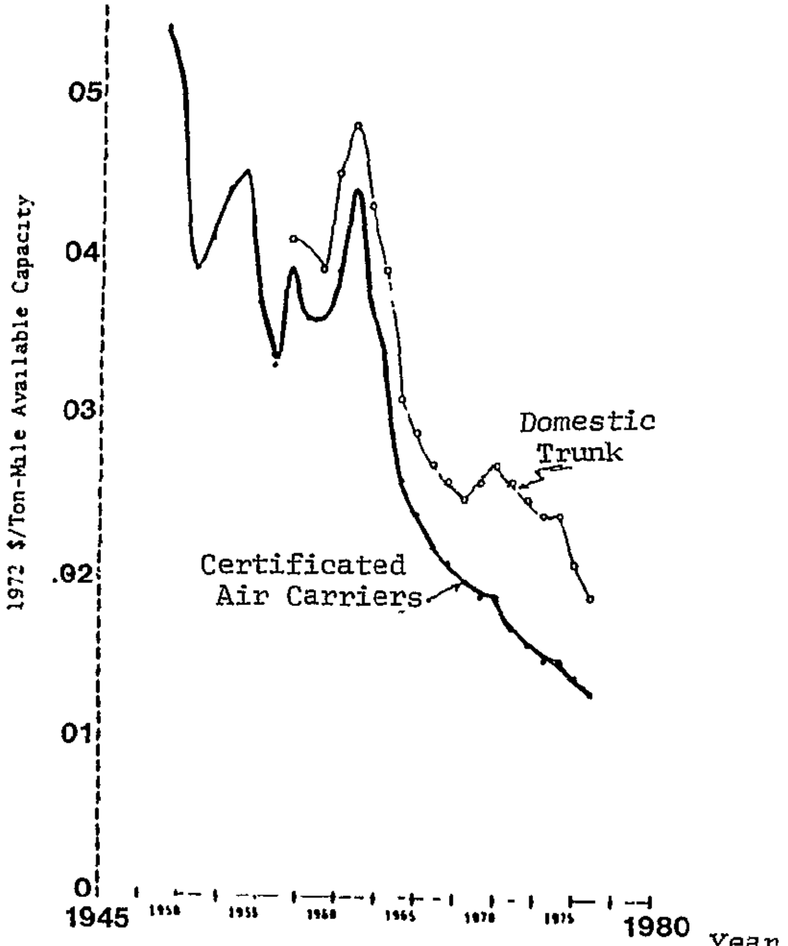


Figure IV-39 Depreciation Costs, 1972 $ per Ton-Mile Available Capacity.

	Depreciation Costs, 1972 $/Ton-Mile	
Year	Certif'd Air Carriers	Domestic Trunk
1949	0.0541	
1950	0.0489	
1951	0.0390	
1952	0.0412	
1953	0.0440	
1954	0.0449	
1955	0.0362	
1956	0.0332	
1957	0.0389	0.0410
1958	0.0359	0.0356
1959	0.0364	0.0387
1960	0.0386	0.0452
1961	0.0445	0.0482
1962	0.0366	0.0426
1963	0.0331	0.0394
1964	0.0260	0.0305
1965	0.0235	0.0285
1966	0.0222	0.0271
1967	0.0206	0.0264
1968	0.0197	0.0251
1969	0.0190	0.0260
1970	0.0186	0.0267
1971	0.0172	0.0258
1972	0.0160	0.0246
1973	0.0151	0.0242
1974	0.0149	0.0240
1975	0.0139	0.0214
1976	0.0127	0.0195

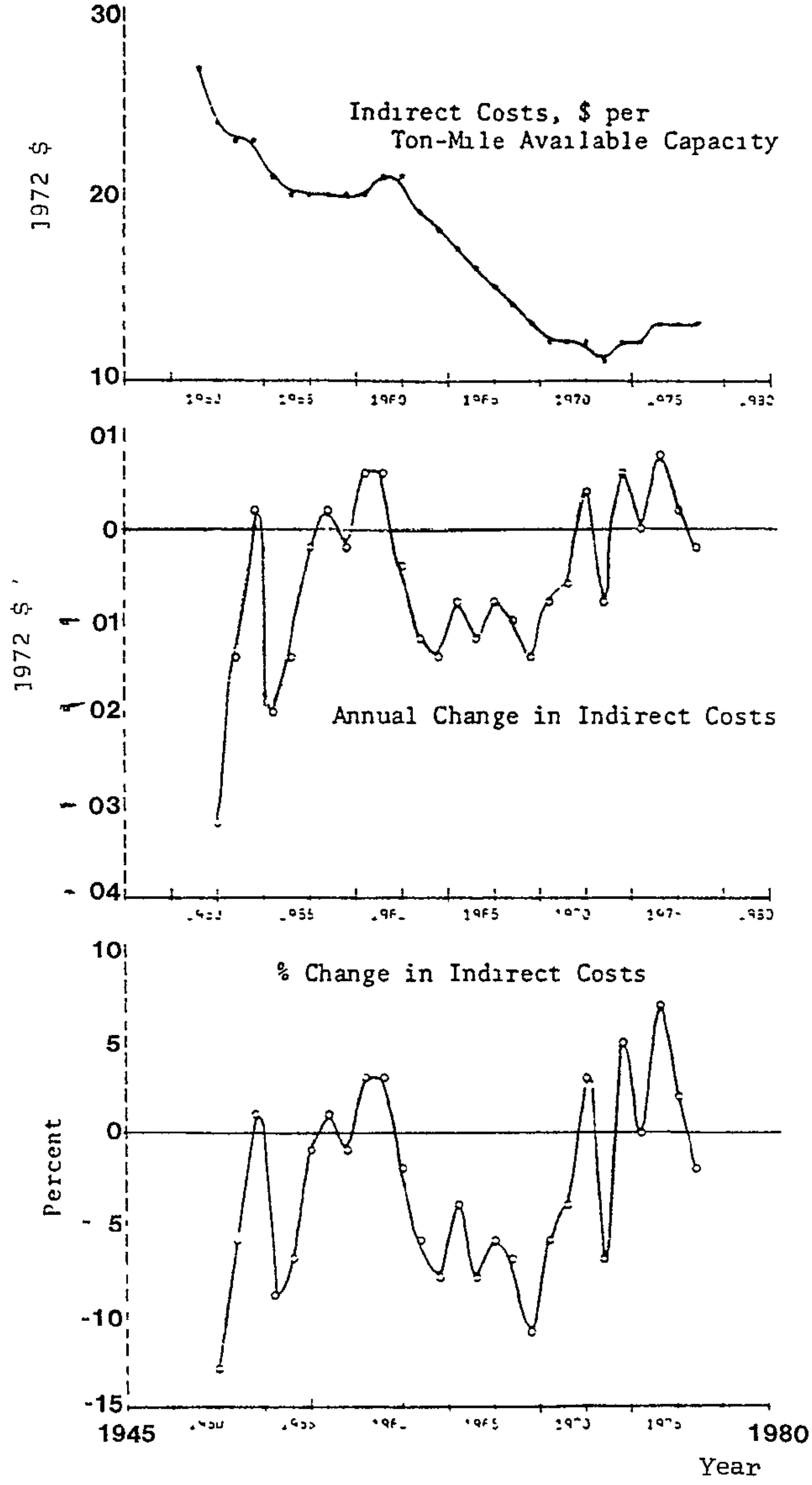
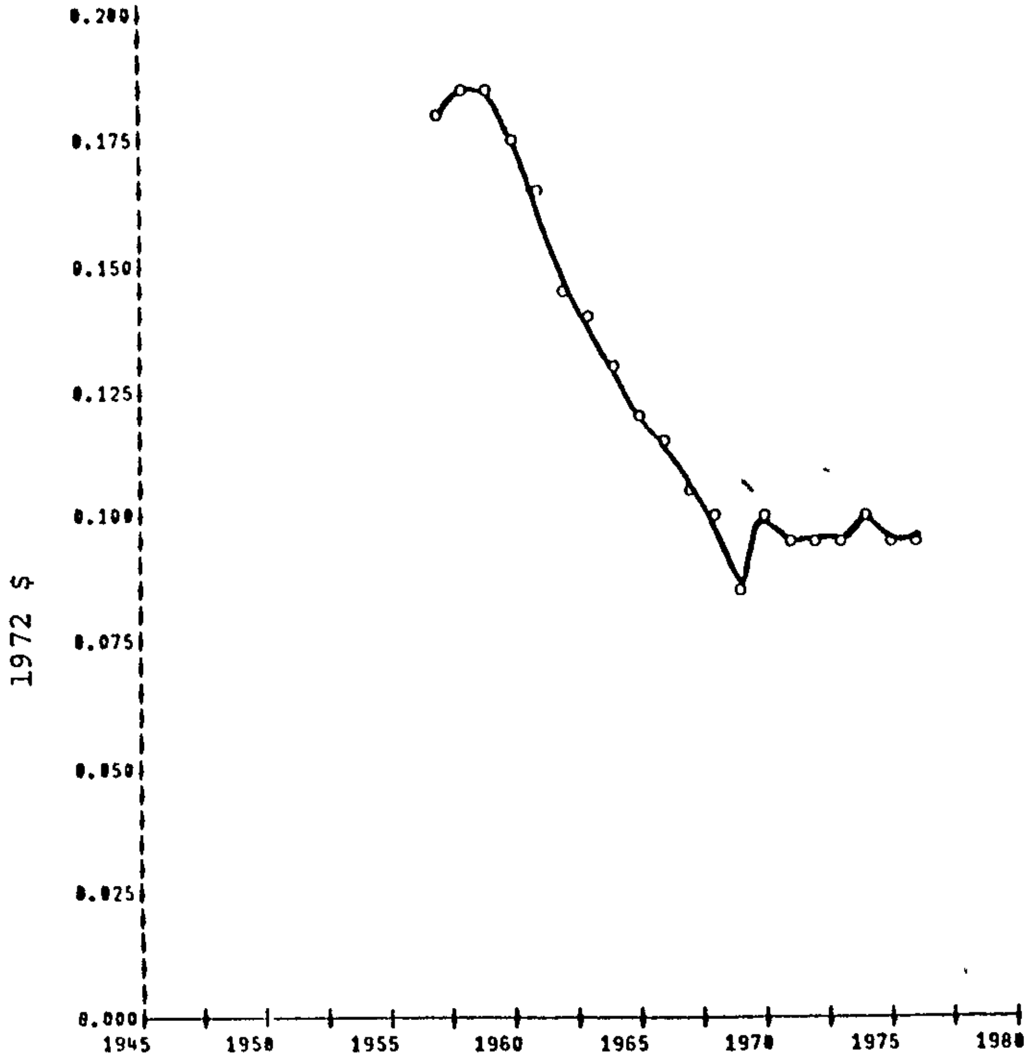
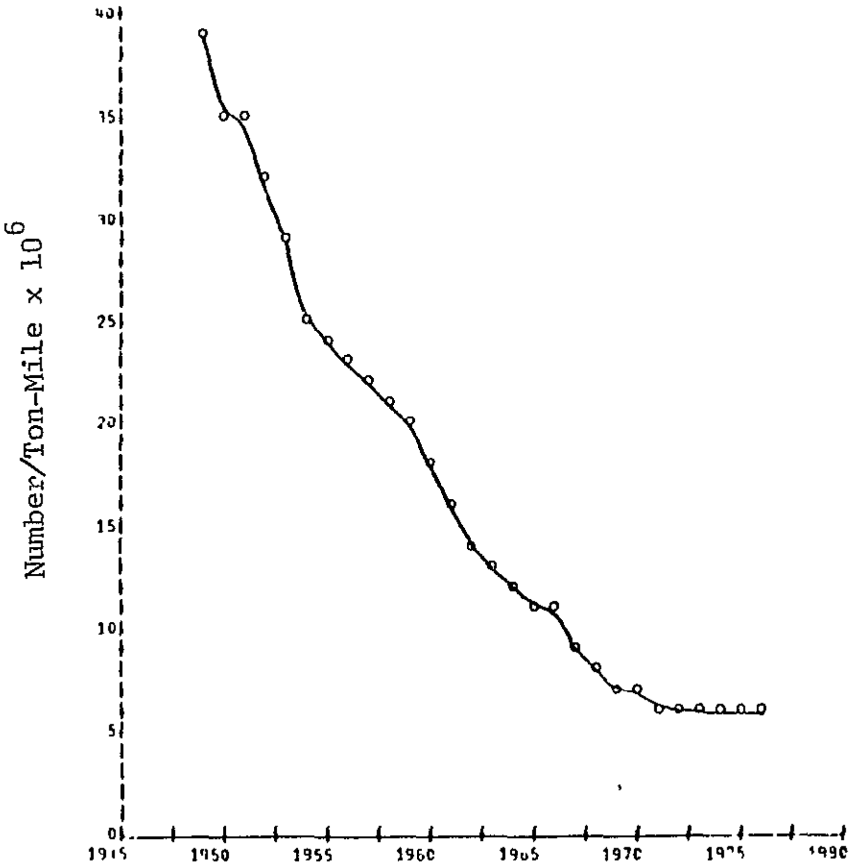


Figure IV - 40 Historical Indirect Costs and Its Rate of Change, Certified Air Carriers



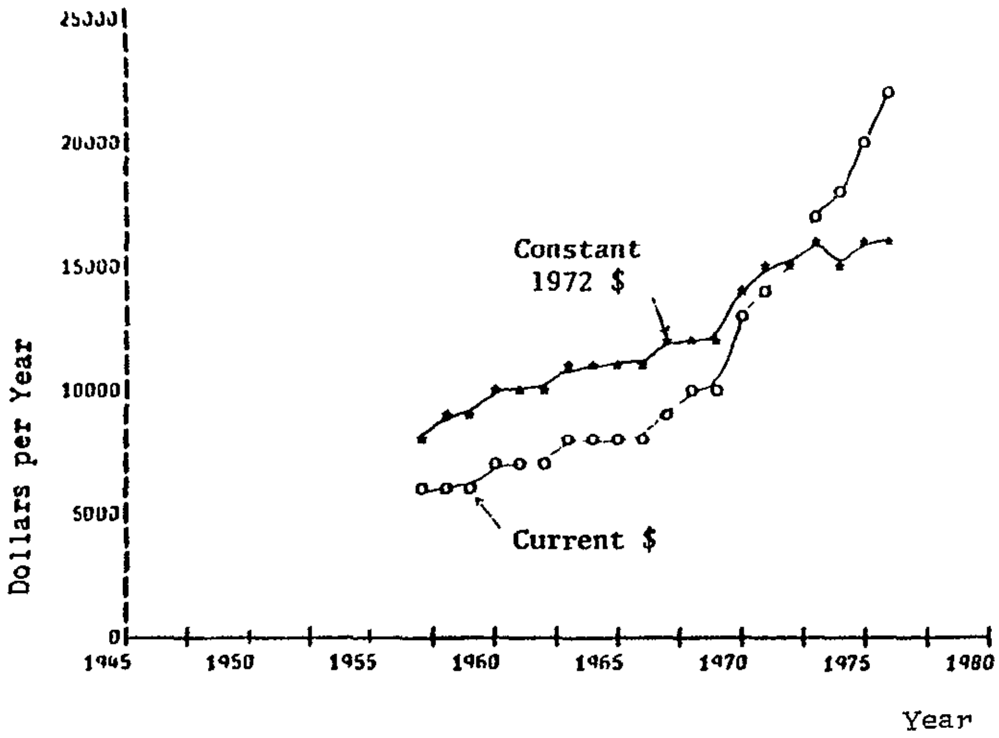
Year	1972 $ Per Ton-Mile
1957	0.180
1958	0.183
1959	0.183
1960	0.176
1961	0.164
1962	0.147
1963	0.138
1964	0.130
1965	0.119
1966	0.113
1967	0.106
1968	0.100
1969	0.085
1970	0.098
1971	0.093
1972	0.096
1973	0.096
1974	0.098
1975	0.095
1976	0.096

Figure IV - 41 Employee Cost Per Ton-Mile Available Service
(Certificated Air Carriers)



Year	Number x 10^6
1949	39 680
1950	35 449
1951	35 467
1952	32 343
1953	29 001
1954	25 409
1955	24 126
1956	23 254
1957	22 599
1958	21 159
1959	20 211
1960	18 107
1961	16 289
1962	14 198
1963	13 993
1964	11 894
1965	10 869
1966	10 564
1967	8 891
1968	8,057
1969	7 277
1970	6 878
1971	6 285
1972	6 298
1973	6 168
1974	6 369
1975	6 018
1976	5 941

Figure IV-42 Number of Employees per Million Ton-Mile Available Capacity, U.S. Certified Air Carriers



Year	Labor Costs per Employees per Year Current	1972
1949		
1950		
1951		
1952		
1953		
1954		
1955		
1956		
1957	5607.303	8333.661
1958	5969.032	8639.389
1959	6316.914	9063.742
1960	6867.569	9698.935
1961	7192.687	10058.946
1962	7494.286	10368.034
1963	7790.055	10650.314
1964	8076.320	10910.127
1965	8273.200	10968.835
1966	8300.443	10703.203
1967	9487.930	11889.636
1968	10306.769	12399.121
1969	10247.350	11698.416
1970	13272.071	14303.234
1971	14303.030	14769.044
1972	15280.496	15280.496
1973	16542.704	15589.115
1974	18103.946	15381.548
1975	20310.182	15805.292
1976	21071.745	16088.614

Figure IV-43 U.S. Commercial Airline's Labor Costs,$ per Employee per Year.

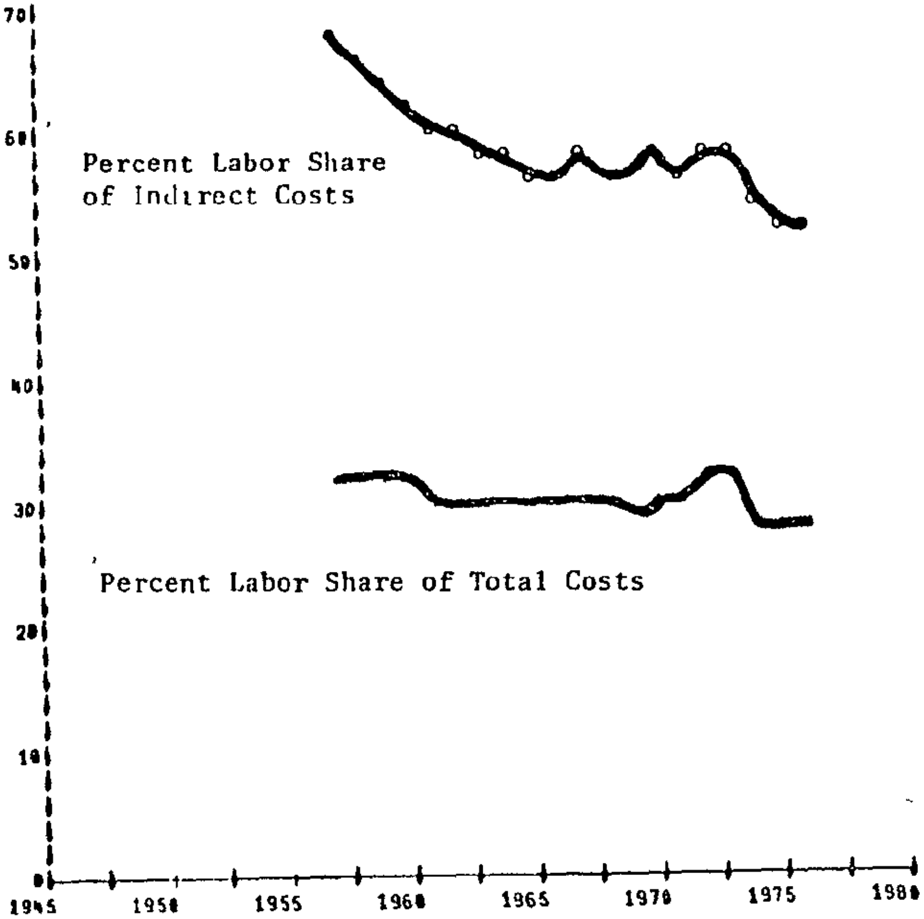
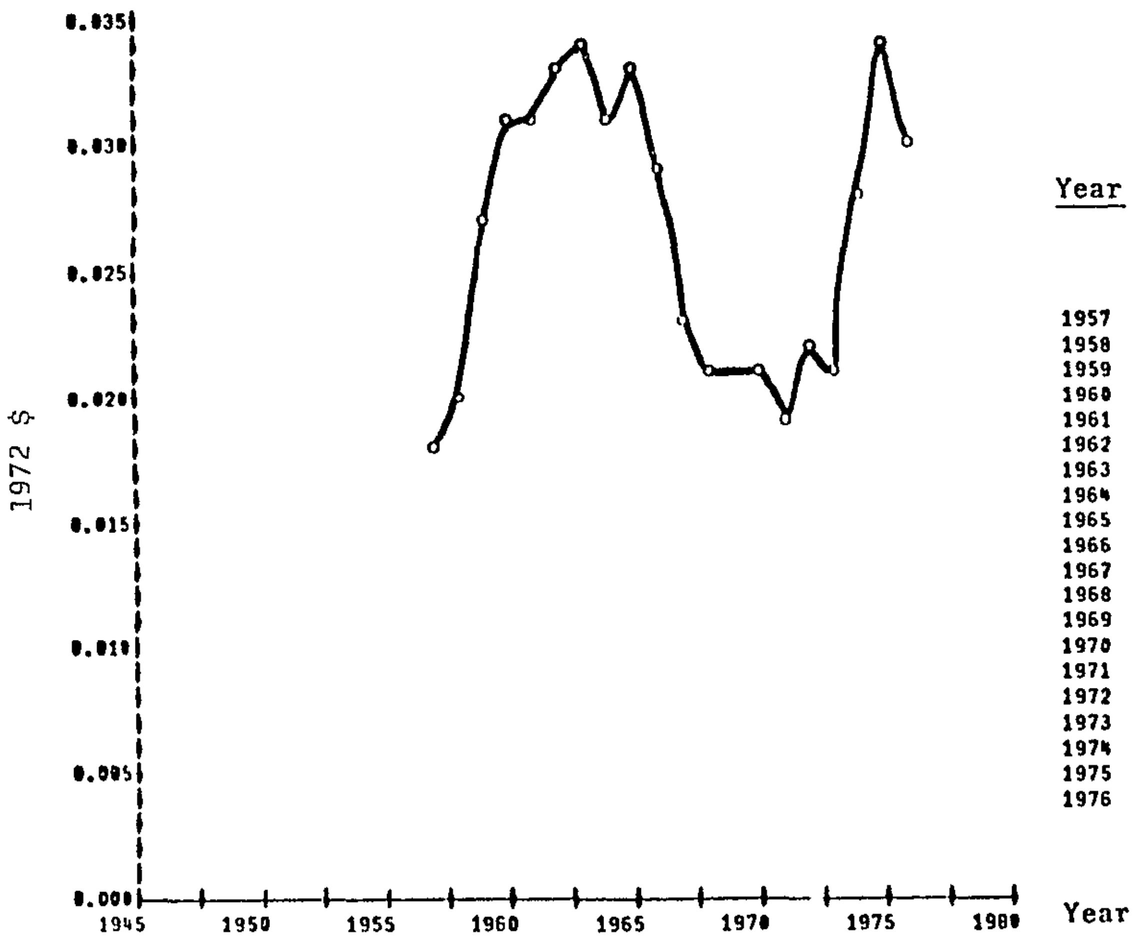


Figure IV-44 Non-Crew Labor Share of Cost.

Year	Percent Labor Share of Indirect Costs	Percent Labor Share of Total Costs
1957	67.144	31.417
1958	66.363	32.074
1959	64.097	31.458
1960	62.692	31.044
1961	60.870	29.906
1962	59.466	29.809
1963	58.173	29.796
1964	58.745	30.349
1965	56.209	29.684
1966	55.304	29.160
1967	57.250	29.766
1968	56.967	29.821
1969	48.506	25.406
1970	57.855	30.963
1971	56.984	30.421
1972	57.091	31.458
1973	57.170	31.596
1974	54.236	28.857
1975	51.440	27.850
1976	52.829	28.172



Year	1972 $ per Ton-Mile
1957	0.018
1958	0.020
1959	0.027
1960	0.031
1961	0.031
1962	0.033
1963	0.034
1964	0.031
1965	0.033
1966	0.029
1967	0.023
1968	0.021
1969	0.031
1970	0.021
1971	0.019
1972	0.022
1973	0.021
1974	0.028
1975	0.034
1976	0.030

Figure IV - 45 Non-Labor Indirect Costs Per Ton-Mile Available Service (Certificated Air Carriers)

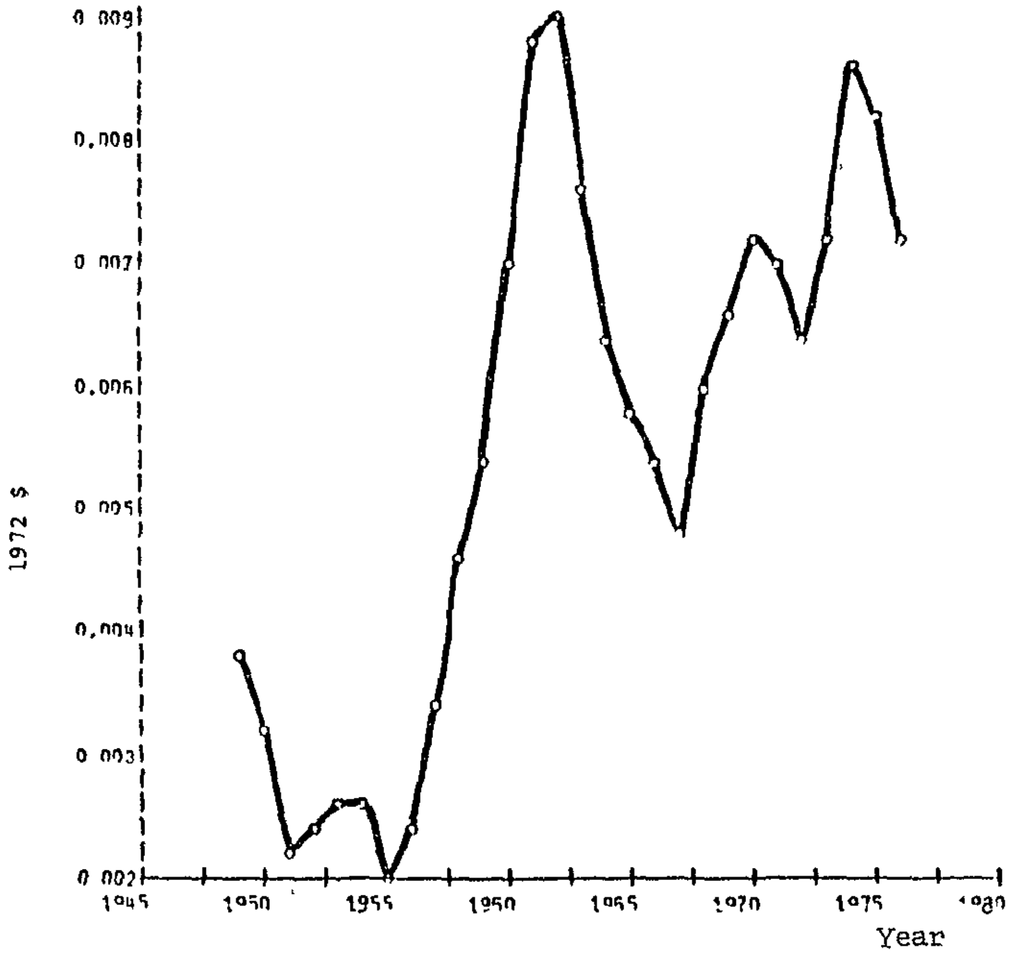


Figure IV-47 Interest Expense Per Ton-Mile Available Capacity.

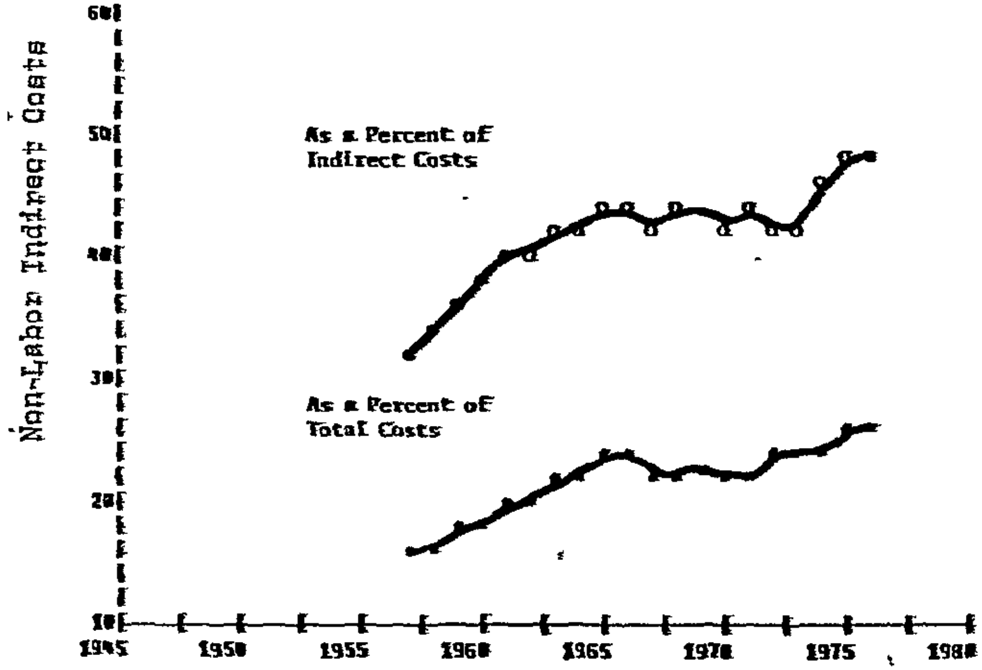


Figure IV — 46: Non-Labor Indirect Costs.

Year	Non-Labor Indirect As a Percent of Indirect Costs	Non-Labor Indirect As a Percent of Total Costs
1957	32.856	15.371
1958	33.637	16.257
1959	35.903	17.621
1960	37.388	18.475
1961	39.130	19.225
1962	40.534	20.319
1963	41.827	21.423
1964	41.255	21.313
1965	43.791	23.126
1966	44.696	23.567
1967	42.750	22.227
1968	43.033	22.527
1969	51.494	26.971
1970	42.145	22.556
1971	43.016	22.964
1972	42.909	23.643
1973	42.830	23.671
1974	45.764	24.349
1975	48.560	25.290
1976	47.171	25.155

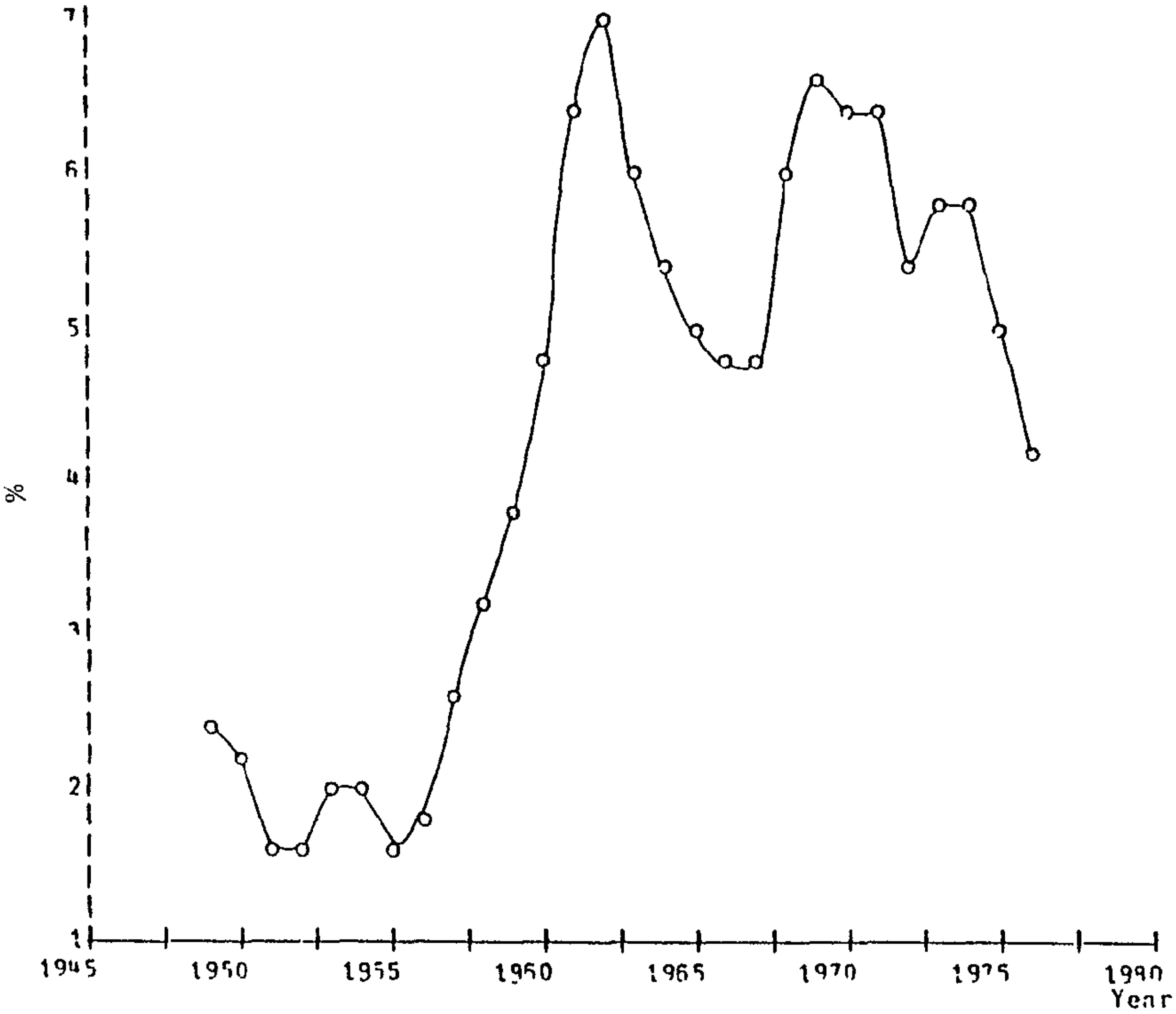


Figure IV - 48 Interest Expense as a Percentage of Indirect Costs.

Year	Percent
1949	2.377
1950	2.265
1951	1.582
1952	1.593
1953	1.917
1954	2.035
1955	1.600
1956	1.849
1957	2.515
1958	3.265
1959	3.730
1960	4.826
1961	6.382
1962	6.928
1963	6.059
1964	5.389
1965	4.992
1966	4.884
1967	4.749
1968	5.933
1969	6.533
1970	6.482
1971	6.450
1972	5.341
1973	5.735
1974	5.775
1975	4.935
1976	4.193

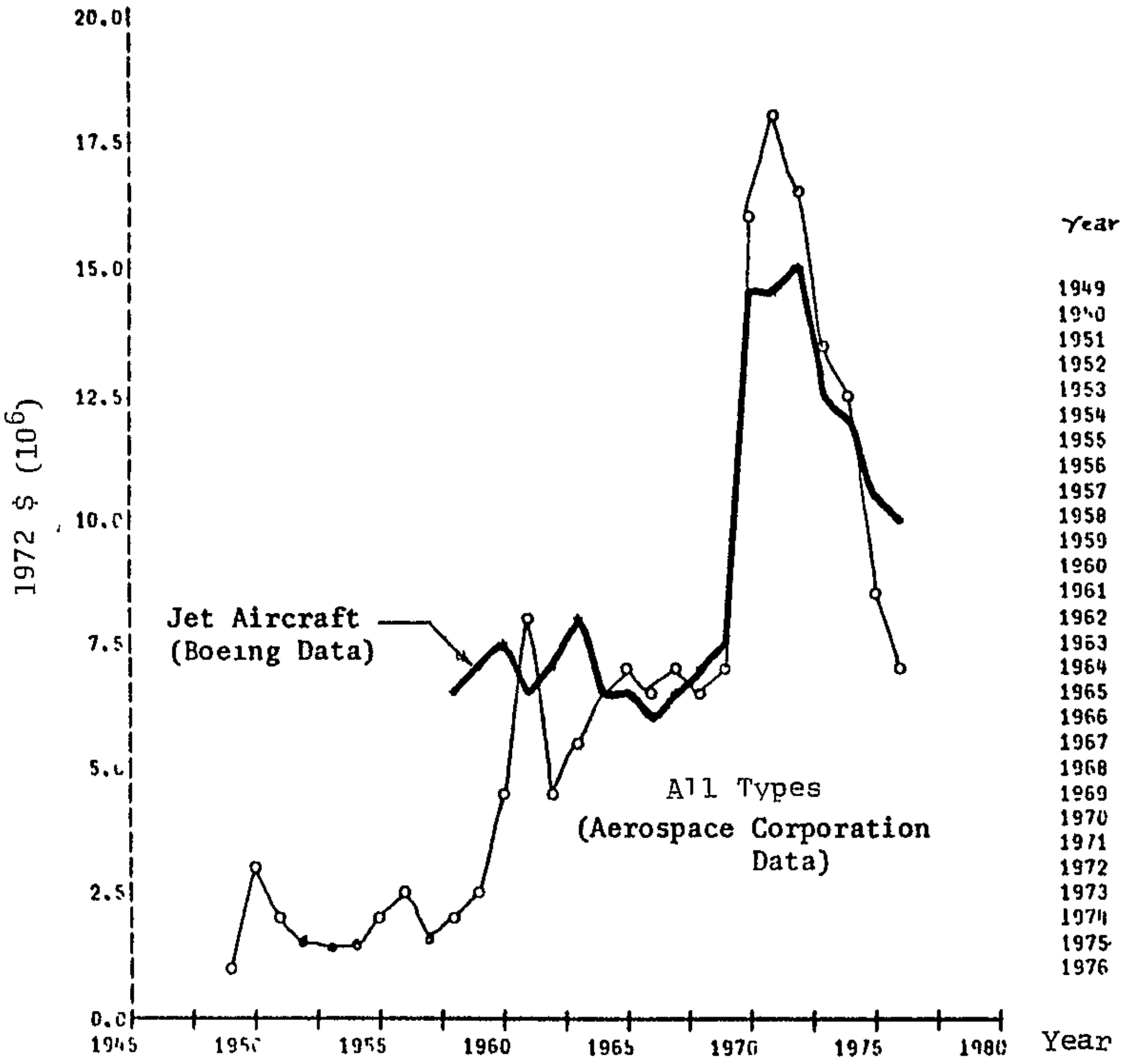
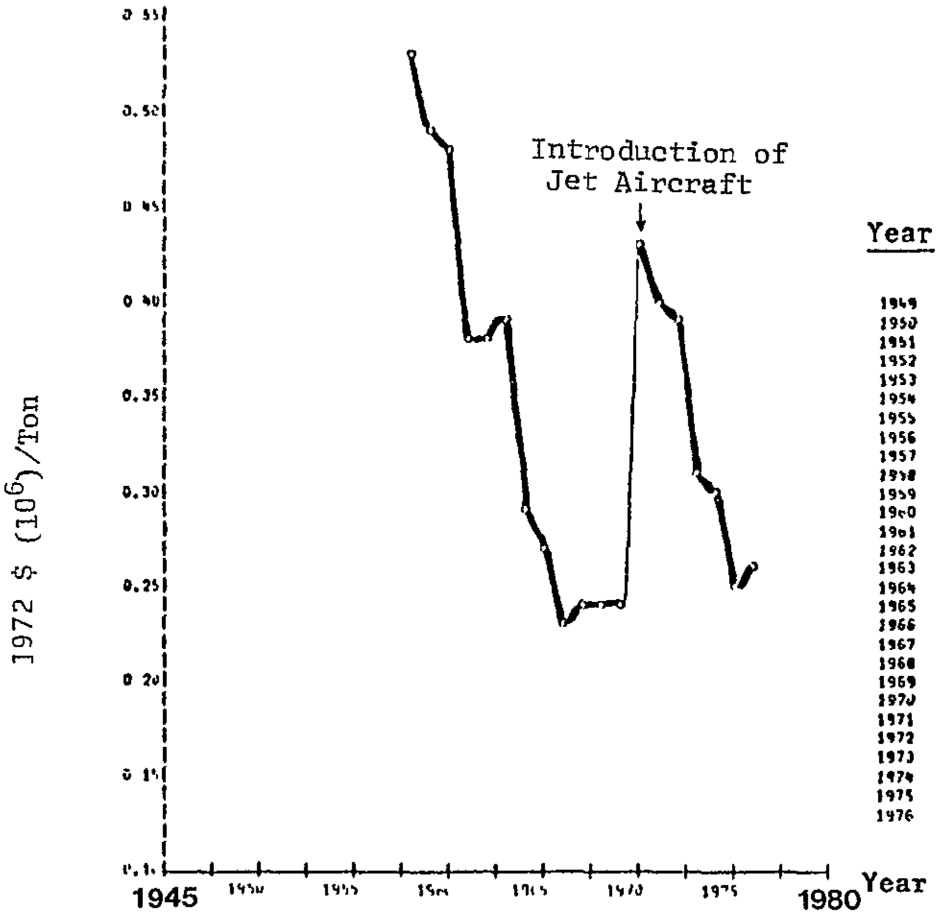


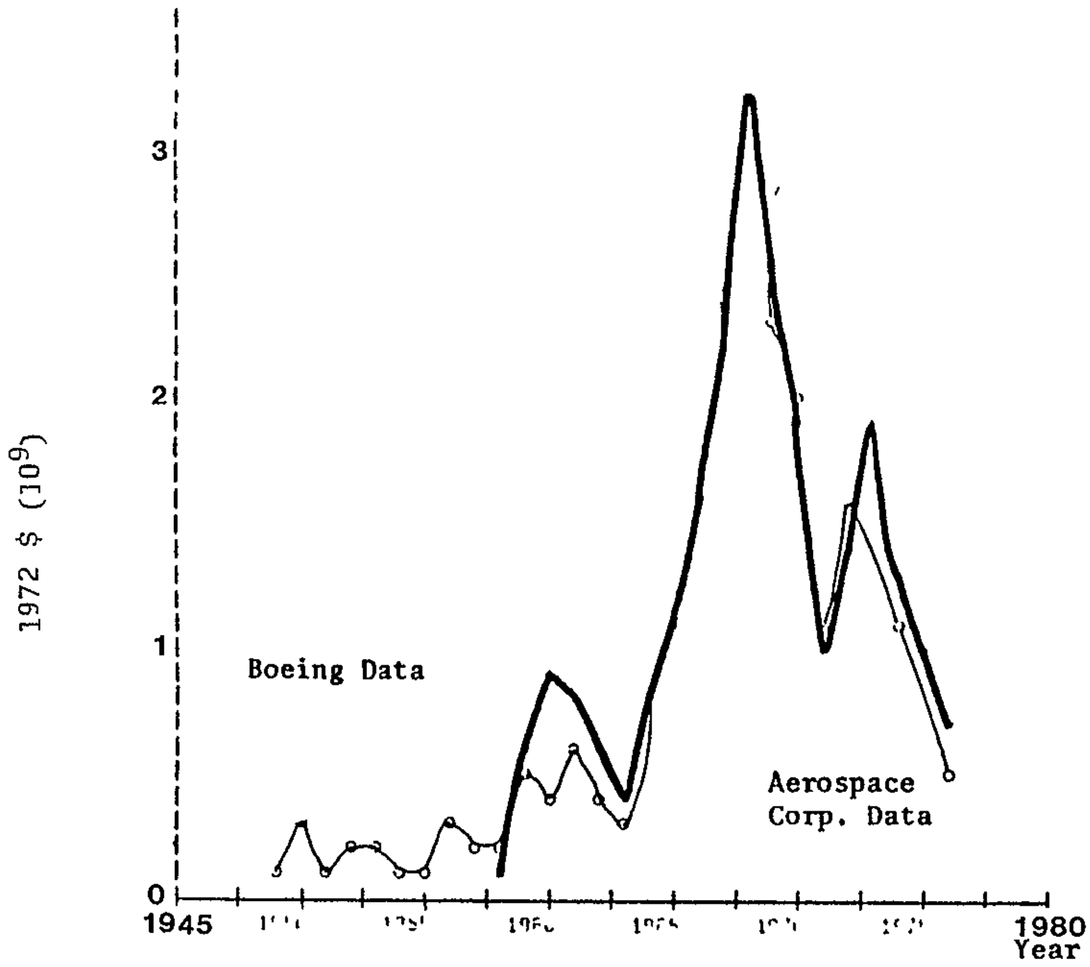
Figure IV - 49 Average Price of New Transport Aircraft (US)

Year	Price, 1972 \$ (10^6 All Types	 Jets
1949	0.8	1.8
1950	2.9	1.7
1951	1.8	1.6
1952	1.3	1.6
1953	1.6	1.6
1954	1.5	1.6
1955	2.1	1.6
1956	2.6	1.5
1957	1.4	1.5
1958	1.8	6.5
1959	2.6	6.8
1960	4.7	7.4
1961	8.1	6.4
1962	4.4	6.9
1963	5.5	7.8
1964	6.4	6.4
1965	7.2	6.4
1966	6.3	5.8
1967	7.0	6.4
1968	6.7	6.9
1969	6.9	7.3
1970	15.9	14.4
1971	18.0	14.4
1972	16.5	15.1
1973	13.7	12.6
1974	12.6	12.2
1975	8.3	10.4
1976	7.0	10.2



Year	1972 $ (10^6) Ton
1949	0.260
1950	0.241
1951	0 213
1952	0 197
1953	0.187
1954	0.176
1955	0.169
1956	0 158
1957	0.130
1958	0.527
1959	0.489
1960	0.481
1961	0 378
1962	0 378
1963	0.390
1964	0.289
1965	0.271
1966	0.234
1967	0.242
1968	0.242
1969	0.238
1970	0.433
1971	0.400
1972	0 393
1973	0.311
1974	0.299
1975	0 254
1976	0 262

Figure IV - 50 Price of New Transport Jet Aircraft (US) Capacity of New Aircraft, Ton



·Figure IV - 51 US Airline Industry Investment in Flying Equipment

Year	Reported By	
	Aerospace	Boeing
1949	95.7	0.0
1950	291.8	0.0
1951	109.7	0.0
1952	213.3	0.0
1953	197.3	0.0
1954	117.5	0.0
1955	103.1	0.0
1956	305.4	0.0
1957	170.8	0.0
1958	167.0	52.1
1959	514.7	589.7
1960	370.6	852.0
1961	646.8	795.7
1962	351.5	501.7
1963	314.9	458.2
1964	807.8	805.1
1965	1119.0	1103.4
1966	1647.2	1642.8
1967	2422.3	2177.9
1968	3114.6	3209.6
1969	2282.1	2545.9
1970	2[illegible].7	1963.2
1971	1059.4	1006.8
1972	1556.0	1417.0
1973	1911.1	1916.8
1974	1132.5	1266.8
1975	1049.8	1034.2
1976	512.6	704.7

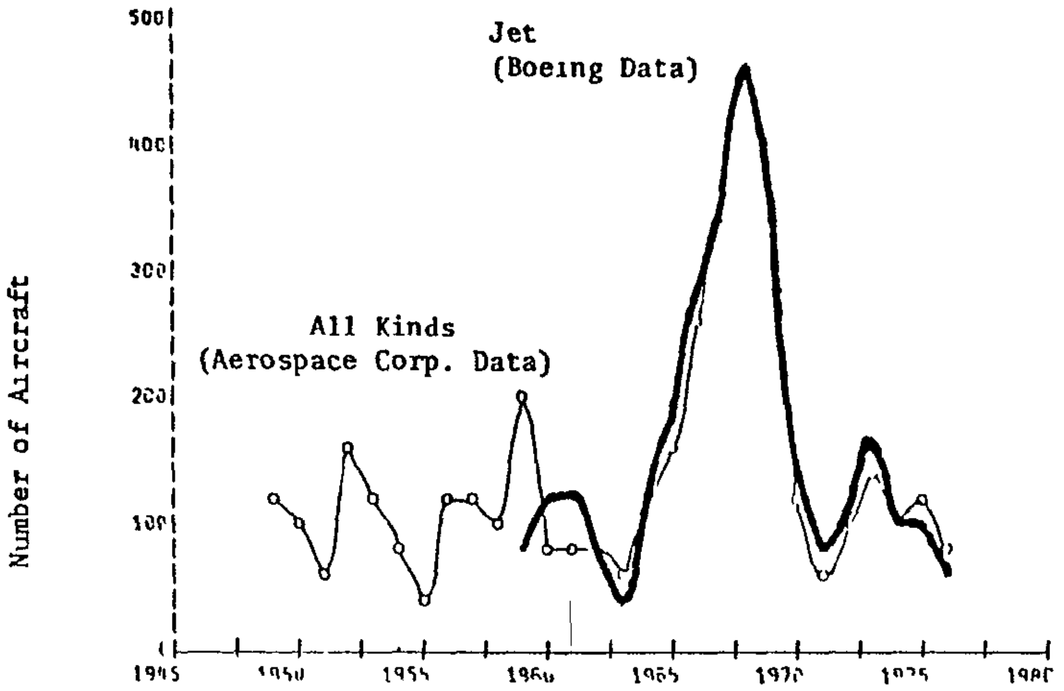


Figure IV - 52 Number of Transport Aircraft Delivered to US Airlines

Number of Transport Aircraft

Year	All Kinds	Jet
1949	115	
1950	102	
1951	61	
1952	169	
1953	126	
1954	81	
1955	48	
1956	118	
1957	118	
1958	91	8
1959	197	87
1960	79	115
1961	80	124
1962	82	81
1963	57	46
1964	126	125
1965	156	172
1966	260	281
1967	345	341
1968	463	467
1969	333	347
1970	127	132
1971	59	70
1972	94	94
1973	140	152
1974	92	104
1975	127	99
1976	76	69

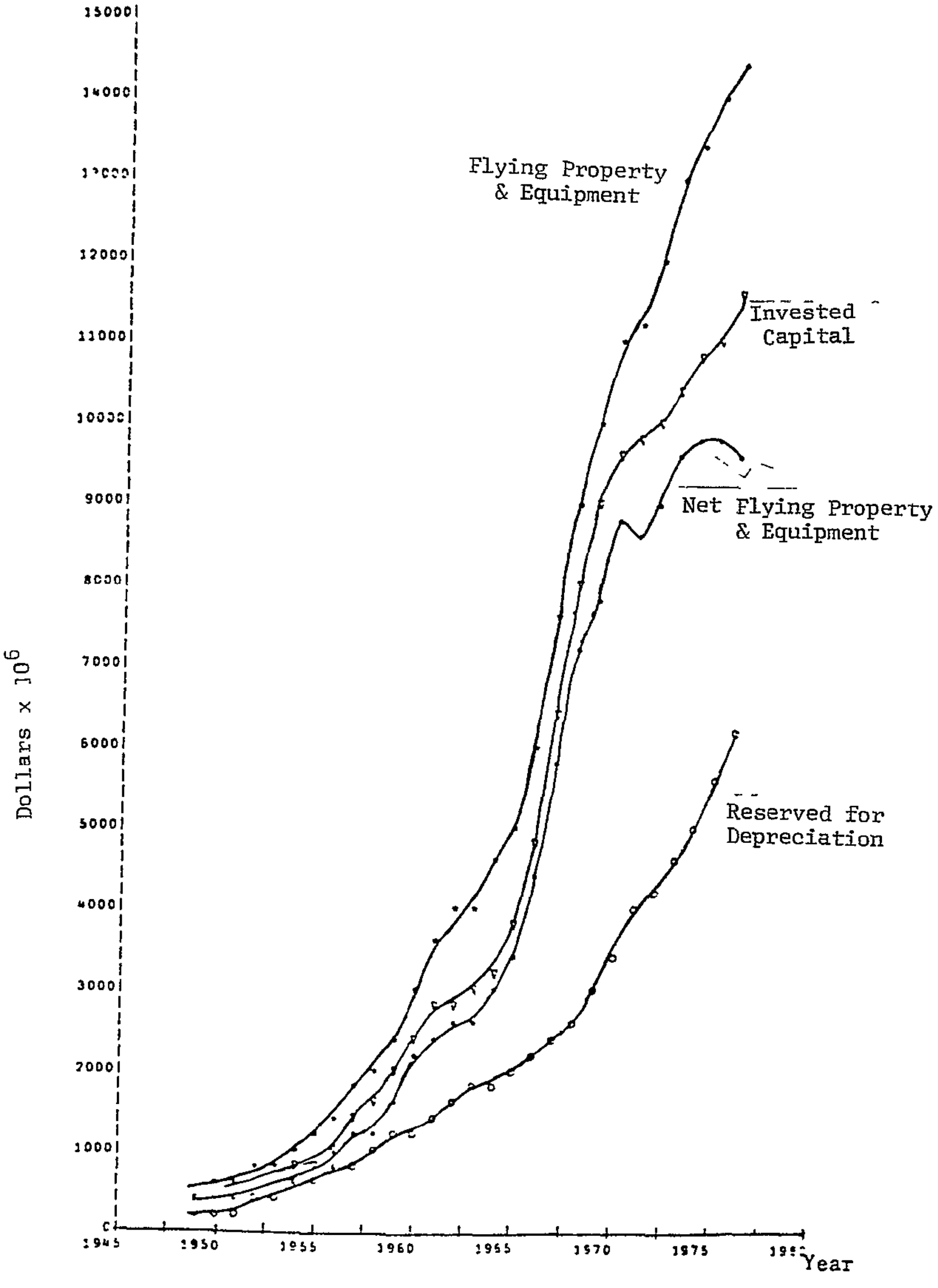


Figure IV - 53 Equipment and Investment (Certificated Air Carriers)

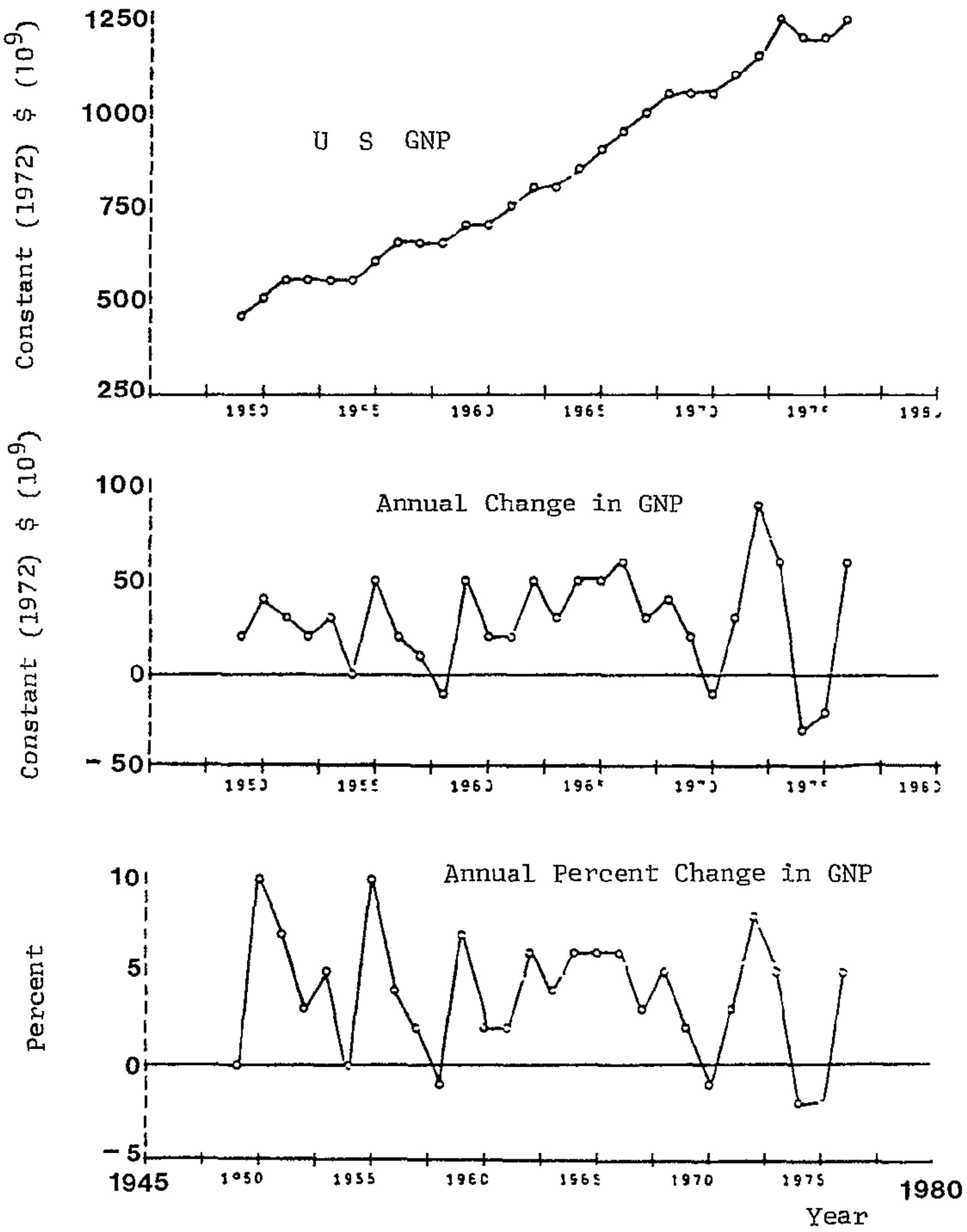
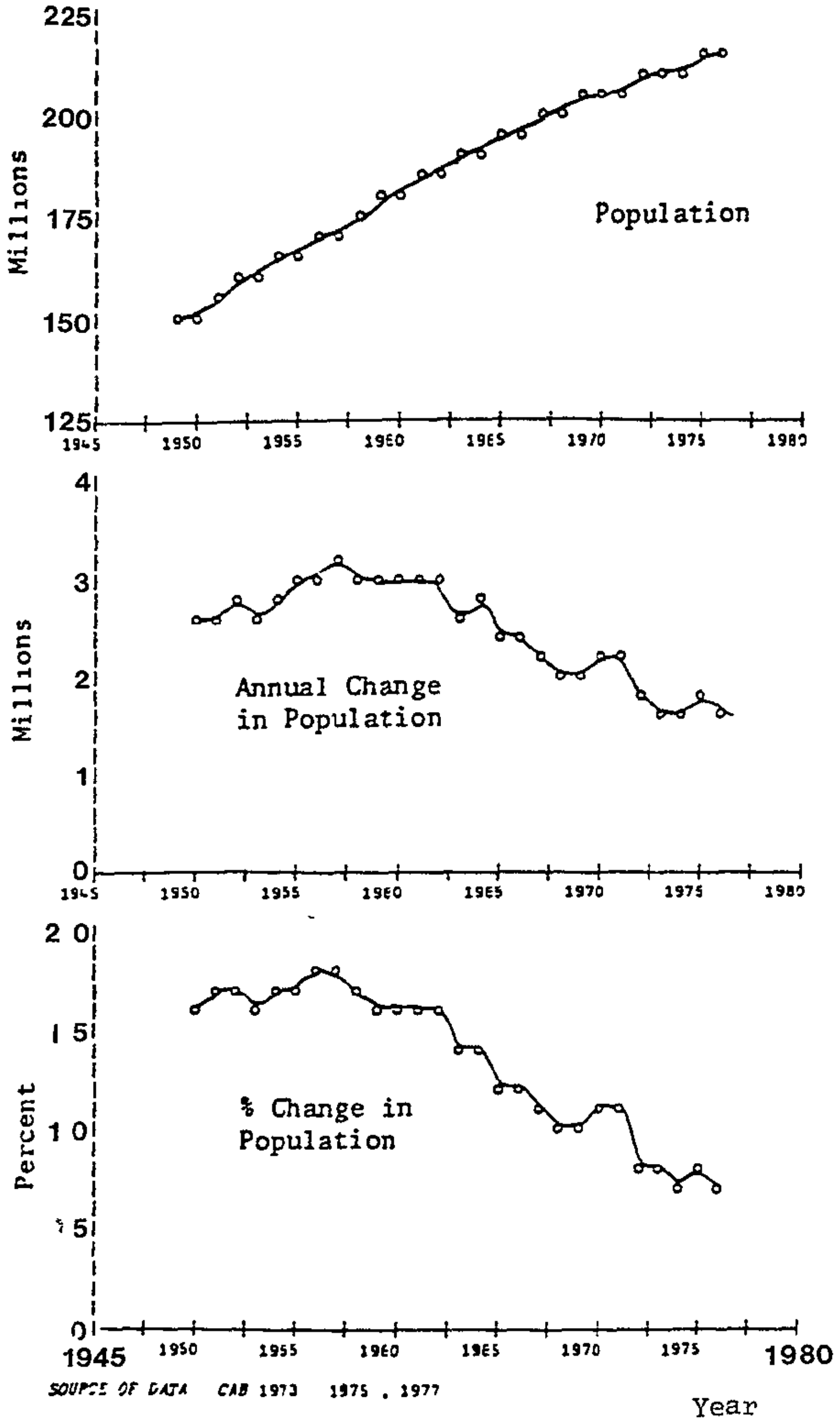


Figure IV - 54 U S Gross National Product (GNP) and Its Rate of Change



SOURCE OF DATA CAB 1973 1975 , 1977

Figure IV - 55 U. S. Population and Its Rate of Change

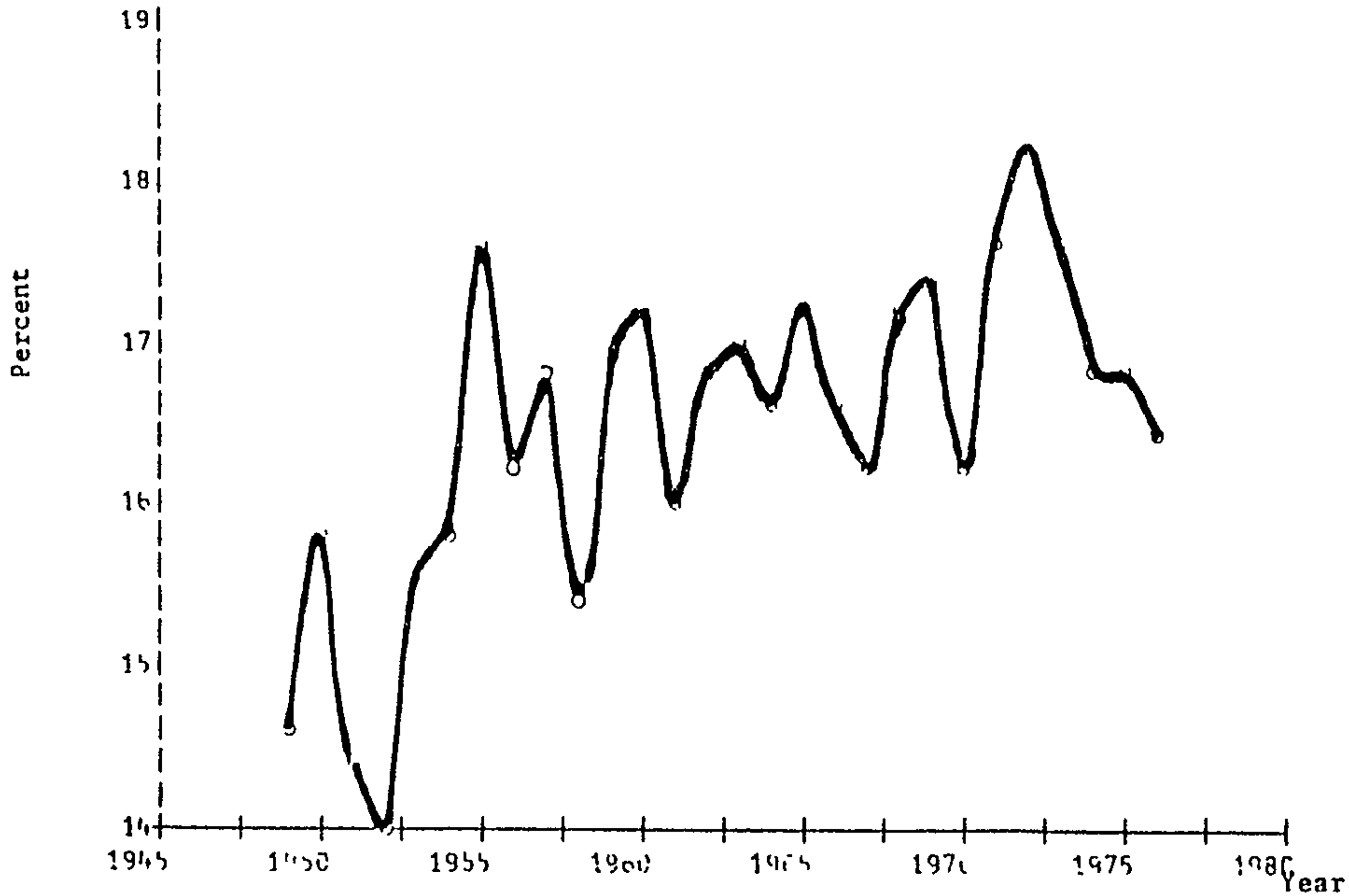


Figure IV - 56 Percentage of Personal Consumption Expenditure Spent on Transportation

Year	Percent
1949	14.621
1950	15.845
1951	14.370
1952	14.046
1953	15.635
1954	15.707
1955	17.578
1956	16.250
1957	16.869
1958	15.472
1959	16.932
1960	17.185
1961	15.941
1962	16.744
1963	17.067
1964	16.507
1965	17.254
1966	16.602
1967	16.212
1968	17.214
1969	17.462
1970	16.169
1971	17.593
1972	18.228
1973	17.642
1974	16.846
1975	16.788
1976	16.356

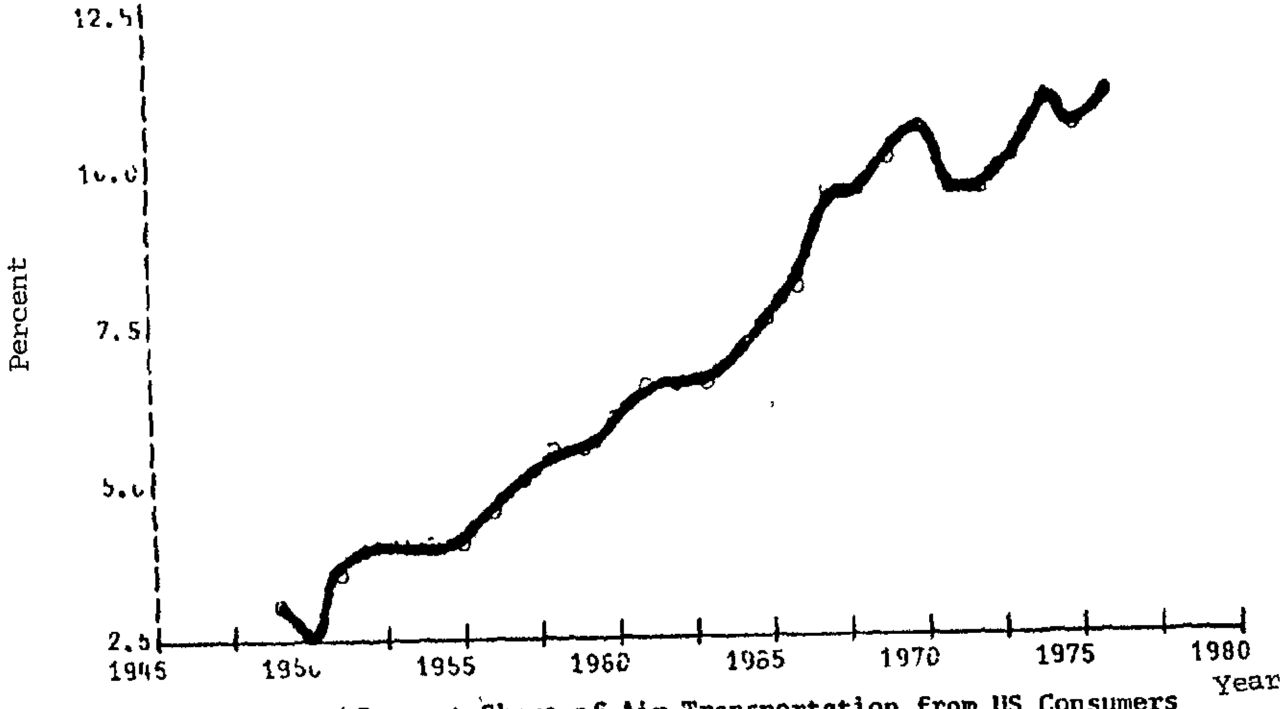


Figure IV - 57: Percent Share of Air Transportation from US Consumers Spending on Transportation

Year	Percent
1949	2.859
1950	2.672
1951	3.491
1952	4.063
1953	3.813
1954	4.199
1955	4.110
1956	4.721
1957	4.823
1958	5.443
1959	5.567
1960	5.874
1961	6.357
1962	6.392
1963	6.610
1964	7.122
1965	7.337
1966	8.082
1967	9.385
1968	9.422
1969	9.959
1970	10.559
1971	9.708
1972	9.699
1973	9.846
1974	10.914
1975	10.382
1976	11.239

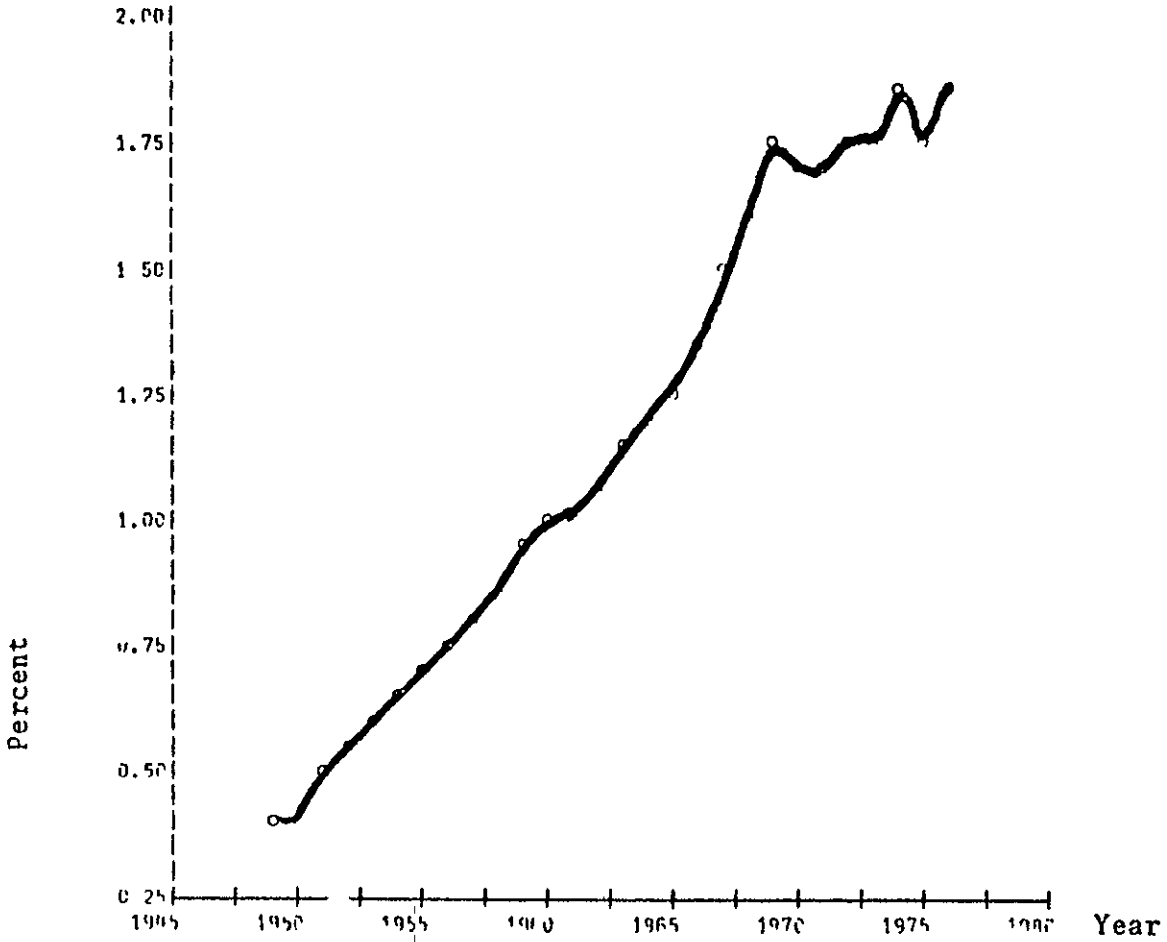


Figure IV - 58 Percentage of Personal Consumption Expenditure Spent on Air Transportation

CHAPTER V

SCENARIOS ON SOCIO-ECONOMIC FACTORS OF THE MODEL

With the modeling approach introduced in Chapter II, prediction of the future of a phenomenon requires numbers expressing the future behavior of the exogenous variables of the model. These numbers may come from another model or the result of a scenario. In the latter case, the numbers are explicit statements of the often vague inferences from a cloudy picture of the future visualized by a futurist stated in a narrative scenarios. In other words, a scenario becomes a bridge between complete fuzziness and complexity of the surrounding environment and the explicity of the asserted relationship in the model.

SCENARIOS

In Chapter II of this report, the scenario approach and its purpose are discussed in general. With that framework, in this Chapter, examples of scenarios on the future of surrounding social and economical systems (see Figure I-1) will be introduced and plausible numbers on the future of the exogeneous variables of the model, inferred from these scenarios, will be generated. The narrative portions of the scenarios presented here is a summary of five scenarios developed, for UCLA-NASA project on "Future Aviation Fuels". (See English, 1978). These scenarios encompass the spectrum of some level of pessimism.

1. "Limits to Growth" scenario, pessimistic scenario popularized by books such as, "The Limits To Growth" by Donella Meadows, 1972; "World Dynamics" by J. W. Forrester, 1973, and "Models of Doom" by H. S. D. Cole, et al., 1973).

The fundamental assumption of this scenario is that the resources on the earth are finite and their recyclability has practical limitations. By its underlying Malthusian theory, the scenario assumes that population is growing faster than food production and the supply of other needs. Economic growth produces pollution; it exhausts the materials on earth; and man's ability, interest and faith to overcome the rate of material exhaustion is declining. In this scenario it is assumed that GNP sooner or later has to stop growing and eventually will decline. Efforts towards population control will not succeed.

2. "Societal Constraints Growth" scenario is based on the assumption of inefficiency and wastes associated with market imperfections as well as in institutional inadequacy. It

C-2

relies on the analysts' and planners' comprehension and the control exercised by the governments. This scenario infers a need for caution in the direction of growth. Growth, from this perspective, is not necessarily progress. We achieve something while losing some other things. Resources are capable of supporting the economy only if institutional regulations are imposed to control consumption.

3. "Interrupted Growth" scenario is based on the assumption that interruption in energy supply will be reflected in a corresponding interruption in economic growth but that society will eventually overcome the difficulties and growth will resume.

4. "Uninterrupted Growth" scenario assumes that things are going to continue more or less the way they have been in the past 200 years. Energy problems will be temporarily solved by coal and shale oil production. Within a decade or two, breeder reactors will be built. Many conservation measures will be implemented. We will be able to overcome resource scarcity. Our increasing efficiency (through advancements of technology) will always catch up with the increasing degree of dilution of resources. However, while this is optimistic, growth will be modest and steady.

5. "Technology and Growth Enthusiastic" scenario is the most optimistic one in the realm of feasibility. Its basis is that our learning capacity is always increasing. Computers and artificial intelligence devices will enhance this capacity exponentially. We will be able to use energy and materials with increasing efficiency and conservation. As has been the case throughout man's history, the growth in the efficiency of man's effort and the rate of expansion of his power will always exceed the rate of dilution of material and energy resources.

Perhaps, at a time of continuing energy crisis, the most plausible scenarios are the middle ones, namely, the "Societal Constraints", the "Interrupted Growth" and the "Uninterrupted Growth" scenarios. Since most shorter term economic projects are usually based on continuity of things growing pretty much as they have been in the past, or "business as usual", the uninterrupted growth scenario will be taken as a baseline case. More details on the assumptions underlying the scenarios are to be found in English, 1978.

INTERRUPTED GROWTH SCENARIO

Until recently, people of the industrial world never perceived the fallacy of unlimited energy resources. But, progressively, the pinch gets harder as the gap between supply and demand increases. Of course, supply and demand will be equilibrated somehow by price adjustment, rationing, or simply by failure to develop full economic potentials. Therefore, instead of steady growth or steady decline, there will be a period of depression. However, this depression will be followed by a resurgence of growth as new energy sources are developed and put into production. As it will be shown, there is a well-established historical correlation between energy consumption and GNP. While there are those who contend that this is not a causative relation (Stobaugh & Yergen, 1979), there is supporting evidence that indeed it may be so. If energy does underpin GNP, then it is clear, as the world shifts its energy dependence from petroleum to coal, nuclear and other sources, that an inability to provide a continuing smooth energy supply will indeed cause a disruption of world economies. This scenario is predicated on dependence of GNP on energy and so the possibility for such an energy development-lag must be considered.*

The U.S., which accounts for over 30% of world petroleum consumption (Bureau of Mines, 1976), may be the key economy in determining the shape of the world energy future. If the U.S. does not move quickly enough to convert from a major dependence on oil to some other energy source, a disruption of the world economy may occur regardless of what other countries do. For this reason, the interrupted growth or energy-constraint scenario is developed largely in terms of events within the U.S.

It would take 10 to 15 years or even longer from the initiation of a serious program to develop new energy sources before the rate of production of new energy is sufficient to affect declining petroleum production. This may occur even if a serious conservation effort is made. The curve in Figure V-1 shows total energy supply and its components under the following postulations:

1. Coal: 2% annual growth to 1984, 4% to 1990, 10% to 2000, and 4% to 2025 as demand may again be in balance with supply.
2. Domestic Oil and Gas: 2.2% annual decline to 1978, 10% decline to 1995, and constant production to 2025.
3. Hydro & Geothermal: 3% annual growth to 2025 (a small and non-determinant component).

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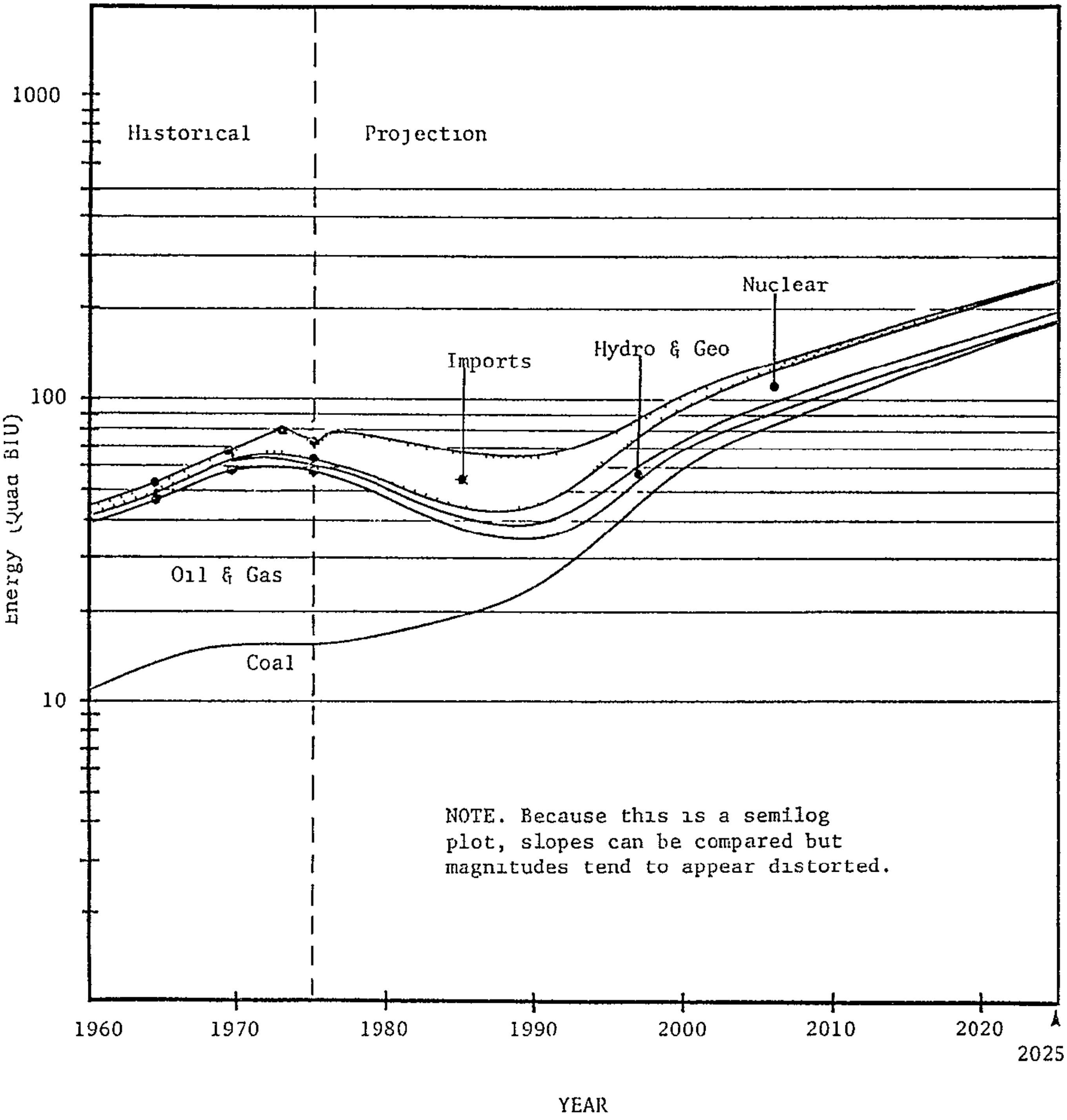
*The WAES workshop (Wilson, 1977) recognizes the same problem of a gap, but their scenarios are not conceived in such a way as to explain how the gap will be filled. They clearly recognize that either the supply side must adjust upward or the projected GNP growth will fail to materialize as envisioned.



NOTE. Because this is a semilog plot, slopes can be compared but magnitudes tend to appear distorted.

Figure V - 1 U S Energy Supply -- Historical and Projected to 2025

Source Historical Data
Bureau of Mines 1976

4. Nuclear:* 8% annual growth to 1984, 10% to 2000, 6% to 2010, and 4% to 2025 as the demands may by then be in balance with supply.
5. Imports:* 10% annual growth to 1982, 0% to 1990, and 10% decline to 2025.

Economic Growth and Energy Consumption

The economy, as measured by GNP, has been closely coupled with energy use. There has been, however, a decline of energy use per unit of GNP. This relationship is expressed as energy intensity--BTU's per dollar of GNP. Since 1920, the energy intensity of the U.S. economy has been declining on the average at the rate of about one-half percent per year. It is conceivable that this long-term trend might accelerate under conditions of a constrained energy supply. Emphasis on conservation, improved automobile efficiency, more efficient heating and cooling, might lead to an expectation that considerable savings of energy are possible. However, the potential savings may be illusory, because two things serve to reduce hoped-for savings. Firstly, government policies for encouragement of energy conservation might continue to go largely unheeded. Secondly, many programs aimed at conserving energy over the long run, might even in the short run, impose additional energy demands. Switching to smaller automobiles, increasing insulation in homes, building of solar systems, and the like, will all require energy investments. For these reasons, it is logical to assume that the long term trend of declining energy intensity will continue in the future much as it has in the past--about 1.2% a year (Figure V-2). At the same time, a net energy savings during the depression period might induce an acceleration of the improvement in energy intensity of the economy. Therefore, in Figure V-2, a 1% per year rate of decline of energy intensity during the depression years is assumed. (It has been -1.6% since 1975.) Even with this somewhat optimistic early gain from conservation, a 30% shortfall in energy, relative to requirements by the end of 1990, will occur (see Figure V-3 and Table V-1). Thus, with the assumed causative relationship between

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*These were the assumptions made in 1977-78. Due to recent perturbation in the world oil supply and nuclear safety (Three-Mile Island) the percentage should be revised as:

Nuclear: 0% to 1990, 15% to 2000, 10% to 2010, 4% to 2025.
Imports: 3% to 1982.

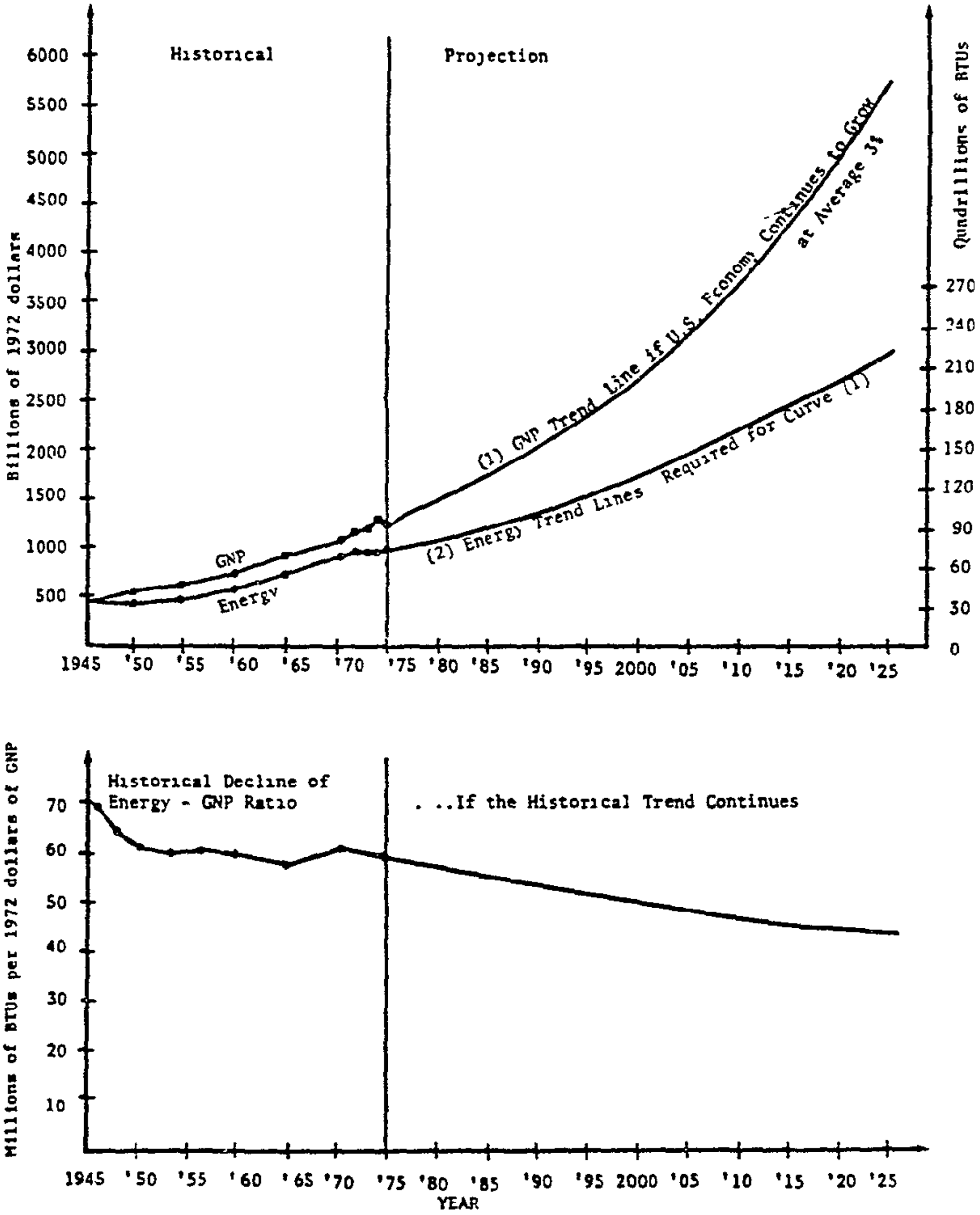


Figure V - 2 Energy and Gross National Product (GNP) Trend Lines

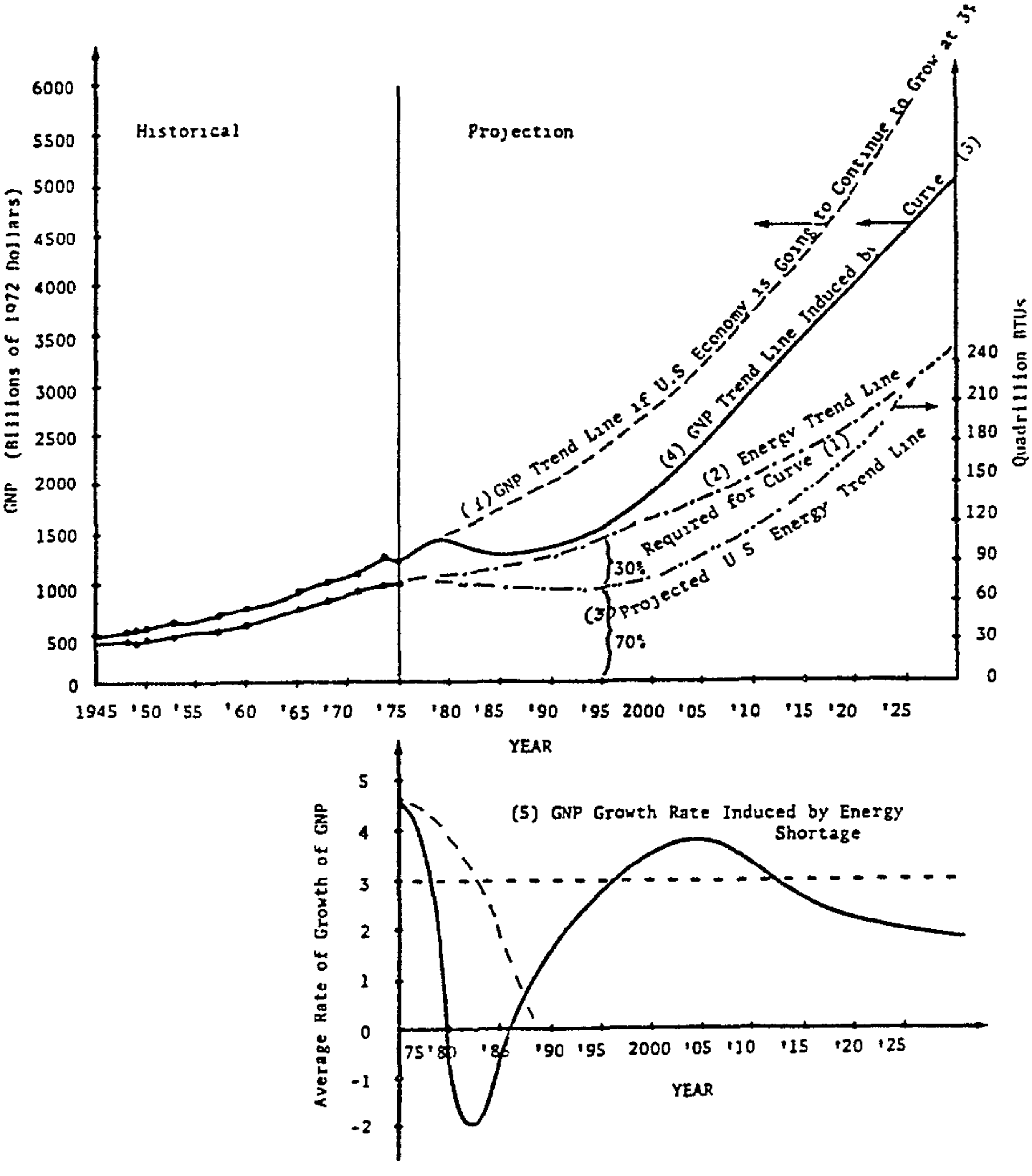


Figure V - 3 Energy and GNP Trend Lines for Interrupted Growth Scenario

Year	If the long-run historical trend continues		If the Energy Shortage curtails growth	
	Energy - Available (Quad BTU)	GNP 1972$	Energy Available (Quad BTU)	GNP 1972$
1977	75.6	1333.0	76.6	1333.0
1978	78.0	1385.0	78.0	1365.0
1979	80.1	1424.0	81.8	1414.1
1980	81.9	1458.5	82.2	1428.3
1981	83.8	1503.0	82.4	1442.6
1982	85.7	1548.7	82.7	1457.1
1983	87.6	1595.9	82.9	1471.8
1984	89.6	1544.5	83.0	1485.9
1985	91.7	1694.5	83.1	1501.5
1986	93.7	1745.2	83.2	1515.5
1987	95.9	1799.4	83.2	1531.8
1988	98.1	1854.2	83.2	1547.2
1989	100.3	1910.5	83.3	1552.8
1990	102.6	1958.8	84.6	1600.0
1991	104.9	2028.8	85.7	1632.0
1992	107.3	2090.6	87.1	1670.0
1993	109.7	2154.2	88.0	1700.0
1994	112.2	2219.8	91.1	1759.4
1995	114.8	2287.4	94.3	1841.5
1996	117.4	2357.1	97.6	1915.7
1997	120.1	2428.9	101.1	1995.0
1998	122.8	2502.9	104.7	2076.4
1999	125.6	2579.1	108.4	2161.1
2000	128.5	2657.6	112.2	2249.3
2001	131.4	2738.6	115.2	2341.1
2002	134.4	2822.0	120.4	2436.7
2003	137.4	2907.9	124.7	2536.1
2004	140.6	2996.5	125.5	2558.4
2005	143.7	3087.7	128.4	2538.7
2006	147.0	3181.8	131.3	2710.9
2007	150.4	3278.7	134.2	2785.1
2008	153.8	3378.5	137.2	2861.3
2009	157.3	3481.4	140.2	2939.7
2010	160.9	3587.4	143.4	3020.1
2011	164.5	3696.7	146.5	3102.8
2012	158.3	3809.2	149.8	3187.7
2013	172.1	3925.3	153.1	3274.9
2014	176.0	4044.8	156.5	3364.5
2015	180.0	4168.8	160.0	3456.6
2016	184.1	4294.9	163.6	3551.2
2017	188.3	4425.7	167.2	3648.4
2018	192.6	4568.5	170.9	3748.3
2019	197.0	4699.4	174.7	3850.8
2020	201.5	4842.5	178.6	3956.2

TABLE V-1 Future trends in U.S. Energy availability and GNP under two scenarios.

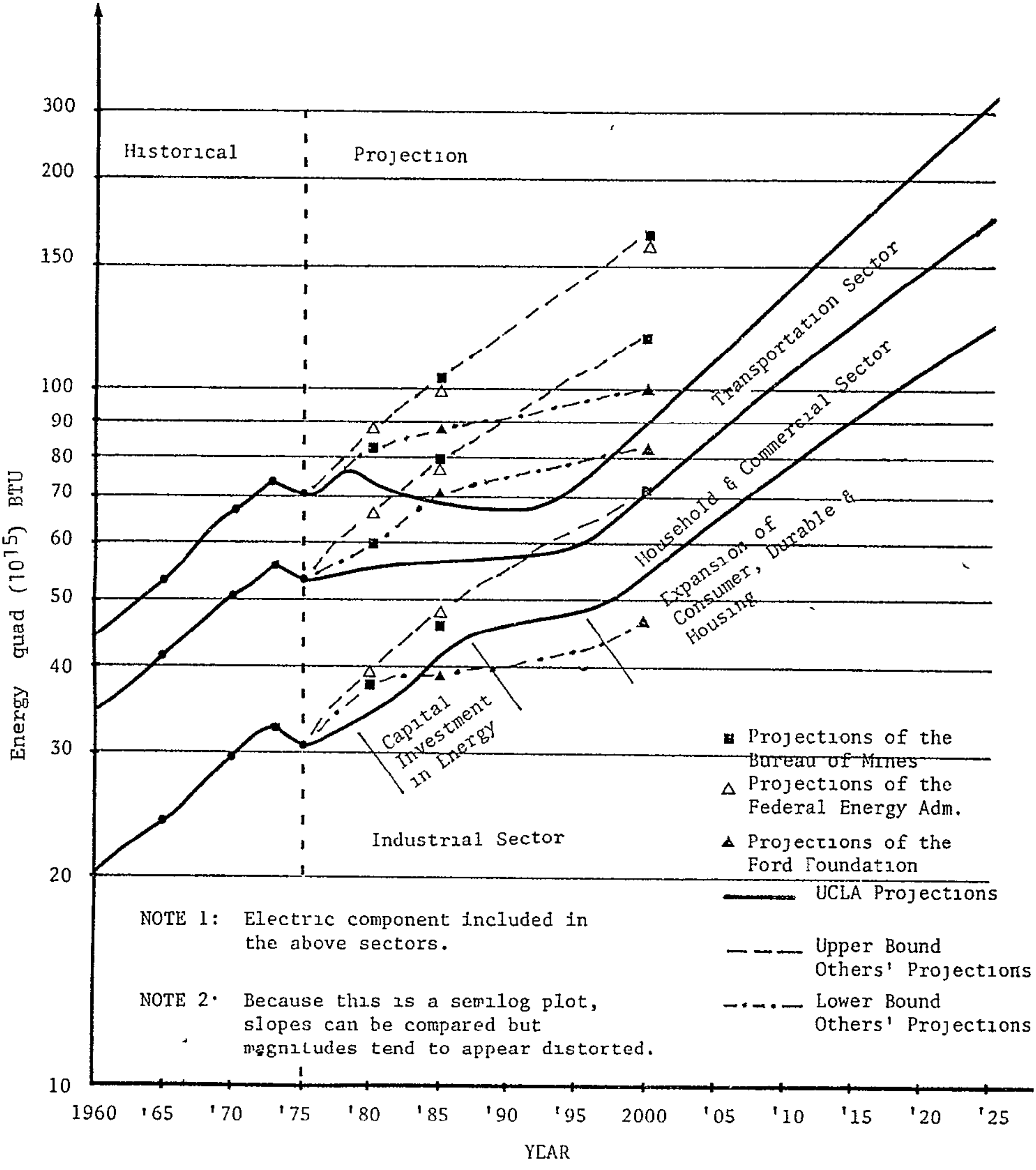
energy and GNP, such a disparity assumes catastrophic proportions. Clearly, technological advances would also slow so that a 30% gap would not reflect in a proportionate increase in unemployment. Nevertheless, this gap between potential output and capacity utilization could translate into unemployment in the order of 15% to 20% and a subsequent overall decline in living standards. Such a depression level is roughly the same as the depression period of the 1930's. On the more optimistic side of the scenario, expanding new energy supplies during the late 20th century will spark recovery of economy.

Technological change which accounts for productivity increases can be expected to develop normally at a rate of 2% to 3% in consonance with the uninterrupted growth scenario. With allowance for the declining trend of energy intensity, the normal expectation of energy demand would be 110 Quads by 1990. However, the availability of energy at the low point of supply is only 69 Quads. This means that at the nadir of the depression period, the economy will be operating at about 70% of its potential (Figure V-3) in terms of available energy. Under such depressed conditions, the rate of technological changes, as already noted, will also tend to be considerably retarded, so that the potential demand will be well below an energy economy that demand 110 Quads.

Energy Sharing

In context with the depression economy, an intense competition may arise from the "squeezed down" supply of energy. Those sectors more vital for survival will command higher priorities than the luxury-oriented sectors of the ecomomy. However, recall that the scenario requires eventual economic turn-around accompanied by a renewed rapid energy expansion in the 1990's. In order for this to happen, large scalar capital projects will have to be pushed ahead vigorously during the 1980's. Therefore, even during depressed conditions, heavy industrial expansion must be taking place. Thus, the industrial sector will be growing and, even with improved efficiencies, will be creating proportionately higher energy demands. If coal and nuclear energy are expanding at a rate of 10% per year by the 1990's, the capital goods industries will have had to expand at a comparable rate all through the 1980's. This could required 10% - 15% growth rates for the energy-related industrial sector.

On the other hand, strong government emphasis on energy conservation for space heating and automobile use is bound to have its effect, even it less than desired. A decline in demand of 5% per year for each of these uses, while quite ambitious, is plausible, as shown in Figure V-4.



NOTE 1: Electric component included in the above sectors.

NOTE 2: Because this is a semilog plot, slopes can be compared but magnitudes tend to appear distorted.

Figure **V-4**: U S Sectorial Gross Energy Input

Source Historical Data
Bureau of Mines, 1976

Transportation

Transportation of products used for personal consumption will most likely be constrained. Railroads, as an essential component of industrial development, will need to expand. They will also have to modernize to accomodate an expanding coal and steel demand. However, rail shipments of automobiles and other consumer goods may decline. Such effects will translate into major geographical shifts in freight movement.

The effects on trucking can be analyzed by considering separately, lightweight trucking and heavyweight trucking. Lightweight trucking, devoted mainly to transport finished goods for urban consumer market, should be constrained for the same reasons as for automobiles. Heavyweight trucking activities, on the other hand, might or might not decrease, depending on the availability of railroad services. Regardless, interstate heavyweight trucking may be expected to function under greatly improved operating procedures. For example, round-trip cargo hauling may be encouraged, whereas, regulations often require one-way cargo hauling today.

It seems likely that the automobile will be the most readily constrained mode of transport. As people feel less affluent, they will be more readily disposed to car-pool. Automobiles will be lighter and more efficient. Long vacation trips will be restricted and average mileage per car reduced. Furthermore, urban mass transit systems will be better utilized. Even with all of these, it is unlikely that the rate of decline will level off as the pressures of economic contraction diminish and, when growth resumes, a newly structured automobile transportation system will grow in keeping with the economy as a whole. The driving habits of the public will never again be the same as in the past. The automobile may tend to be used more for pleasure than for journey-to-work trips because the impetus of the depression decade may start a major growth of efficient public transportation.

UNINTERRUPTED GROWTH SCENARIO

In the uninterrupted growth scenario, it is assumed that the world economy will continue to grow as it has in the past. Although such a postulated growth may not be smooth, there will be no major interruption in the overall economic growth as was hypothesized in the interrupted growth scenario. As presented in the "Interrupted Growth Scenario," energy was assumed to be the key factor in determining GNP growth. In this scenario, however, energy is not considered to be the key factor in the determination of GNP growth even though it must be considered as one of the key factors supporting that growth. In order to maintain a steady growth in the world's economy, there must be, among other things, sufficient energy to support development programs which lead to economic growth. The case of the U.S. is discussed in the following section.

Economic Growth and Energy Consumption

Energy intensity of the U.S. economy, in terms of energy-/GNP ratio, was shown to be declining in the previous section. This is primarily due to technological advancement, through which the economy can produce more with less and less energy input. This trend, as shown in Figure V-5, is assumed to continue as pointed out earlier, but in addition, the economy will shift from an industrial society with its emphasis on consumption of physical goods to a post-industrial society with increasing demand for services. This historical trend will be achieved in the face of increasing energy intensities of certain sectors of the economy...notably in the extractive industries and transportation. At the same time, services, which have been growing steadily and can be expected to continue growing faster than the economy as a whole, are not energy intensive.

To meet this energy demand and maintain a healthy uninterrupted growth, domestic production strategies and energy demand management are necessary. For instance, if the U.S. continues to import at present rates, it is likely that its economy will soon be disrupted by huge oil dollar deficits.* Import quota systems may be necessary to control imports, while in other cases it may be necessary to impose conservation measures designed to moderately reduce consumption in the short run. The assumption in this scenario is that these measures will exist to prevent a decline in growth. At the same time, domestic production increases will be pressed. If oil exploratory activities continue at the same rate as in the past, or even intensify somewhat, it is improbable that any significant contribution to total energy will be seen. Therefore, coal, which the U.S. has in abundance, will supply this energy demand deficit needed to support the economy. Coal supply may not grow rapidly at first because of lack of expanded facilities. It will be expected to grow between 4% and 5% if domestic energy demand is to be met. Hydropower and geothermal energy will probably continue to grow at 3% per year but this is an insignificant contribution to total energy. Figure V-5 shows the total energy supply under the following postulations.

1. Coal: 2% annual growth to 1978, 5% annual growth to 2000, and 7% annual growth to 2025.
2. Domestic Oil and Gas: 2.2% annual decline to 2025.
3. Hydro & Geothermal: 3% annual growth to 2025.
4. Nuclear: 10% annual growth to 2010, 5% annual growth to 2025.

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*This was beginning to show signs of developing in late 1979.

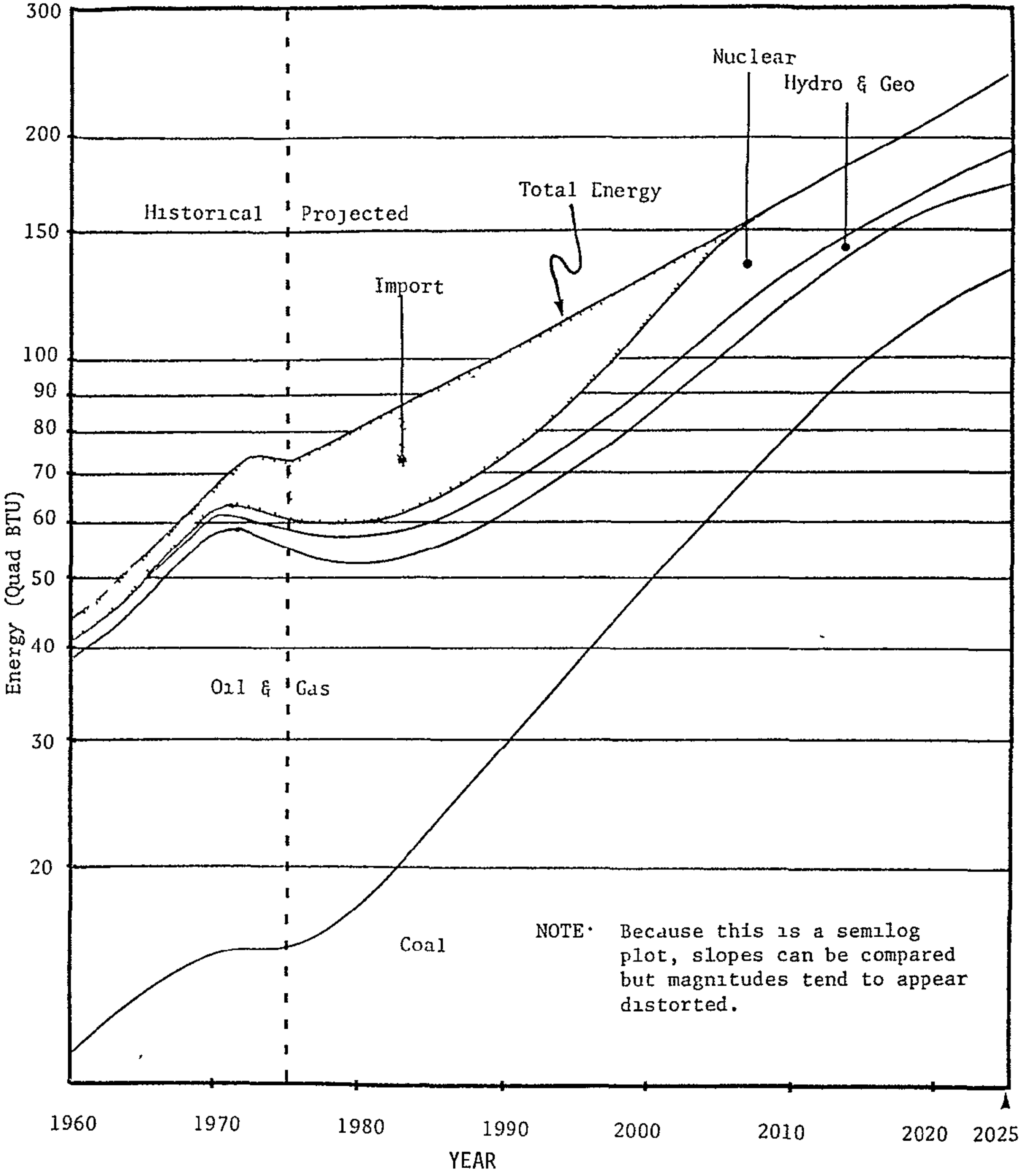


Figure V - 5 U S Energy Supply - Historical & Projected to 2025

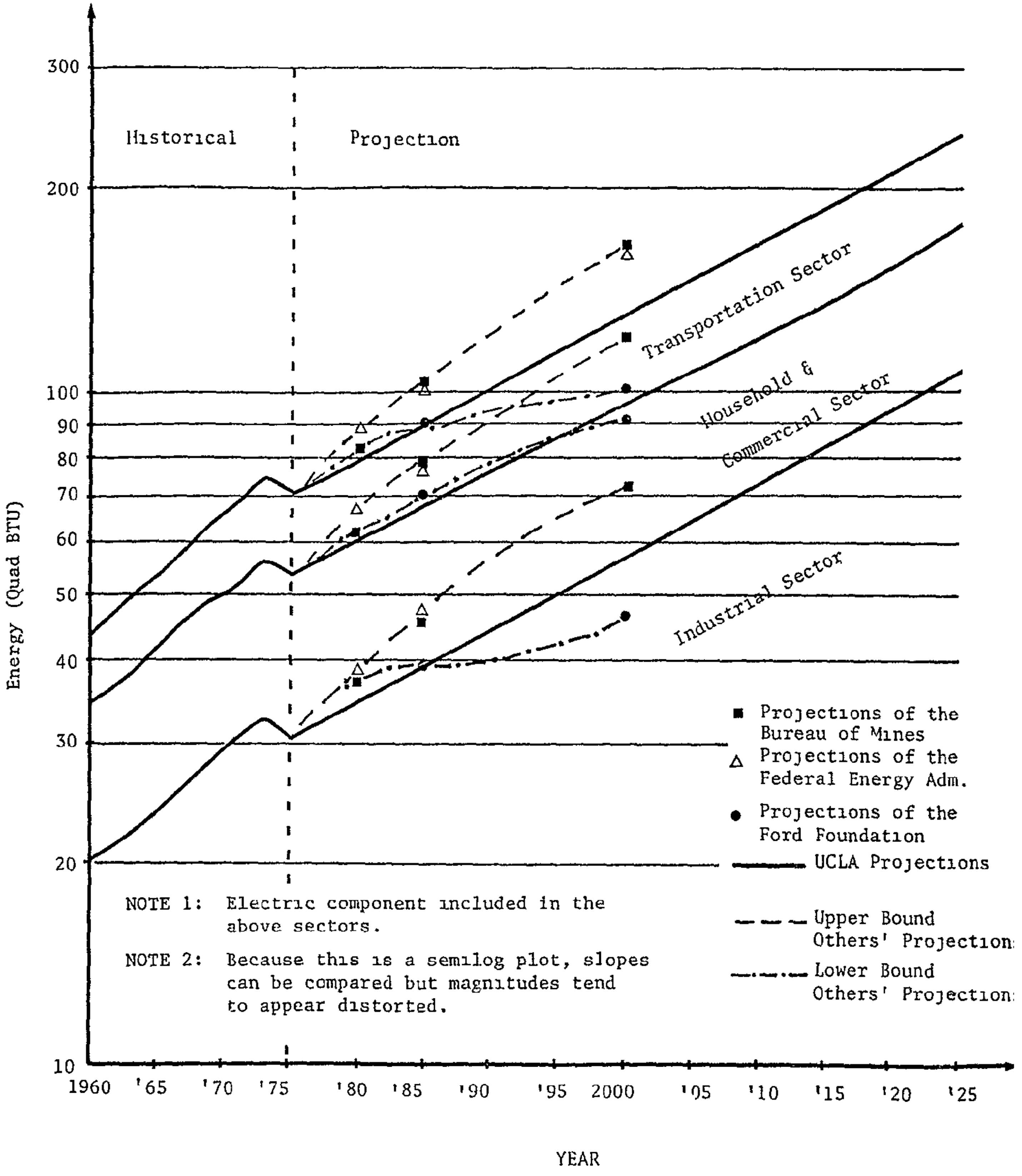
This energy trend is different from the case depicted for the interrupted growth scenario. There is no dip in total production around year 1990 as indicated in the interrupted growth scenario. Rather, energy growth is upward and smooth. Imports grow at rates sufficient to support the economy. Nuclear may not grow at the 17% per year rate projected by various studies but could grow between 5% and 10% per year. The current hiatus in nuclear development would have to give way soon to a renewal of the growth rate that existed prior to the Three-Mile Island incident.

Energy Sharing

Energy-consuming sectors in the economy, namely, transportation, household, commercial and industrial, will be competing for this available energy. All sectors are expected to grow and, hence, energy to support this growth is also expected to increase. Conservation measures aimed at reducing energy consumption may, in the long run, increase consumption for the following reasons. In the industrial sector, attempts to replace more energy intensive materials with less energy intensive materials could result in designing of inefficient operating equipments. The household and commercial sectors have a potential for decreasing energy consumption as efficient appliances replace old energy-consuming devices. Though such conservation measures could be implemented, their impact will depend on the extent of these measures. Sectorial energy consumption is estimated to follow the trend shown in Figure V-6. This trend will be able to support the economy without any interruption.

Transportation

Within the framework of the uninterrupted growth scenario, as in the other scenarios, the transportation sector depends on GNP and population growth rates, as well as on a shifting demand for transportation, relative to other goods and services. With the assumed GNP and population growth rates in the socio-economic environment the overall transportation would be experiencing a low growth rate by the year 2025, although sectors such as air transportation, waterbound transportation (mainly international) and farming will continue to grow. Slow growth rate by the year 2025 occurs mainly because of the saturation level which some of the ground modes of transportation will have reached (i.e., automobile and trucks for urban use). This slow-down could occur for the following reasons: 1) population growth may be limited; 2) if historical growth patterns continue, most of our cities could be experiencing such a high level of congestion that parking fees and travel time will be driven to such an unacceptable level that public modes of transportation would become a more economically



NOTE 1: Electric component included in the above sectors.

NOTE 2: Because this is a semilog plot, slopes can be compared but magnitudes tend to appear distorted.

Figure V - 6 U S Sectorial Gross Energy Input

Source. Historical Data
Bureau of Mines, 1976

feasible alternative; and finally, 3) as intercity modes of transportation such as highspeed train and commercial airlines become more efficient and economically accessible to the society, they may replace private automobiles for intercity traveling.

FUTURE OF AIRLINE COST ELEMENTS

The two distinct socio-economic scenarios presented in this chapter provide background for conjecture of the cost elements of the aviation industry and the exogenous variables of the model. Although it is appropriate to provide some rationalization for each item and variable (exogenous variables) of the model, as presented for scenarios of GNP and energy, it is only practical for institutions with sizable research staffs. However, to show applicability of the model, we will present the future behavior of costs and necessary exogenous variables of the model. Assumptions concerning these variables will be based on historical information and socio-economic background scenarios defined in this chapter.

Aviation fuel cost constitutes a considerable portion of direct operating cost (DOC). Because we are in a period of instability of energy price and supply, it is appropriate to analyze the cost in terms of price and fuel quantity separately.

1-a Fuel Consumption

The primary factors that determine fuel consumption are the technology of the aircraft and its engines, as well as the operation of the fleet. Historically, the introduction of the jet engine was accompanied by a large increase in fuel consumption per ton-mile available capacity. Subsequent technological improvements, particularly with the turbo-fan, resulted in a continuing decrease in fuel consumption.

Introduction of the wide-body aircraft in 1970 afforded a significant decrease in fuel consumption per ton-mile available capacity, and conservation measures taken in the 1975-76 period yielded a further decrease (see Figure IV-27).

As aircraft embodying new technology (such as the Boeing 767) are introduced into the fleet, the fuel consumption per ton-mile available capacity will continue to decrease.

1-b Aviation Fuel Price

In projecting future aviation fuel price two things must be considered: First, the price of energy in general and crude oil in particular; and second, the ratio of aviation fuel price to the crude oil price. Uncertainty on energy price is twofold: Technological uncertainties and therefore, uncertainty on the marginal cost of production; and political uncertainty which dominates world energy supply. With the two energy scenarios presented in this chapter and historical data of:

a) Aviation fuel price in 1972 $, Figure IV-29.
b) Ratio of aviation fuel price to crude oil price, Figure IV-30.
c) Ratio of aviation fuel price to the price of fossil fuel Figure IV-31.

the future trend of aviation fuel price is projected to follow the pattern of Figure V-7.

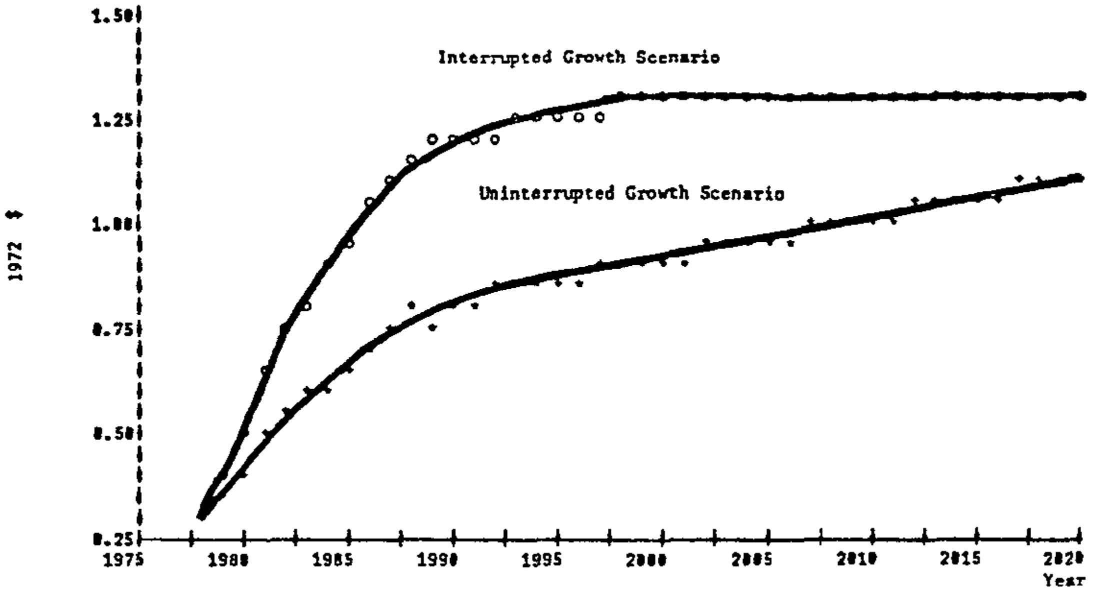


Figure V-7. Projected Aviation Fuel Price per Gallon

2 Crew Cost

The dominant factor of crew cost is the economy of scale. The size of aircraft has reached almost its practical limit, at least for the time being (see Figure IV-4). The general economic condition will not have significant effect on the crew cost. It is anticipated that the relative increase in the salary of the crew will be offset by technological improvement and slight increase in the average size of the fleet. If so, crew cost will continue to remain around its historical value $.029 (1972 $) per ton-mile available capacity.

3 Insurance Cost

The historical records, Figure IV-37 shows the decline in insurance costs to the industry. Even with doubling the capacity, Figure IV-17, the industry pays a sum for the insurance less than it was paying in the early 1960's. It is true that the aircraft is what is being insured, but the insurance cost relates to many other safety measures which depend on the integrated efforts of the whole system. Not only the plane itself becomes more safe, but the system as well. Another reason for the sharp declining of insurance costs is, perhaps, due to the customers direct purchase of insurance for different services and on an optional basis. For the longer run it is reasonable to assume that the insurance costs will fluctuate around the horizontal line of fifty (50) million dollars (1972 $) a year. Therefore, the unit insurance cost will be:

50,000,000 — capacity of the industry.

4 Maintenance Costs

Since the beginning of jet era until the late 1960's, the maintenance costs per ton-mile available capacity show drastic reductions (See Figure IV-35). But since then it has not changed much. The reduction in costs is mainly due to the maintenance approach and procedures, although economy of scale has also contributed to this reduction (Nowlan, 1978). The traditional approach to developing preventive maintenance was based upon the approach that every item on a piece of complex equipment has a right age at which it should be overhauled to enable it to meet the safety requirement. However, through the years, it was discovered that there are many types of failure that could not be prevented or effectively alleviated by scheduled maintenance activities. Thus airplane designers began to develop design practices that took into account failure consequences. Design features such as replicated system, multi-engine, and damage-tolerant structure and so on, improved the relationship between reliability and maintenance.

"Reliability-Centered Maintenance" is the present day approach. The approach is based on decision diagram techniques which follow a straightforward logic to develop scheduled maintenance programs to ensure the maximum safety and reliability while, at the same time, minimize the maintenance costs.

Further maintenance reliability enhancement and cost reduction lie on future progress in the development of equipment that can be more effectively maintained and can achieve yet higher safety levels and greater operational reliability. Such development totally depends on a close partnership of design and maintenance organizations, with each one familiar with the capabilities and limitations of the other. With all these potentials, it is anticipated that the trend of the 70's in the reduction of maintenance cost will continue (see Figure V-8).

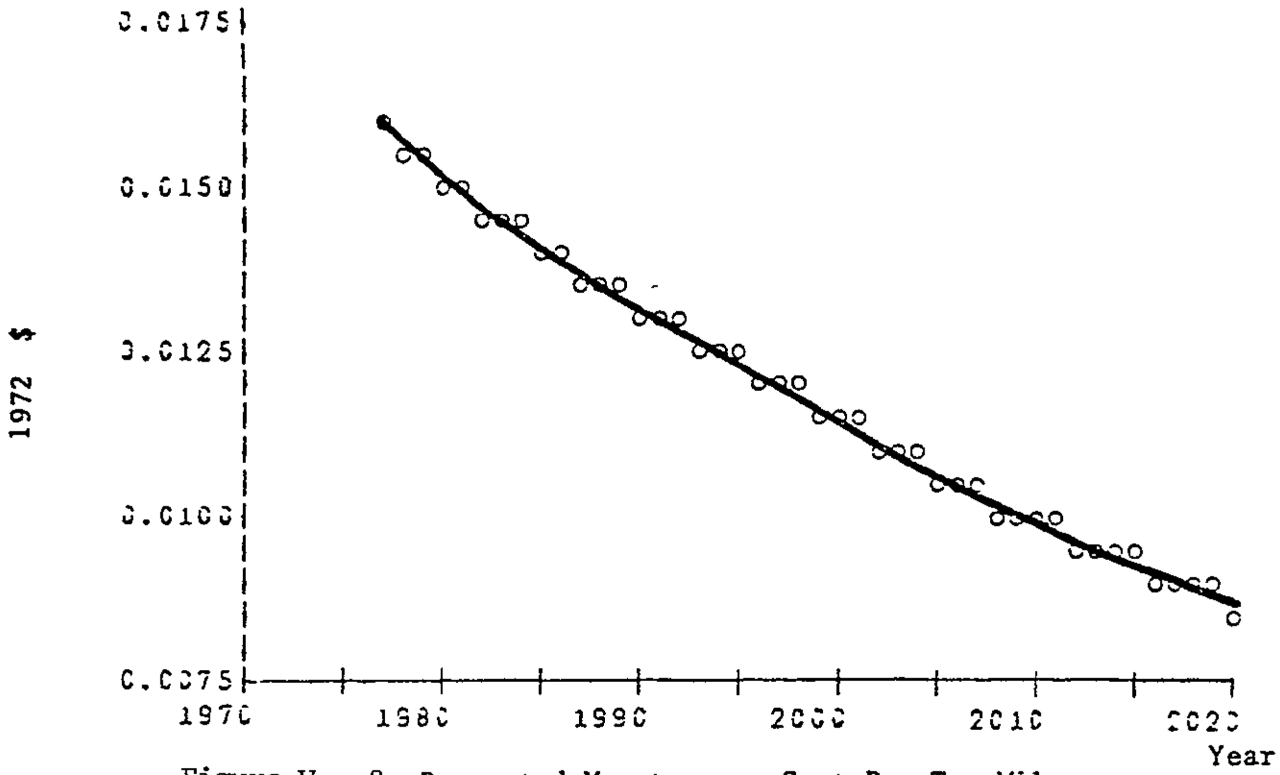


Figure V - 8 Projected Maintenance Cost Per Ton-Mile Available Capacity

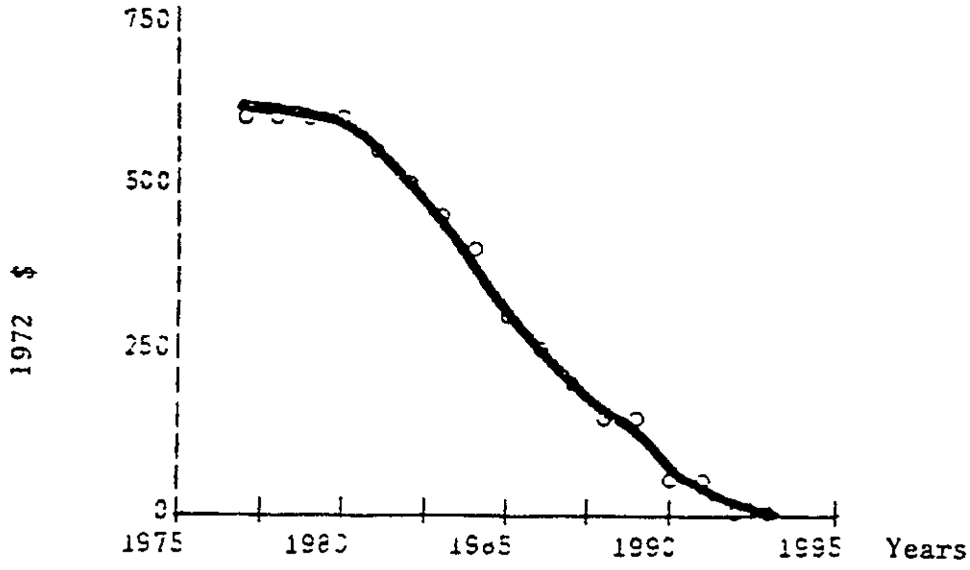


Figure V - 9 Future Depreciation Cost due to Existing Equipment

5 Depreciation Cost

Depreciation is basically allocation of capital expenses over time. Assuming an average life time of eighteen years, existing capital in the system will be depreciated as it is shown in Figure V-9. The total depreciation includes costs due to future purchase of flying equipment. Therefore, this portion of depreciation cost will be projected through the investment sub-model discussed in Chapter VI.

6 Indirect Costs

There are numerous cost items which fall into this category. Analyzing each item separately, for the purpose of this research, is not practical and not necessarily useful. But the major portion (around 60 percent) of indirect costs is non-crew labor cost (Figure IV-44). In analyzing labor cost we may concentrate on labor requirement and labor price. Productivity of labor has increased dramatically until the late 1960's and then leveled off (Figure IV-42). It is expected that improvement of productivity will continue along the trend line of the 1970's as projected in figure V-10.

On the other hand, the price of labor in real terms (1972 $), has been increasing almost with GNP growth. If so, under our two socio-economic scenarios we expect two different patterns of labor cost (Figure V-11).

Conversely, as Figure IV-45 shows, the historical pattern of non-labor portion of indirect cost does not show any general trend of increase or decrease. In the absence of any specific analysis of the constituents of this cost category, all we may postulate is that, in the long run, price of energy and labor, in general, are the dominant factors. These two factors are increasing and therefore, non-labor portion of indirect cost is expected to go up with them according to our socio-economic scenarios (Figure V-12). Projections of the total indirect cost, labor and non-labor will thus also go up (Figure V-13).

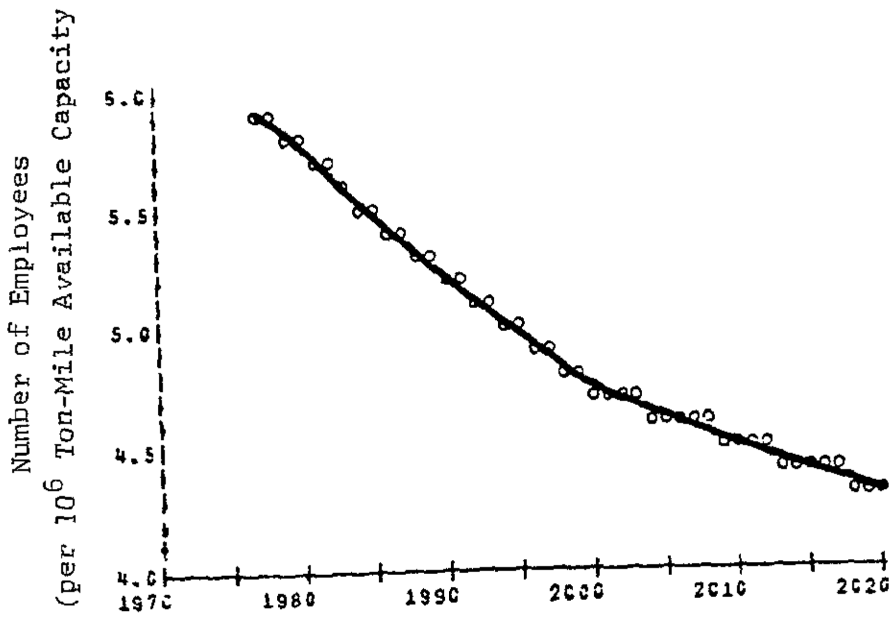


Figure V - 10 Non-Crew Labor Requirement of Airline Industry (Per 1 mm Ton-Mile Available Capacity)

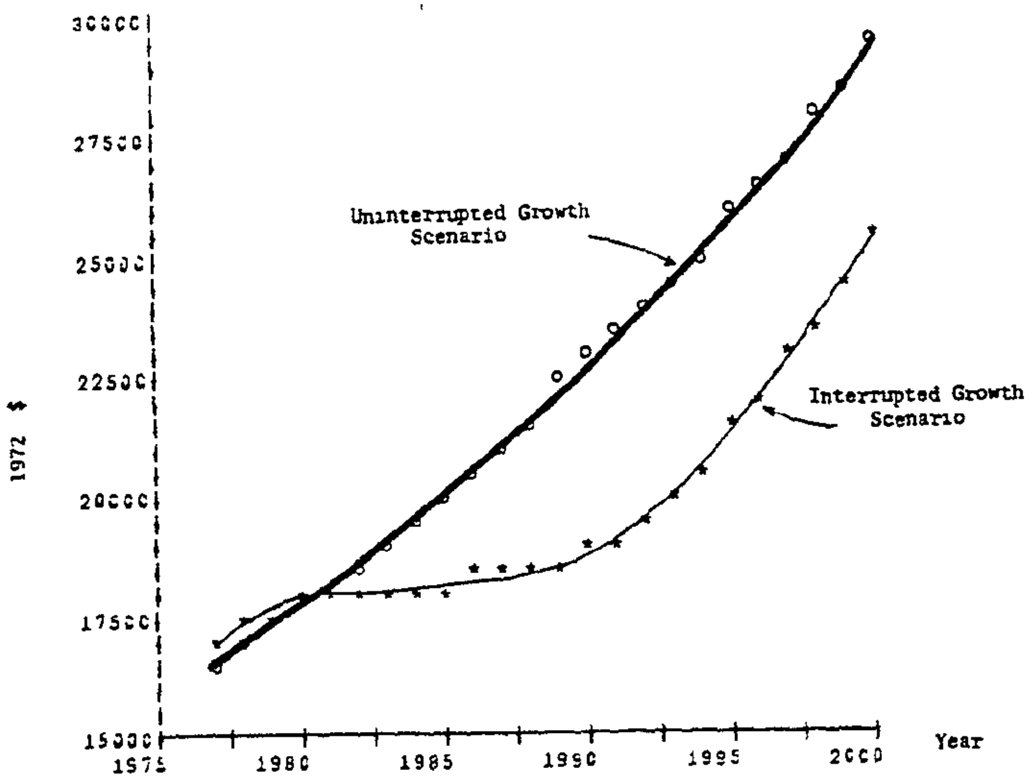


Figure V - 11 Projected Average Annual Employee Cost for Airline Industry

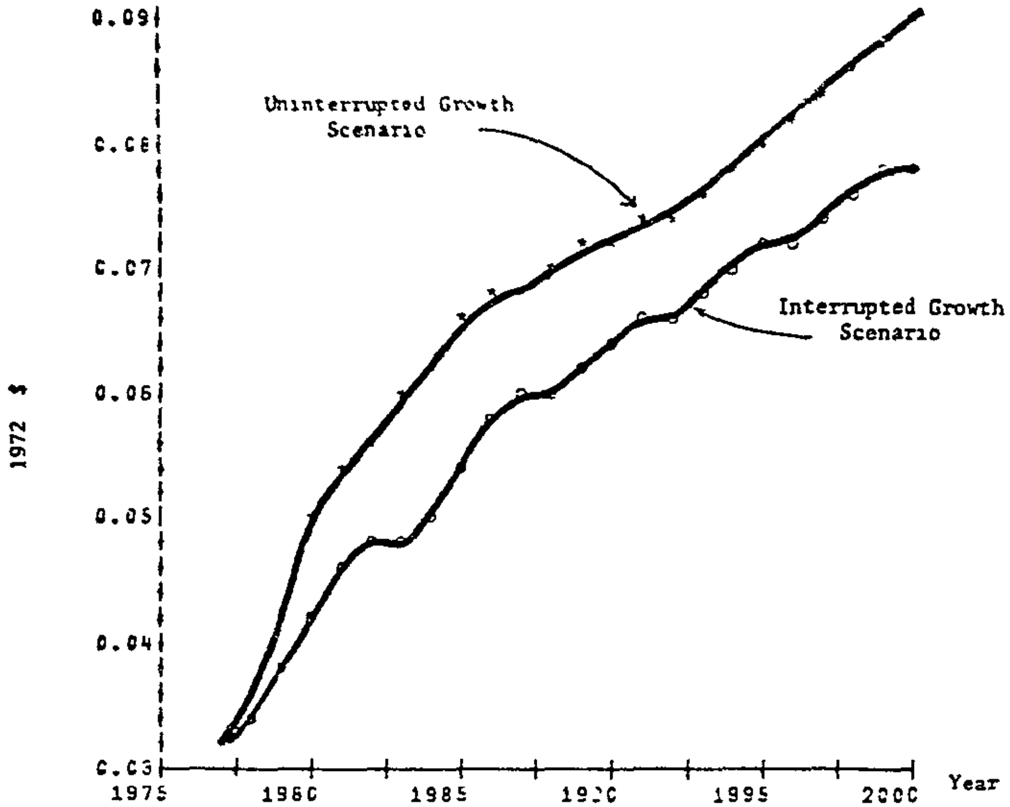


Figure V - 12 Non-Labor Indirect Costs, per Ton-Mile Available Capacity

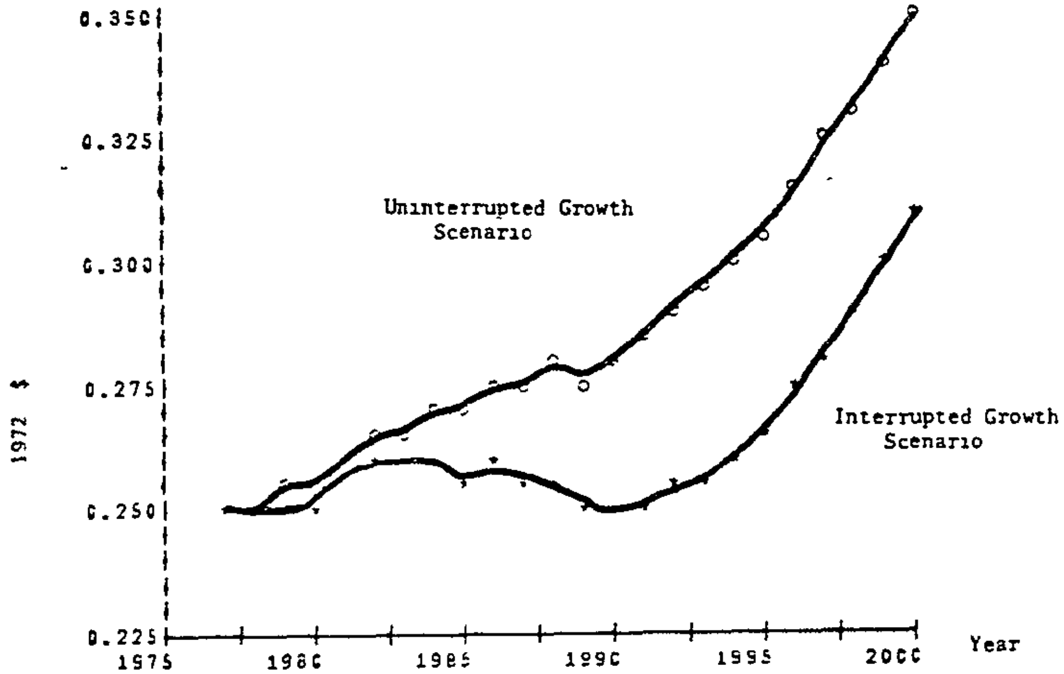


Figure V - 13 Projected Indirect Costs per Ton-Mile Available Capacity

CHAPTER VI
A DYNAMIC MODEL OF AIR TRANSPORTATION

This chapter presents development of a model for U.S. air transportation. The model is designed to project the important variables of the air transportation system such as demand, fare, investment, total aviation fuel consumption, et cetera. The model is an application of digraph methodology as presented in Chapter III.

Variable Set

Decision on the choice of major variables of the system is based primarily on the best judgement of UCLA/NASA "Future Aviation Fuels" research team acquired through a set of questionnaires conducted in 1977 (see English, 1978). With regard to the major variables of the air transportation demand model, the system is limited to the variables shown in Figure VI-1.

Relationships Among Variables

Like the decision of major variables of the system, decision on the existence of important relationships, among the possible permutation of variables in Figure VI-1, is also based, primarily, on the judgement of the research team. However, as we will see in the next pages, some statistical analysis has been employed to guide and correct these judgments.

Choice of the variables and relationships is rationalized on the basis of the following reasonings:

1) Determinants of Demand

First, as a principle of economic theory, demand is, of course, a function of fare and vice versa. Second, although the quality of service has many dimensions such as seat comfort, passenger service, meals, speed, et cetera, most literature consider the schedule frequency as the single most important factor of service quality (Miller, 1972). Load factor is considered inversely as the index of schedule frequency.

Third, change in personal income affects the demand. Two main categories of air transportation are passenger and cargo. Passenger travel, business travel, and pleasure travel are often distinct. Two variables, disposable personal income and gross national product (GNP) are considered to have income effects on demand for air transportation. In particular, an increase in disposable personal income increases potential for pleasure travel; a change in GNP affects the business travel and cargo movement. Finally, as population increases so does the demand for air transportation.

2) Determinants of Fare

Determinants of fare, other than demand, are considered to be variable costs and fixed costs. It is widely recognized

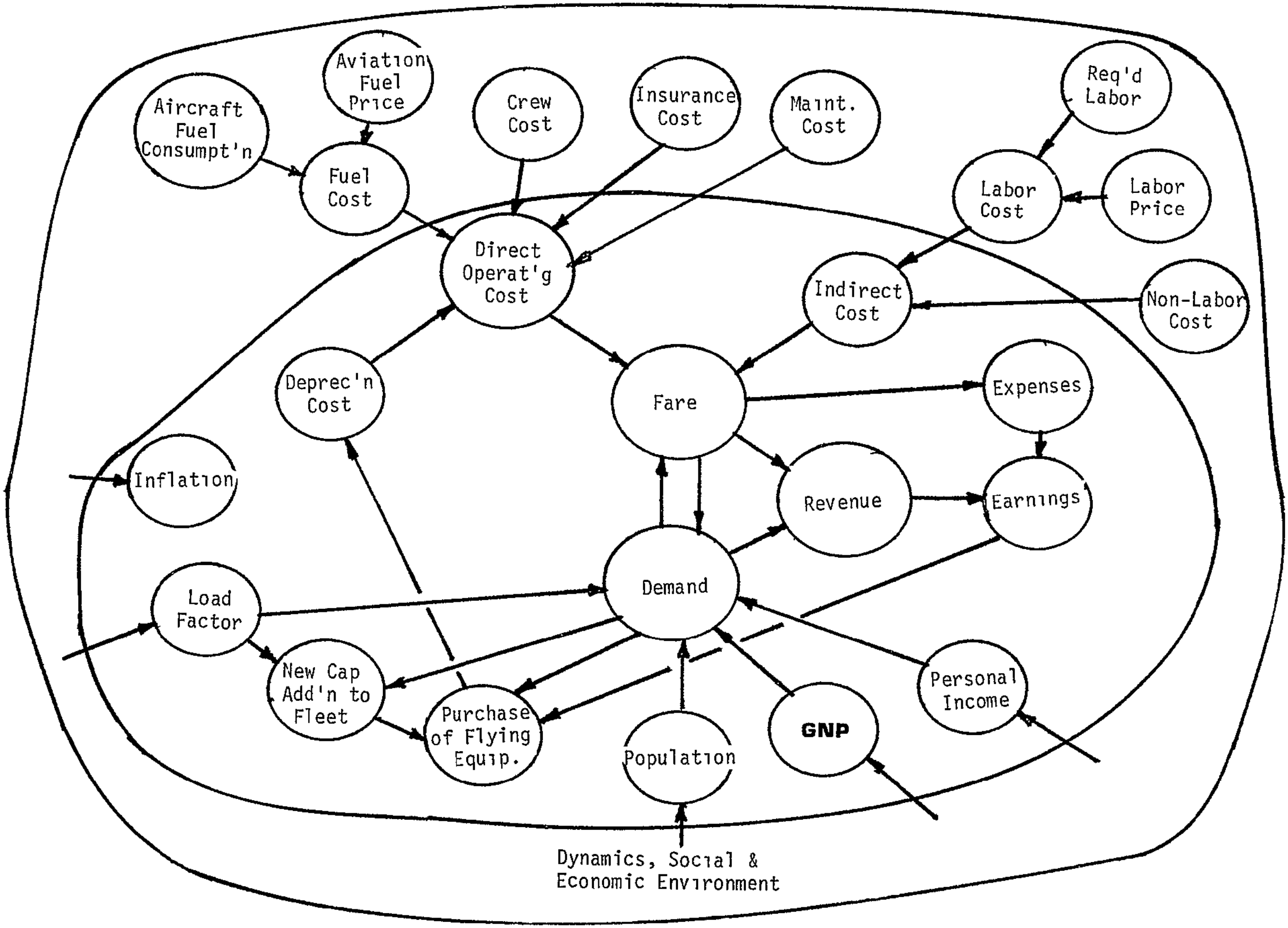


Figure VI - 1 A Conceptual Dynamic Model of Air Transportation Economics that the industry sooner or later shifts any new costs to the fare charged to the customer. But the distinction between two type of costs, variable and fixed, is due to the time lag effect. Variable costs usually affect the fare rather immediately, while fixed costs presumably affect the fare after some time lag. It should be kept in mind that the concept of fixed and variable costs is a relative matter depending on the time span of interest.

Inflation, as it distorts the price system, may affect consumer behavior. We will try to detect if the consumer responds to monetary or real price change (money illusion). Inflation as a variable does not affect other variables, but it may affect the relationships involving monetary variables.

3) Determinants of Investment

When one asks the experts in the field what induces airlines to buy new aircraft, perhaps, one or more of the following reasons will be expressed.

1) Airlines order new equipment when they have high earnings (Spencer, 1978).

2) Airlines order when they experience high increase in demand for air transportation services.

3) Airlines order when they are faced by competition to retire old aircraft.

4) Airlines order when they have access to external or internal funds.

and the list may go on.

For building a model the chosen variable must be more specific and measurable. For example, the first two expressions relate to variables (earning and demand) which have been measured rather precisely. The third expression refers to "old aircraft" which is not, technically and economically, as clear cut. Likewise, the fourth expression is quite undefined.

Historically, the pattern of increase and decrease of total earnings, change in traffic volume, and purchase of flying equipment (dollar value) in spite of sharp fluctuations, consistently follow each other. (See Figure VI-2.) This supports the first two expressions and suggests that earnings and change in demand are two candidates for two determinants of investment in flying equipment. On the other hand, the industry must retire some of its old aircraft sooner or later. Historical data on the number and capacity of retired aircraft are not available. However, it is plausible that new orders to replace old aircraft, among other things, relate to the existing capacity of the fleet.

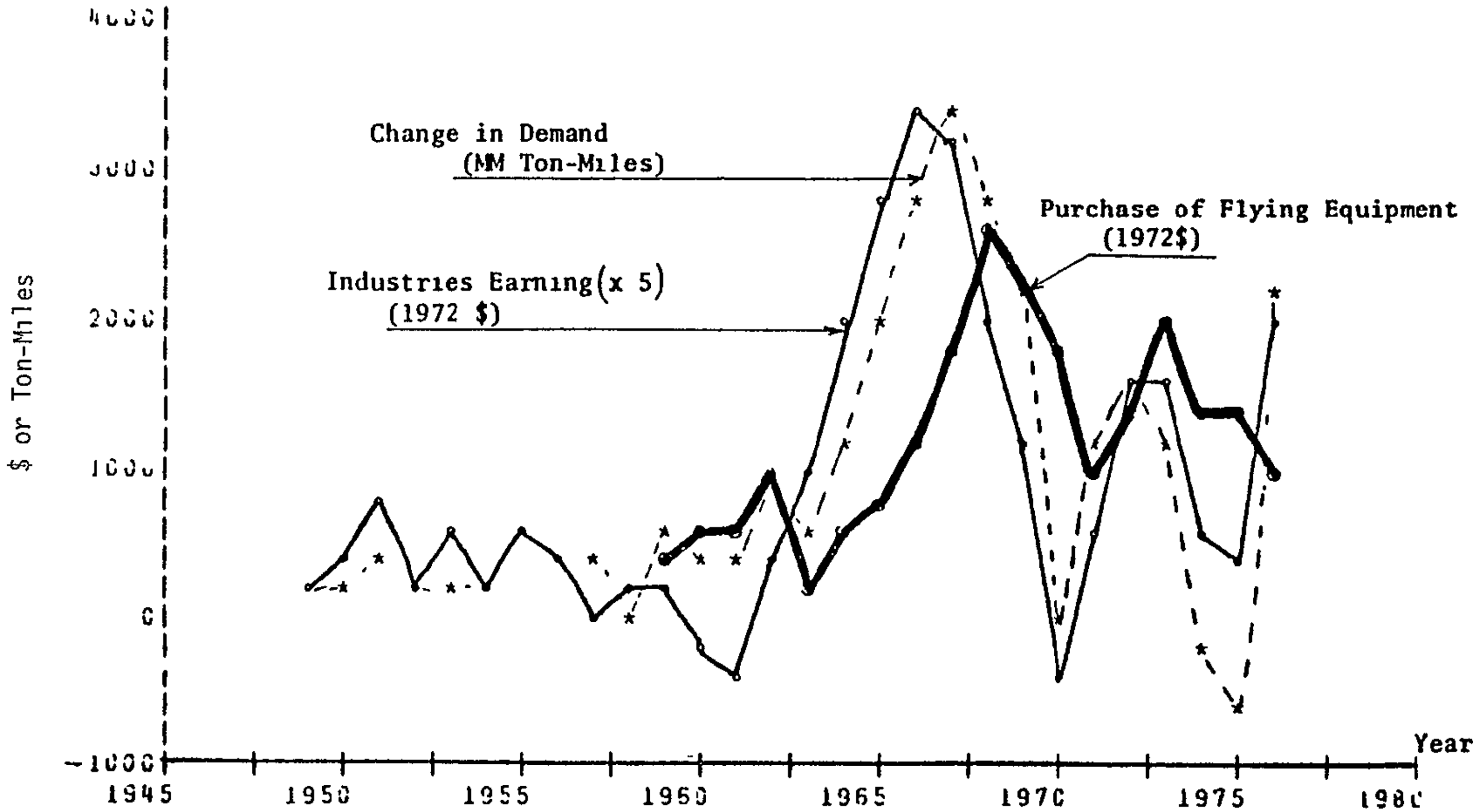


Figure VI - 2 Investment Follows Earning and Change in Demand

Formulating The Relationships

The incoming arrows on each node (Figure VI-1) are assumed to be the cause of change in the value of that node. Any other cause for change in that variable, if any exist, is ignored. One way to establish relationship among variables is to consider each node which has one or more incoming arrows in isolation from the rest of the system and assess the simultaneous effect of change on that variable.

Formulating Demand Model

Isolating the node representing the demand, d, and its determinants: Fare, f, Load Factor, l, Disposable Income, i, GNP, g, and Population, p, we will have Figure VI-3, which is a smaller digraph without any feedback. Note that in this digraph the fare, f, itself an endogenous variable in the air transportation demand model, Figure VI-1, becomes an exogenous variable.

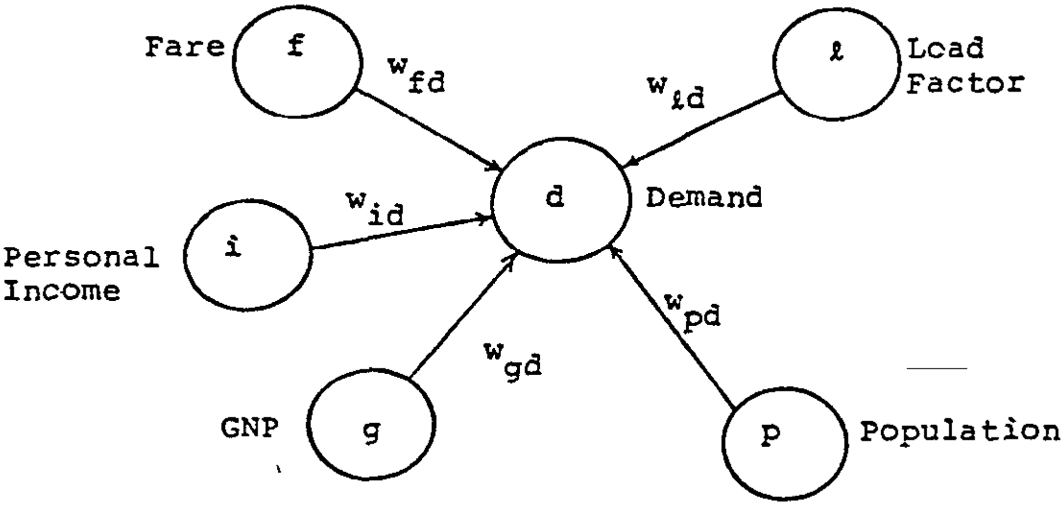


Figure VI-3. A Subdigraph of Demand and Its Determinants

As it is mentioned in Chapter III, each element w may be a constant, or a time variable, or any linear or non-linear function of one or more variables of the system. If we are convinced that assumption of a constant number for all w's is reasonable, and if reliable historical data exist; then by applying multiregression analysis we can determine the historical value of w's. (Appendix A presents a formulation of Multiple Regression Analysis, abstracted from Kerlinger and Pedhaur, 1973). These historical values of w's will be a base for experts' judgment on the value of w's in the future. Historical values for the annual change in demand and corresponding annual change for its components are presented in Table VI-1.

The results of Multiple Regression Analysis on the data of Table VI-1 are the following, where a and b_1 are regression coefficients, R^2 is the variance, and the F-function distribution:

Independent Variable	a	b_1	R^2	F
	1987.6		0.0561	5.658
f		-8008.3		
ℓ		19806.8		
i		0.5		
g		21.5		
p		-776.6		

The difficulty with this result is that first, the relationship between population and demand is negative, which is wrong; second, the relative weight of fare and load factor is not correct; third, the set of independent variables explains only 5.61 percent of the change in the independent variable. All reasons suggest that assumption of linear relationship should be dismissed. Therefore, a set of non-linear relationships must be sought.

By analogy to the elasticity relationship in economic theory, we have:

$$\Delta D = \mu \frac{D}{F} \cdot \quad \Delta F \qquad \text{Eq. (VI-1)}$$

Where
D = Demand,
ΔD = Change in Demand
F = Fare

Similar relationships between demand and other determinants, GNP, Load Factor, Disposable Personal Income and Population are plausible. By applying Multiple Regression Analysis to the historical data based on changes over the year before, Table

Year	Change in Demand Ton-Mile MM	Change in Fare 1972 $	Change in Load Factor	Change in Real (1972 $) Personal Income	Change in Real (1972 $) GNP	Change in U.S. Population
1949	149.0	¯0.026	0.017	28.5	2.1	3.2
1950	280.0	¯0.140	0.042	5.3	44.7	2.5
1951	422.0	¯0.107	0.045	10.9	33.8	2.6
1952	278.0	¯0.045	¯0.021	¯335.8	15.8	2.7
1953	292.0	0.008	¯0.018	360.6	25.5	2.6
1954	246.0	¯0.052	¯0.011	29.6	¯2.4	2.8
1955	594.0	¯0.027	0.012	21.4	54.2	2.9
1956	485.0	¯0.013	¯0.004	6.9	23.7	3.0
1957	420.0	¯0.025	¯0.023	2.9	10.0	3.1
1958	81.0	0.009	0.000	22.5	¯8.2	2.9
1959	649.0	0.005	0.005	10.3	46.6	2.9
1960	380.0	0.004	¯0.028	15.2	17.3	2.9
1961	364.0	¯0.015	¯0.028	23.6	16.6	3.0
1962	925.0	¯0.027	¯0.004	20.1	47.2	2.9
1963	592.0	¯0.008	¯0.015	30.7	32.2	2.6
1964	1199.0	¯0.028	0.000	35.6	47.0	2.7
1965	2003.0	¯0.047	0.011	32.7	53.8	2.4
1966	2836.0	¯0.066	0.027	24.5	58.9	2.3
1967	3439.0	¯0.042	¯0.021	26.4	27.9	2.1
1968	2723.0	¯0.032	¯0.021	13.3	44.8	2.0
1969	2137.0	¯0.015	¯0.019	21.2	22.4	2.0
1970	32.0	¯0.005	¯0.010	23.2	¯9.0	2.2
1971	1159.0	¯0.010	¯0.008	32.3	31.6	2.2
1972	1502.0	0.003	0.018	49.0	86.5	1.7
1973	1243.9	¯0.001	¯0.004	¯13.1	60.2	1.6
1974	¯157.7	0.021	0.022	6.7	¯30.6	1.5
1975	¯582.6	0.009	¯0.011	28.8	¯20.7	1.7
1976	2144.3	¯0.006	0.019		64.3	1.5

Table VI - 1 Historical Change in Demand for Air Transportation and its Determinants.

Year	Change in Demand Over the Year Before	Change in Fare (1972$) Over the Year Before	Change in Load Factor Over the Year Before	Change in Real (1972$) Personal Income over the year Before	Change in Real GNP Over the Year Before	Change in Population Over the Year Before
1949	0.138	-0.022	0.032	0.048	0.005	0.022
1950	0.228	-0.123	0.077	0.079	0.099	0.017
1951	0.280	-0.107	0.077	0.014	0.068	0.017
1952	0.144	-0.051	-0.034	0.029	0.030	0.017
1953	0.132	0.010	-0.029	-8.387	0.047	0.016
1954	0.098	-0.060	-0.018	0.900	-0.004	0.017
1955	0.216	-0.033	0.020	0.069	0.095	0.018
1956	0.145	-0.017	-0.007	0.047	0.038	0.018
1957	0.110	-0.032	-0.036	0.015	0.015	0.018
1958	0.019	0.012	0.000	0.006	-0.012	0.017
1959	0.150	0.007	0.008	0.047	0.072	0.017
1960	0.076	0.006	-0.049	0.021	0.025	0.016
1961	0.068	-0.020	-0.051	0.030	0.023	0.017
1962	0.162	-0.037	-0.008	0.044	0.065	0.016
1963	0.089	-0.011	-0.028	0.036	0.041	0.014
1964	0.166	-0.040	-0.001	0.065	0.058	0.014
1965	0.238	-0.070	0.021	0.057	0.063	0.013
1966	0.272	-0.104	0.053	0.050	0.065	0.012
1967	0.259	-0.074	-0.039	0.036	0.029	0.011
1968	0.153	-0.062	-0.041	0.037	0.045	0.010
1969	0.110	-0.030	-0.038	0.018	0.022	0.010
1970	0.001	-0.011	-0.020	0.028	-0.008	0.011
1971	0.054	-0.020	-0.017	0.030	0.030	0.011
1972	0.066	0.006	0.039	0.040	0.080	0.008
1973	0.051	-0.003	-0.009	0.058	0.051	0.008
1974	-0.006	0.046	0.046	-0.016	-0.025	0.007
1975	-0.023	0.019	-0.021	0.008	-0.017	0.008
1976	0.087	-0.012	0.040	0.033	0.055	0.007

Table VI-2 Historical Change in Demand for Air Transportation and Its Determinants Over Their Value in the Year Before.

VI-2, and with elasticity relationships the result is as follows:

Independent Variables	a	b_i	R^2	F
	0.006		0.823	20.445
f		-1.355		
ℓ		0.016		
i		-0.006		
g		0.798		
p		3.635		

The result is satisfactory since 82% (R^2 = .823) of the variance in demand is explained by the independent variables, and the F ratio is quite high ($20.44 > F_{.01} = 9.4$ with N = 28 and K = 5 rejects the null hypothesis).

The unexpected number is $b_g = {}^{-}0.006$ for the relationship between Disposable Personal Income and Demand for Air Transportation. The reason is that the correlation between GNP and Disposable Personal Income is quite high; and since Disposable Personal Income constitute the major portion of the GNP, the effect of Disposable Personal Income on Demand is already taken care of in the relationship of GNP and Demand (with $b_g = 0.8$). (See discussion on Path Analysis, causality and correlation in Kerlinger and Pedhaur, 1973). Therefore, removing the Disposable Personal Income from the digraph of Figure VI-3 should improve the analysis. Using Multiple Regression Analysis for the digraph of Figure VI-3, without Disposable Personal Income, gives the following result which is not much different from what we had with this variable:

Independent Variable	a	b_1	R^2	F
	0.006		0.811	24.646
f		-1.267		
ℓ		0.018		
g		0.924		
p		3.358		

Now, if the causal map of Figure VI-2 with the elasticity relationship and with b_1 coefficient is correct, we ought to be able to predict the history. Meaning that: given the value of exogenous variables, the model should generate data consistent with what actually has happened. To examine this, we run the digraph model of Figure VI-3 according to the technique presented in Chapter III.

The initial values are the values of all five variables in Figure VI-3 in 1947:

Variables	d	f	ℓ	g	p
Initial Value	1077	1.166	0.53	448.2	146

The result of the simulation run is depicted in Figure VI-4. The estimate is quite close to actual data and acceptable for our practical purpose. Although by using a more sophisticated computer program (within the digraph simulation program), it is possible to minimize the deviation, the practice does not change the fact that kind of analyses we attempt are crude in their nature. Moreover, as the results of multiple regression showed, if the causal relationship established in the model is correct, only 75-85 percent of the change in the dependent variable is taken into account and the rest depends on other unaccounted reasons (R^2 = 0.75 to 0.85).

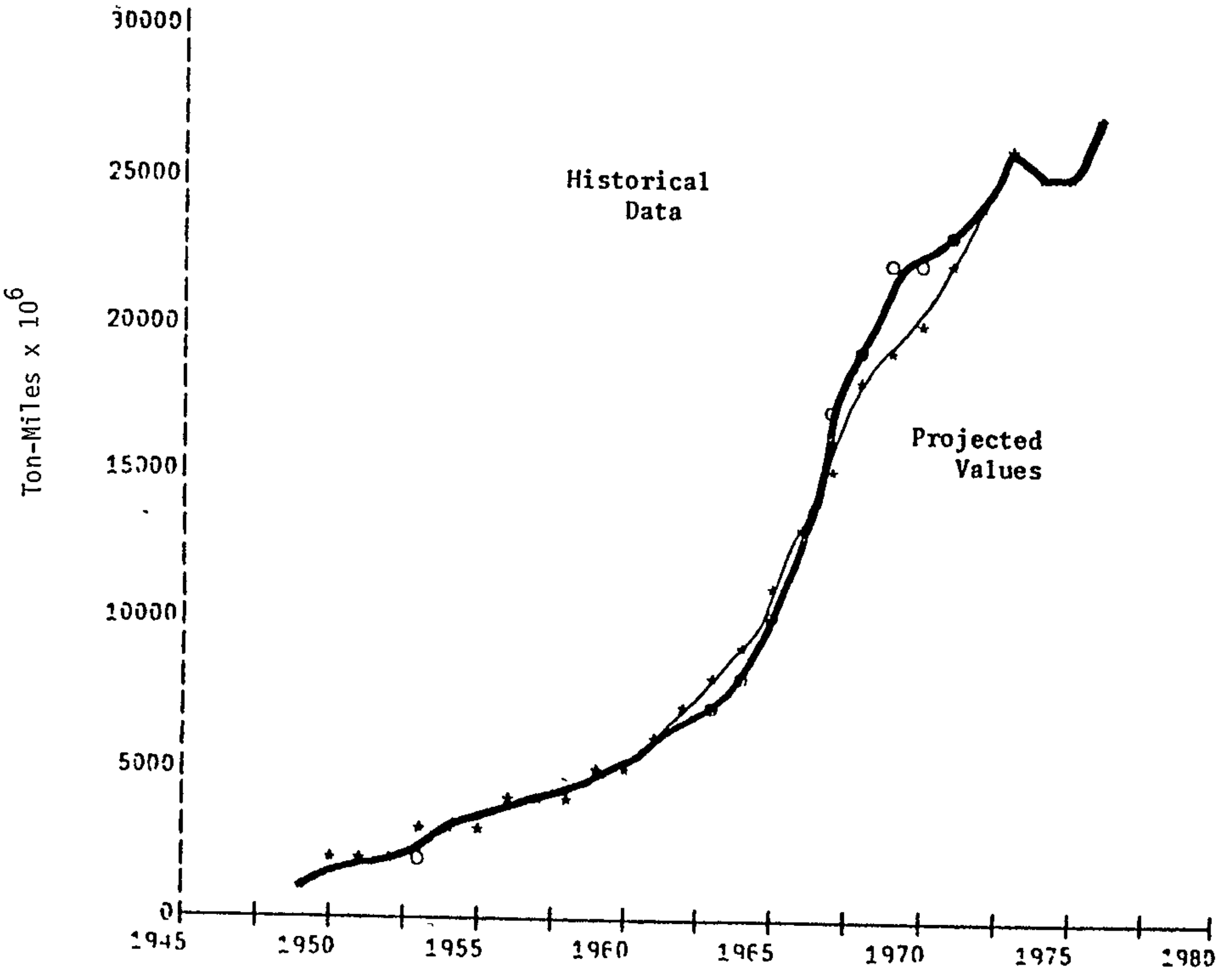


Figure VI - 4 Projected and Actual Demand for Air Transportation.

Deviations from Historical Data

Year	%
1949	-2.3
1950	4.3
1951	2.9
1952	4.0
1953	0.2
1954	3.7
1955	2.0
1956	0.1
1957	1.2
1958	2.9
1959	0.1
1960	0.1
1961	3.8
1962	4.1
1963	5.5
1964	4.9
1965	1.2
1966	-1.5
1967	-9.1
1968	-9.4
1969	-10.5
1970	-6.4
1971	-2.7
1972	0.4
1973	3.4
1974	-1.2
1975	0.4
1976	1.2

Sensitivity Analysis

To determine the sensitivity of the predicted value with regard to different changes in weight of the relationship, the value of one parameter at a time is changed while the rest of the parameters are held their value of original run (used in Figure VI-4). Figure VI-5 and its associated Table shows how change in the elasticity of demand with respect to fare is affecting the accuracy of the model prediction. Figure VI-6, VI-7, and VI-8 are similar presentations for other parameters.

One benefit of this practice is in helping to adjust the parameters for a better prediction. From the previous tables, after some trial and error, the following values for the parameters slightly improve the prediction.

$$b_f = {}^{-}1.27$$

$$b_\ell = {}^{-}0.2$$

$$b_g = 0.92$$

$$b_p = 3.35$$

To check if a better model can be obtained by using current dollars for the monetary variables of the model, rather than constant dollars we have been using so far, the procedure was repeated. The result of multiple regression on the data of Table VI - 3, is the following:

Independent Variable	a	b_i	R^2	F
	0.027		0.808	24.151
f		-1.135		
ℓ		0.070		
g		0.917		
p		2.567		

And the result of the simulation run, with the following initial values, is depicted in Figure VI-9.

b	-1.000	-1.100	-1.200	-1.267	-1.300	-1.400	-1.500
Avge Absolute % Error	11.312	7.328	4.095	3.184	3.788	6.693	11.358
Standard % Error	13.537	9.480	5.725	4.264	4.334	7.458	12.333
Year	Percentage Error	100 (Actual Value-Predicted Value) / Actual Value					
1949	-2.803	-2.608	-2.412	-2.281	-2.217	-2.022	-1.826
1950	1.147	2.327	3.511	4.306	4.699	5.890	7.086
1951	-2.465	-0.474	1.548	2.903	3.578	5.639	7.724
1952	-2.621	-0.193	2.277	3.956	4.709	7.343	9.940
1953	-5.885	-3.624	-1.327	0.232	1.006	3.374	5.780
1954	-3.985	-1.150	1.746	3.722	4.706	7.728	10.815
1955	-6.275	-3.238	-0.125	2.004	3.066	6.335	9.684
1956	-8.430	-5.317	-2.121	0.060	1.161	4.529	7.905
1957	-8.119	-4.719	-1.217	1.180	2.391	6.105	9.930
1958	-6.332	-2.980	0.468	2.833	4.014	7.861	11.410
1959	-8.664	-5.454	-2.154	0.108	1.237	4.721	8.301
1960	-8.598	-5.436	-2.109	0.036	1.147	4.572	8.029
1961	-5.670	-2.231	1.309	3.739	4.952	8.701	12.558
1962	-6.183	-2.455	1.397	4.048	5.374	9.481	13.720
1963	-5.124	-1.259	2.738	5.491	6.869	11.140	15.554
1964	-6.599	-2.456	1.845	4.817	6.307	10.937	15.738
1965	-11.275	-6.791	-2.108	1.143	2.779	7.879	13.199
1966	-15.362	-10.534	-5.243	-1.644	0.325	6.182	12.341
1967	-23.392	-18.301	-12.909	-9.119	-7.198	-1.152	5.246
1968	-24.744	-19.310	-13.521	-9.435	-7.358	-0.798	6.182
1969	-26.204	-20.659	-14.736	-10.544	-8.411	-1.660	5.543
1970	-23.010	-17.141	-10.865	-6.419	-4.156	3.013	10.670
1971	-20.883	-14.155	-7.403	-2.749	-0.336	7.315	15.503
1972	-17.725	-11.241	-4.505	0.342	2.811	10.648	19.013
1973	-15.326	-8.731	-1.668	3.341	5.894	13.987	22.646
1974	-18.066	-12.109	-5.764	-1.284	0.992	8.181	15.829
1975	-16.318	-10.403	-4.116	0.315	2.564	9.858	17.108
1976	-15.840	-9.791	-3.364	1.187	3.493	10.773	18.510

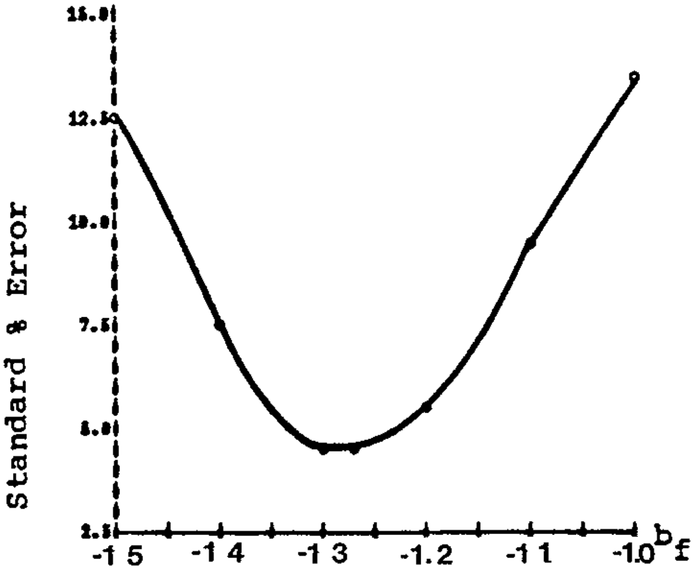


Figure VI-5 Sensitivity of Projection to Different Values of b_f

Avge Absolute % Error \ b	▼1.000	▼0.500	▼0.200	0.000	0.200	0.500
Avge Absolute % Error	6.002	3.995	2.996	3.140	3.898	5.523
Standard % Error	7.538	4.734	3.970	4.212	5.015	6.854
Year		Percentage Error	100 (Actual Value-Predicted Value) / Actual Value			
1949	▼5.163	▼3.748	▼2.899	▼2.332	▼1.766	▼0.917
1950	▼4.821	▼0.384	2.321	4.142	5.977	8.756
1951	▼11.937	▼4.832	▼0.400	2.627	5.712	10.450
1952	▼8.491	▼2.410	1.250	3.732	6.229	10.015
1953	▼9.296	▼4.612	▼1.804	0.064	1.928	4.717
1954	▼4.597	▼0.466	1.972	3.578	5.168	7.522
1955	▼7.789	▼2.970	▼0.086	1.832	3.744	6.601
1956	▼8.975	▼4.509	▼1.851	▼0.090	1.662	4.269
1957	▼4.776	▼1.743	▼0.018	1.090	2.165	3.711
1958	▼3.233	▼0.148	1.606	2.733	3.826	5.399
1959	▼6.528	▼3.174	▼1.250	▼0.003	1.213	2.979
1960	▼2.262	▼0.964	▼0.341	0.008	0.304	0.650
1961	6.097	5.146	4.382	3.794	3.146	2.052
1962	7.192	5.852	4.857	4.117	3.310	2.012
1963	11.527	8.752	6.908	5.610	4.260	2.143
1964	10.881	8.090	6.239	4.936	3.503	1.462
1965	5.061	3.342	2.118	1.226	0.275	▼1.256
1966	▼2.191	▼1.636	▼1.523	▼1.539	▼1.627	▼1.894
1967	▼6.668	▼7.644	▼8.442	▼9.060	▼9.744	▼10.890
1968	▼3.677	▼6.295	▼8.064	▼9.319	▼10.631	▼12.699
1969	▼1.531	▼5.797	▼8.511	▼10.375	▼12.278	▼15.196
1970	5.060	▼0.455	▼3.884	▼6.289	▼8.559	▼12.121
1971	10.879	4.268	0.219	▼2.503	▼5.237	▼9.347
1972	10.277	5.608	2.605	0.531	▼1.595	▼4.869
1973	14.533	9.232	5.864	3.852	1.194	▼2.417
1974	4.063	1.750	0.067	▼1.169	▼2.492	▼4.630
1975	8.074	4.555	2.168	0.472	▼1.301	▼4.093
1976	4.988	3.482	2.240	1.279	0.214	▼1.568

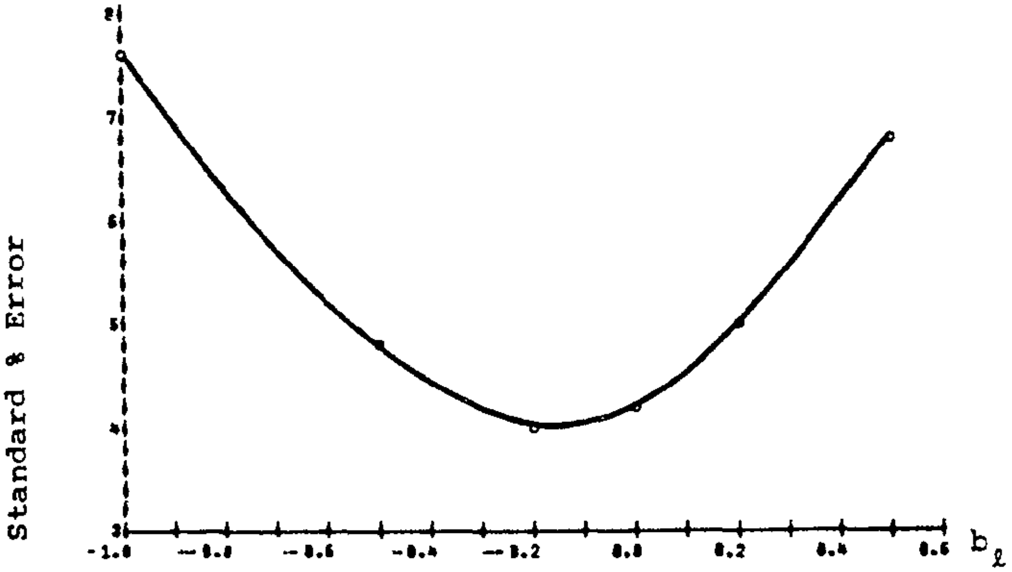


Figure VI-6 Sensitivity of Projection to Different Values of b_ℓ

b	0.800	0.900	0.924	1.000	1.200	1.400
Avge Absolute % Error	6.440	3.359	3.184	5.106	15.254	27.779
Standard % Error	8.414	4.634	4.264	5.721	17.111	31.430
Year	Percentage Error	100 (Actual Value-Predicted Value) / Actual Value				
1949	-2.332	-2.291	-2.281	-2.250	-2.168	-2.086
1950	3.273	4.106	4.306	4.940	6.609	8.280
1951	1.201	2.372	2.903	3.953	6.744	9.573
1952	1.908	3.357	3.956	5.224	8.608	12.068
1953	-2.266	-0.255	0.232	1.786	5.958	10.255
1954	1.104	3.227	3.722	5.300	9.535	13.890
1955	-1.476	1.323	2.004	4.104	10.091	16.255
1956	-3.752	-0.600	0.068	2.470	9.012	15.888
1957	-2.840	0.398	1.188	3.725	10.650	17.952
1958	-1.114	2.059	2.833	5.314	12.075	19.183
1959	-4.602	-0.799	0.108	3.024	11.042	19.577
1960	-4.845	-0.925	0.036	3.333	11.674	20.813
1961	-1.581	2.690	3.739	7.120	16.479	26.536
1962	-1.969	2.858	4.048	7.294	18.621	30.277
1963	-1.073	4.191	5.491	9.703	21.514	34.447
1964	-2.317	3.400	4.817	9.418	22.412	36.783
1965	-6.356	-0.350	1.143	6.006	19.839	35.298
1966	-9.435	-3.119	-1.544	3.601	18.343	34.990
1967	-16.661	-10.626	-9.119	-4.189	9.986	26.076
1968	-17.351	-11.020	-9.435	-4.241	10.778	27.960
1969	-18.563	-12.151	-10.544	-5.273	10.014	27.576
1970	-14.722	-8.002	-6.419	-0.966	14.830	32.943
1971	-11.678	-4.540	-2.749	3.133	20.237	39.959
1972	-9.690	-1.678	0.342	6.997	25.540	45.391
1973	-7.538	1.146	3.341	10.593	32.030	57.332
1974	-11.390	-3.321	-1.284	5.432	25.209	48.418
1975	-9.760	-1.713	0.315	6.999	26.628	49.575
1976	-9.538	-0.978	1.187	8.337	29.482	54.448

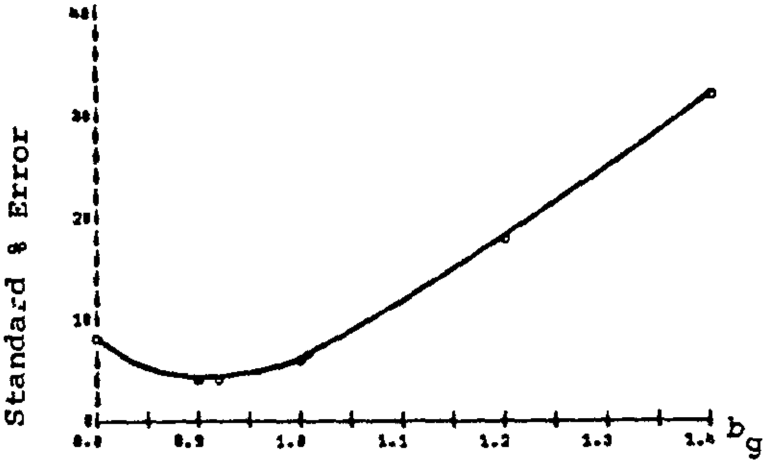


Figure VI-7 Sensitivity of Projection to Different Values of b_g

b	2.000	2.500	3.000	3.358	3.600	4.000
Avge Absolute % Error	23.252	15.610	7.262	3.184	5.956	14.677
Standard % Error	26.295	18.084	9.105	4.264	6.655	15.721
Year	Percentage Error 100 (Actual Value-Predicted Value) / Actual Value					
1949	▼4.885	▼3.927	▼2.968	▼2.281	▼1.817	▼1.050
1950	▼0.228	1.430	3.101	4.306	5.124	6.483
1951	▼3.378	▼1.095	1.222	2.903	4.049	5.962
1952	▼4.388	▼1.376	1.706	3.356	5.497	8.083
1953	▼9.704	▼6.142	▼2.468	0.232	2.090	5.222
1954	▼8.511	▼4.155	0.373	3.722	6.038	9.961
1955	▼11.843	▼5.945	▼1.815	2.004	4.657	9.172
1956	▼15.407	▼9.971	▼4.234	0.068	3.071	8.207
1957	▼16.360	▼10.241	▼3.729	1.108	4.637	10.567
1958	▼16.888	▼10.857	▼2.734	2.833	6.757	13.538
1959	▼20.710	▼13.553	▼5.814	0.108	4.300	11.580
1960	▼22.398	▼14.738	▼6.392	0.036	4.60°	12.585
1961	▼21.164	▼12.720	▼3.449	3.739	0.873	17.875
1962	▼22.384	▼13.478	▼3.631	4.048	9.555	19.256
1963	▼22.656	▼13.227	▼2.736	5.491	11.414	21.890
1964	▼24.436	▼14.693	▼3.783	4.817	11.032	22.069
1965	▼28.121	▼18.422	▼7.503	1.143	7.412	18.582
1966	▼30.339	▼21.241	▼10.269	▼1.544	4.001	15.141
1967	▼37.048	▼27.874	▼17.445	▼9.119	▼3.047	7.038
1968	▼38.087	▼28.660	▼17.988	▼9.435	▼3.101	8.062
1969	▼39.522	▼30.084	▼19.256	▼10.544	▼4.157	7.361
1970	▼37.623	▼27.510	▼15.846	▼6.419	0.514	13.059
1971	▼36.040	▼25.301	▼12.853	▼2.749	4.704	18.232
1972	▼34.676	▼23.420	▼10.323	0.342	8.227	22.574
1973	▼33.370	▼21.610	▼7.877	3.341	11.653	26.812
1974	▼37.002	▼25.601	▼12.237	▼1.284	6.849	21.728
1975	▼36.583	▼24.920	▼11.073	0.315	8.793	24.334
1976	▼36.589	▼24.884	▼10.506	1.107	9.988	25.930

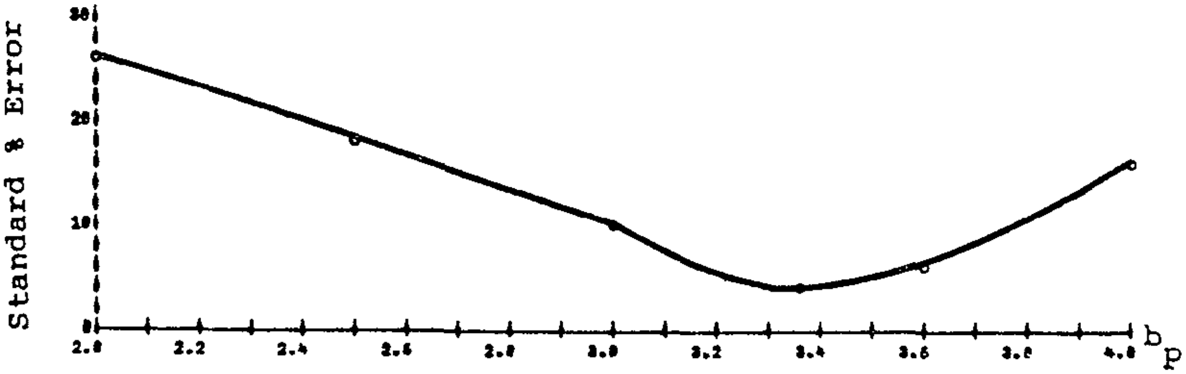


Figure VI-8 Sensitivity of Projection to Different Values of b_p

	Change in Demand Over the Year Before	Change in Current $ Fare Over the Year Before	Change in Load Factor Over the Year Before	Change in Current $ GNP Over the Year Before	Change in Population Over the Year Before
1949	0.138	¯0.022	0.032	0.005	0.022
1950	0.228	¯0.114	0.077	0.110	0.017
1951	0.280	¯0.036	0.077	0.153	0.017
1952	0.144	¯0.030	¯0.034	0.052	0.017
1953	0.132	0.018	¯0.029	0.055	0.016
1954	0.098	¯0.056	¯0.018	0.001	0.017
1955	0.216	¯0.037	0.020	0.091	0.018
1956	0.145	¯0.003	¯0.007	0.053	0.018
1957	0.110	0.003	¯0.038	0.052	0.018
1958	0.019	0.039	0.000	0.014	0.017
1959	0.150	0.016	0.008	0.081	0.017
1960	0.076	0.022	¯0.049	0.041	0.016
1961	0.068	¯0.010	¯0.051	0.033	0.017
1962	0.162	¯0.026	¯0.009	0.076	0.016
1963	0.089	0.001	¯0.028	0.054	0.014
1964	0.166	¯0.028	¯0.001	0.071	0.014
1965	0.238	¯0.052	0.021	0.083	0.013
1966	0.272	¯0.078	0.053	0.095	0.012
1967	0.259	¯0.048	¯0.029	0.059	0.011
1968	0.163	¯0.023	¯0.041	0.089	0.010
1969	0.110	0.022	¯0.038	0.076	0.010
1970	0.001	0.048	¯0.020	0.050	0.011
1971	0.054	0.023	¯0.017	0.075	0.011
1972	0.056	0.039	0.039	0.115	0.008
1973	0.051	0.058	¯0.009	0.116	0.008
1974	¯0.006	0.160	0.046	0.082	0.007
1975	¯0.023	0.112	¯0.021	0.073	0.008
1976	0.087	0.045	0.040	0.116	0.007

Table VI - 3 Historical Change in Demand and Its Determinants over Their Values in the Year Before (Current Dollars)

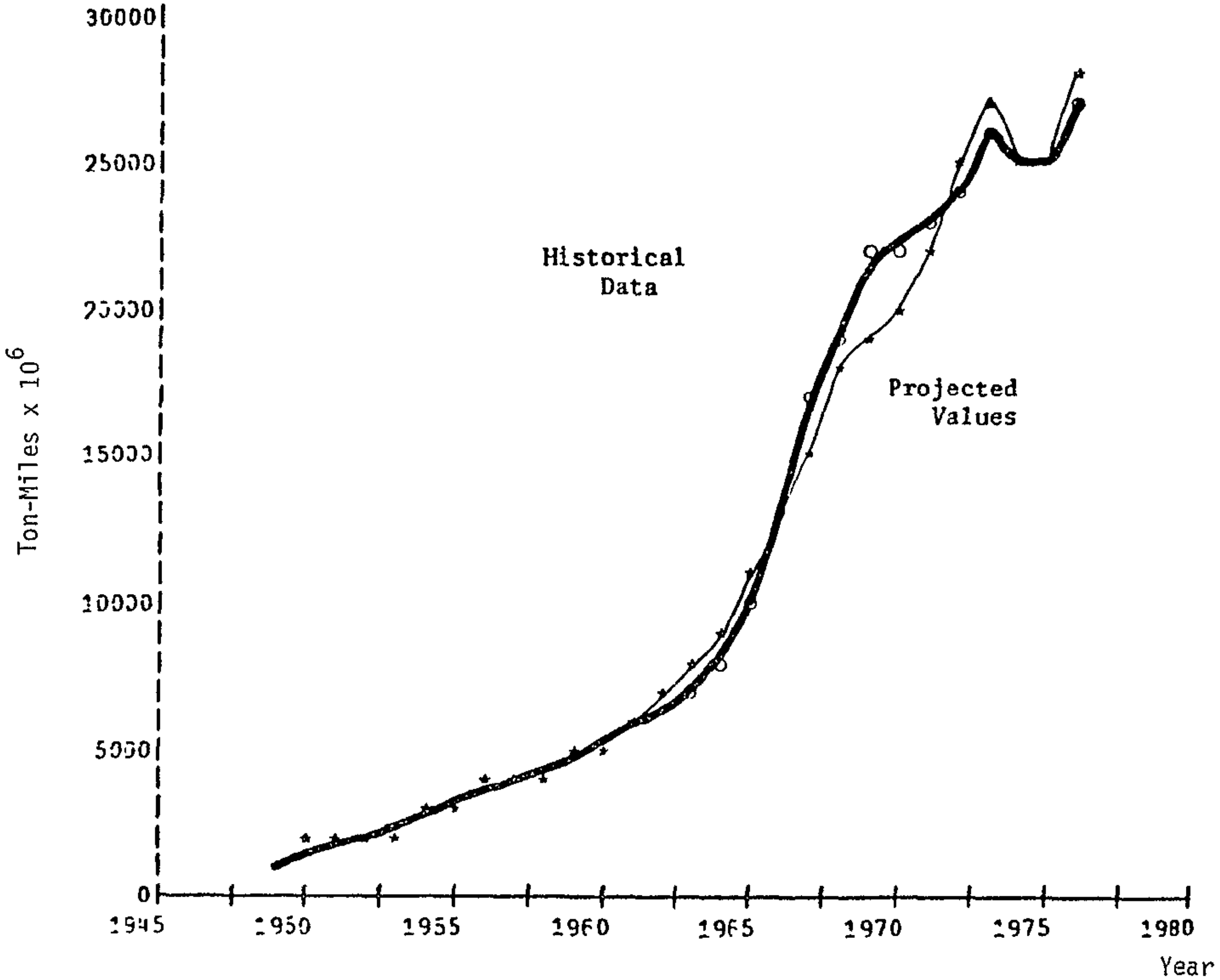


Figure VI - 9 Projected and Actual Demand for Air Transportation.

Deviations from Historical Data,

Year	Percent
1949	▾2.1
1950	4.1
1951	2.3
1952	2.9
1953	▾0.2
1954	3.0
1955	1.6
1956	▾0.2
1957	0.4
1958	2.3
1959	0.2
1960	0.4
1961	4.2
1962	4.7
1963	6.6
1964	6.2
1965	2.5
1966	▾0.3
1967	▾8.2
1968	▾8.6
1969	▾9.9
1970	▾6.0
1971	▾2.1
1972	2.1
1973	5.4
1974	▾0.1
1975	0.8
1976	2.3

Variable	d	f	ℓ	g	p
Initial Value	1077	0.664	0.53	255.3	146.6

In terms of accuracy of the prediction, both models seen comparable. Although a lower value for the constant (under a in the regression result) and a lower value for b_ℓ favors the model using constant dollars, we will decide which model to use when we do the same for fare and compare the results.

Formulating Fare Relationships

The other exogenous variable of the system (Figure VI-1) is the average revenue per ton-mile (fare). Isolating this variable and its determinants produces Figure VI-10

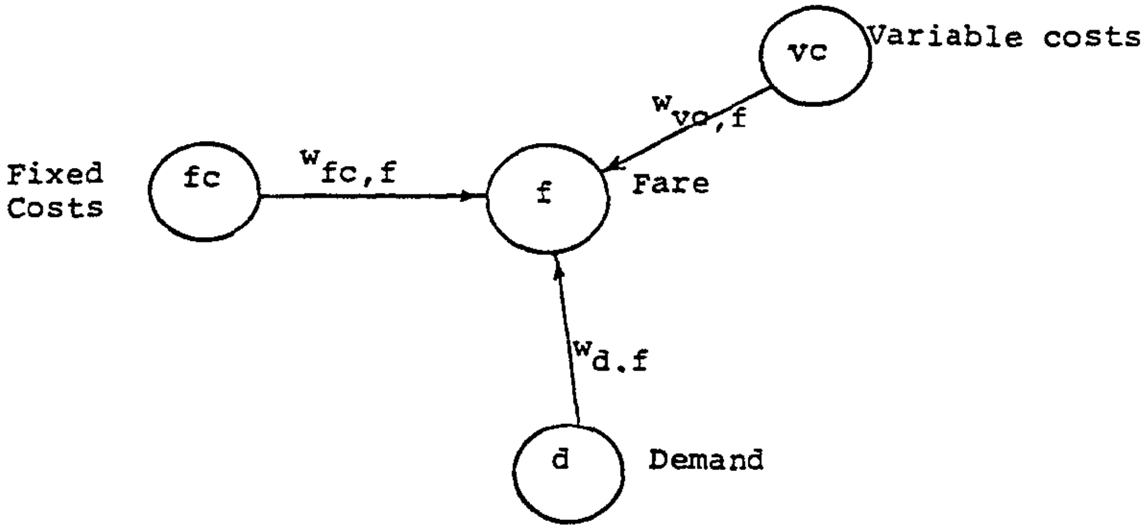


Figure VI-10 Fare and Its Determinants

To establish relationship among these four variables, first we assume that all weights are constant. With this assumption, the result of multiple-regression on historical data, Table VI-4, is the following:

Year	Change in Fare (1972 $)	Change in Demand Ton-Miles MM	Change in DOC (1972 $)	Change in Other Costs (1972 $)
1949	-0.026	149.0	-0 033	-0 033
1950	-0.140	280.0	-0.075	-0.089
1951	-0.107	422.0	-0.076	-0.052
1952	-0.045	278.0	-0.003	0.017
1953	0.008	292.0	0.011	-0.022
1954	-0.052	246.0	-0.008	-0.017
1955	-0.027	594.0	-0.034	-0.009
1956	-0.013	485.0	-0.005	0.006
1957	-0.025	420.0	-0.006	0.010
1958	0.005	81.0	-0.013	0.010
1959	0.005	649.0	-0.002	0.009
1960	0.004	380.0	0.006	0.012
1961	-0.015	364.0	0.004	-0.002
1962	-0.027	925.0	-0.041	-0.026
1963	-0.008	590.0	-0.019	-0.004
1964	-0.028	1199.0	-0.028	-0.024
1965	-0.047	2008.0	-0.035	-0.024
1966	-0.066	2836.0	-0.028	-0.033
1967	-0.042	3439.0	-0.008	-0.016
1968	-0.032	2723.0	-0.007	-0.005
1969	-0.015	2137.0	-0.001	-0.001
1970	-0.005	32.0	0.001	0.013
1971	-0.010	1159.0	-0.009	-0.012
1972	0.003	1502.0	-0.011	0.004
1973	-0.001	1243.9	0.000	0.001
1974	0.021	-157.7	0.023	0.007
1975	0.009	-582.6	0.001	0.010
1976	-0.006	2144.3	-0.006	-0.015

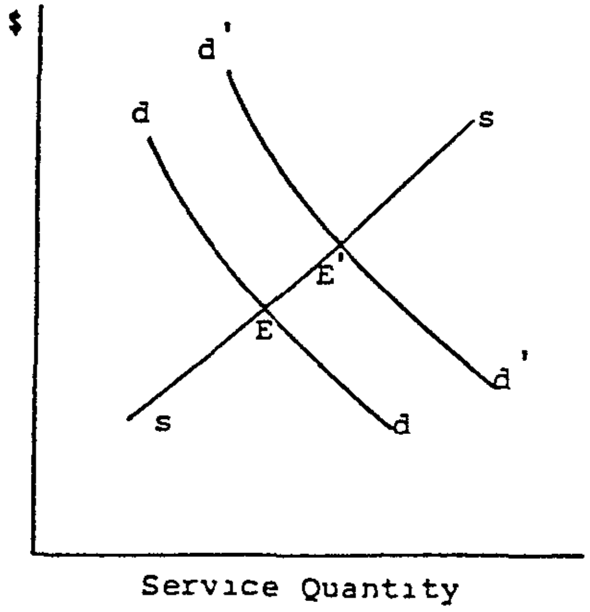
Table VI - 4 **Historical Change in Fare and its Determinants.**

MM = million

Independent Variables	a	b_i	R^2	F
	-0.004		0.747	23.593
d		0.000		
vc		0.775		
fc		0.611		

The hypothesis of linear relationship is rejected on the basis of an economic principle that we know that fare responds to demand, but the result of multiple regression shows the weight of the relationship between fare and demand, b_d, is zero.

Next, as economic theory states, fare responsiveness to demand is elasticity of supply. Consider Figure VI-11. The supply curve is the summation of marginal costs. Increase in demand shifts the demand curve to the right and therefore:



if $\Delta D = \Delta S$,

$$\frac{\frac{\Delta D}{D}}{\frac{\Delta F}{F}} = \text{Marginal Cost}$$

Figure VI-11 Fare and Marginal Cost

Let us assume that the relationships between fare and its determinants are elasticity relationships similar to what we had for the demand model. Analyzing the historical data, Table VI-4, by multiple regression, we obtain:

	a	b_1	R^2	F
	0.004		0.658	15.360
Independent Variables				
d		-0.299		
vc		0.435		
fc		0.411		

The unexpected number is $b_d = -0.299$, since marginal cost cannot be negative. The reason for this inconsistency is that historical data of demands, in fact, reflect the historical balance of supply and demand. And due to continuous technological improvement in aircraft and in air transportation systems, the fare effectively has been going down, Figure VI-12.

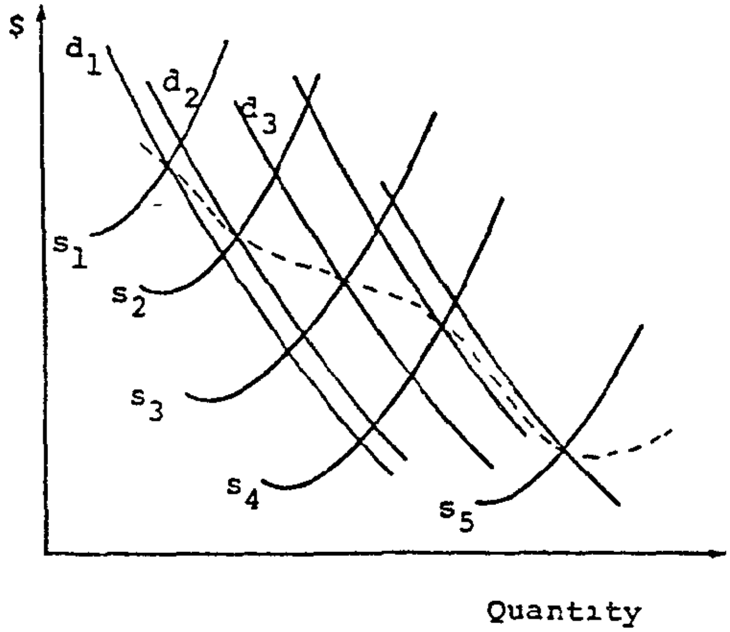


Figure VI-12 Dynamic Change in Supply and Demand

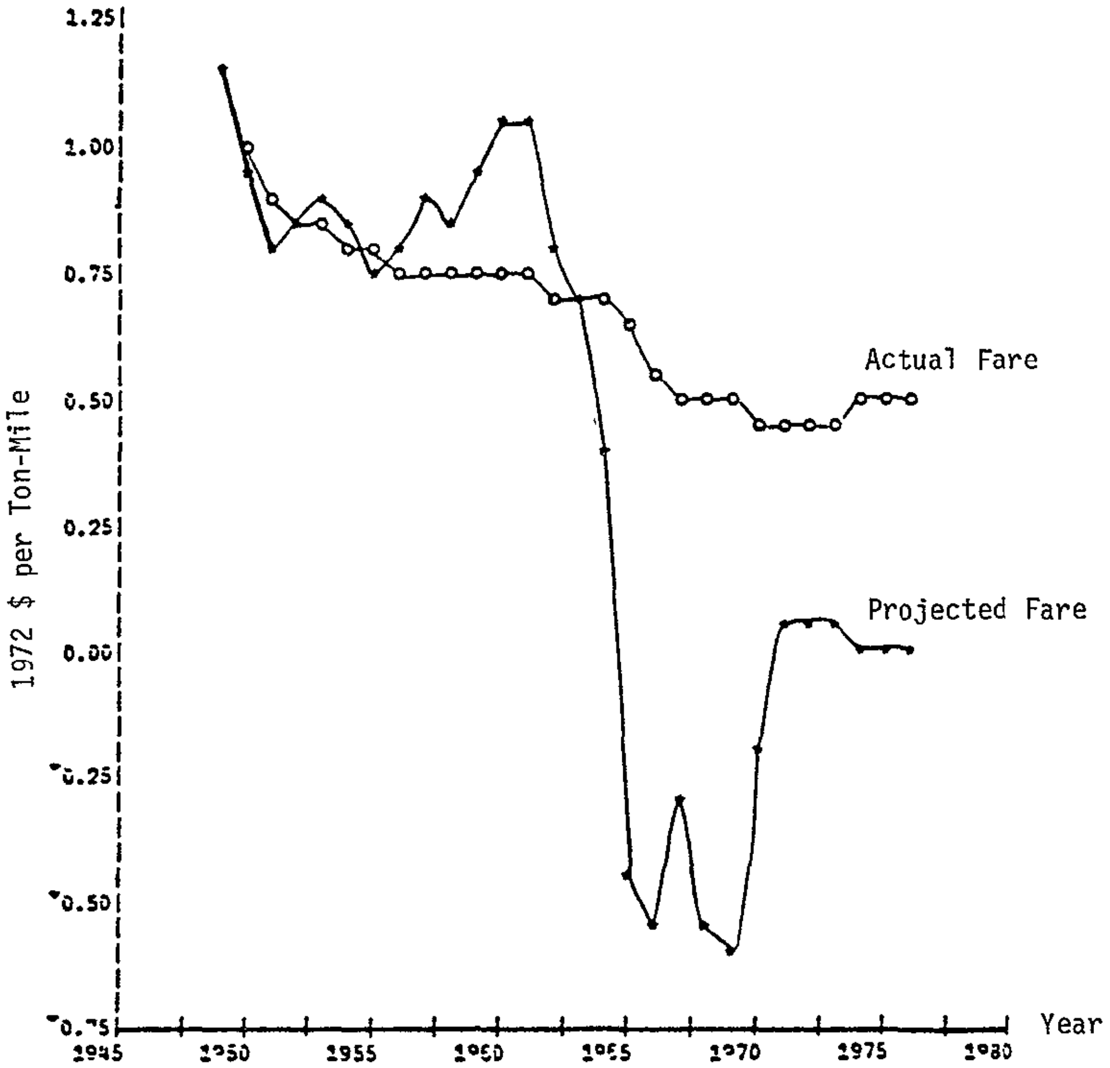


Figure VI - 13 Actual and Projected Data on Fare Model of Figure VI - 10

Therefore, if we had the historical data for marginal cost, we could concentrate on searching the relationship of fare and its other two determinants.

Measuring marginal cost, in general, is a very difficult task when the whole industry and a mix of services is being considered. A wild estimate of marginal cost would be:

$$\text{Marginal cost} = f\ (\text{Average variable cost})$$

$$= h \times (\text{Average variable cost})$$

with the assumption, say h = 1.5, the simulation run resulted in Figure VI-13. The deviation of predicted data from actual data is too much, and the pattern of the two is not consistent.

Alternative Theory

In looking for an alternative theory to explain the determinants of fare, we have to examine again the question: How does the industry respond to the demand (market) in terms of its fare? One answer is that the industry looks at the market with one eye and looks at is own unused capacity with the other eye. In other words, the industry may be looking at the ratio of the two, namely, the load factor. A decreasing load factor is the sign of having excess capacity, and therefore it will induce the industry to lower the fare if it can. With this

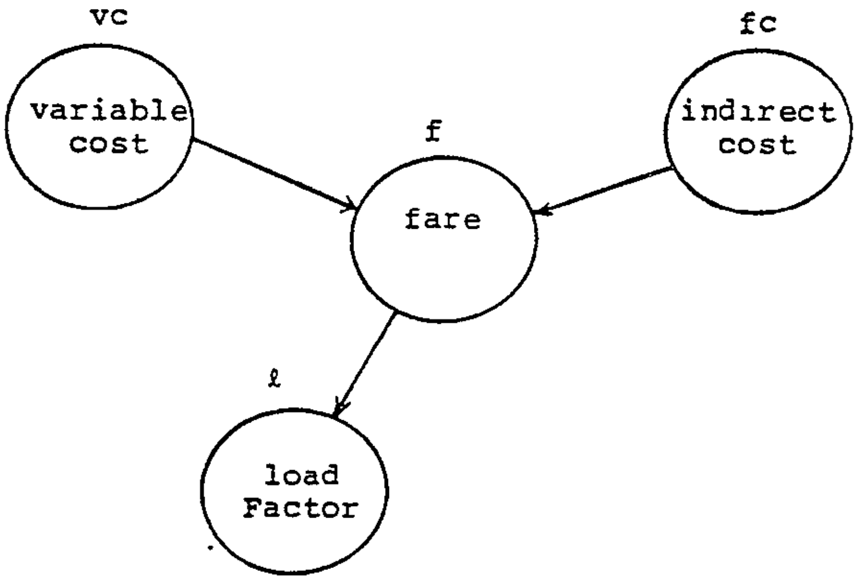


Figure VI-14 Fare and Its Determinants

assumption a subdigraph representation of fare model becomes as Figure VI-14. To establish relationships among the variables of Figure VI-14, first, we examine the assumption of linear relationships between fare and its determinants. The result of multiple regression on historical data, Table VI-5, is the following:

	a	b_i	R^2	F
	-0.004		0.757	24.886
Independent Variable				
ℓ		0.300		
vc		0.860		
fc		0.730		

All b_i's are consistent with theory. Second, to test the validity of the established relationships, we run the simulation model of Figure VI-14. With these constant weights, b_i's and the initial values as following:

Variable	f	ℓ	vc	fc
Initial Value	1.166	0.53	0.33	0.284

and the exogenous pulse as in Table V-6, the result of the simulation run produces Figure VI-15.

Sensitivity of the Fare Projection with Respect to the Parameters

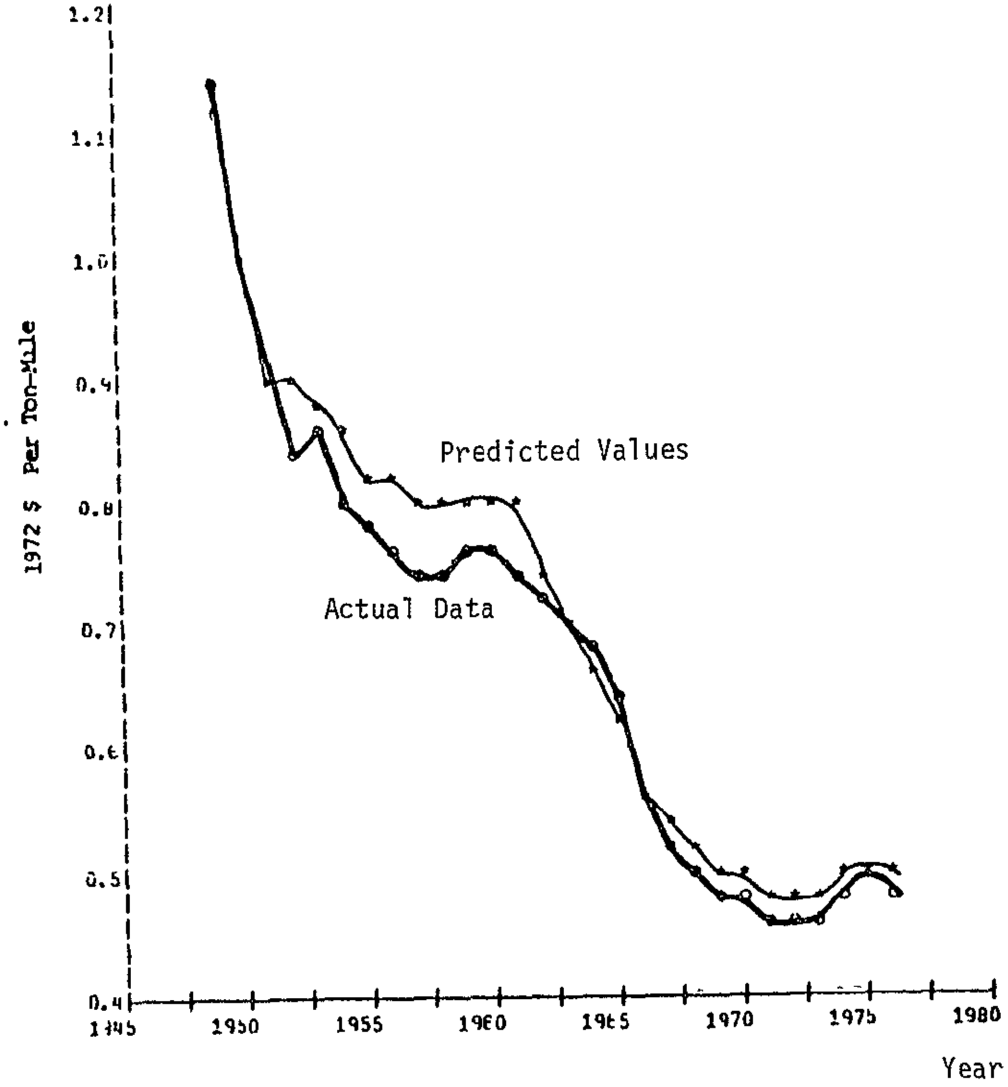
Figure VI-16, VI-17, and VI-18 and their associated tables summarize the sensitivity of projected values in terms of percentage deviation from actual data. The results of sensitivity tests also provide a hint as to which direction the parameters may be changed and how much is needed to get a closer fit with historical data.

	Change in Fare (1972 $)	Change in Load Factor	Change in DOC (1972 $)	Change in Other Costs (1972 $)
1949	¯0.026	0.017	¯0.033	¯0.033
1950	¯0.140	0.042	¯0.075	¯0.089
1951	¯0.107	0.045	¯0.076	¯0.052
1952	¯0.045	¯0.021	¯0.003	0.017
1953	0.008	¯0.018	0.011	¯0.022
1954	¯0.052	¯0.011	¯0.008	¯0.017
1955	¯0.027	0.012	¯0.034	¯0.009
1956	¯0.013	¯0.004	¯0.005	0.006
1957	¯0.025	¯0.023	¯0.006	0.010
1958	0.009	0.000	¯0.013	0.010
1959	0.005	0.005	¯0.002	0.009
1960	0.004	¯0.028	0.006	0.012
1961	¯0.015	¯0.028	0.004	¯0.002
1962	¯0.027	¯0.004	¯0.041	¯0.026
1963	¯0.008	¯0.015	¯0.019	¯0.004
1964	¯0.028	0.000	¯0.028	¯0.024
1965	¯0.047	0.011	¯0.035	¯0.024
1966	¯0.066	0.027	¯0.028	¯0.033
1967	¯0.042	¯0.021	¯0.008	¯0.016
1968	¯0.032	¯0.021	¯0.007	¯0.005
1969	¯0.015	¯0.019	¯0.001	¯0.001
1970	¯0.005	¯0.010	0.001	0.013
1971	¯0.010	¯0.008	¯0.009	¯0.012
1972	0.003	0.018	¯0.011	0.004
1973	¯0.001	¯0.004	0.000	0.001
1974	0.021	0.022	0.023	0.007
1975	0.009	¯0.011	0.001	0.010
1976	¯0.006	0.019	¯0.006	¯0.015

Table VI - 5 **Historical Change in Fare and Its Determinants**
(Figure VI - 14)

Period	f	ℓ	vc	fc
1949	¯0.004	0.017	¯0.033	¯0.033
1950		0.042	¯0.075	¯0.083
1951		0.045	¯0.075	¯0.052
1952		¯0.021	¯0.003	0.017
1953		¯0.018	0.011	¯0.022
1954		¯0.011	¯0.008	¯0.017
1955		0.012	¯0.034	¯0.009
1956		¯0.004	¯0.005	0.005
1957		¯0.023	¯0.006	0.010
1958		0.000	¯0.013	0.010
1959		0.005	¯0.002	0.009
1960		¯0.028	0.006	0.012
1961		¯0.028	0.004	¯0.002
1962		¯0.004	¯0.041	¯0.026
1963		¯0.015	¯0.019	¯0.004
1964		0.000	¯0.028	¯0.024
1965		0.011	¯0.035	¯0.024
1966		0.027	¯0.028	¯0.033
1967		¯0.021	¯0.008	¯0.016
1968		¯0.021	¯0.007	¯0.006
1969		¯0.019	¯0.001	¯0.001
1970		¯0.010	0.001	0.013
1971		¯0.008	¯0.009	¯0.010
1972		0.018	¯0.011	0.004
1973		¯0.004	0.000	0.001
1974		0.022	0.023	0.007
1975		¯0.011	0.001	0.010
1976		0.019	¯0.006	¯0.015

Table VI - 6 **Exogenous Pulse to Fare System of** Figure VI - 14



Year	Deviation from Historical Data, %
1949	-2.251
1950	-0.570
1951	0.874
1952	6.155
1953	3.276
1954	6.630
1955	5.620
1956	6.767
1957	9.211
1958	6.757
1959	6.257
1960	5.903
1961	6.571
1962	2.346
1963	-0.515
1964	-3.129
1965	-3.465
1966	-0.119
1967	2.465
1968	5.117
1969	5.880
1970	7.787
1971	5.081
1972	3.232
1973	2.481
1974	3.606
1975	1.892
1976	0.199

Figure VI - 15 Actual and Predicted Values of Average Revenue per Ton Mile (All Services)

b 2	-1.000	-0.500	0.000	0.347	0.500	1.000
Avge Absolute % Error	9.747	6.929	5.161	4.600	4.498	5.263
Standard Percentage Error	12.409	8.994	6.200	5.195	5.160	6.743
Year	Percentage Error 100 (Actual Value-Predicted Value)/Actual Value					
1949	-4.068	-3.319	-2.570	-2.050	-1.821	-1.072
1950	-7.730	-4.768	-1.805	0.248	1.155	4.117
1951	-14.292	-8.433	-2.573	1.491	3.286	9.145
1952	-6.917	-2.004	2.910	6.318	7.824	12.737
1953	-7.424	-3.597	0.231	2.886	4.058	7.886
1954	-2.807	0.587	3.981	6.336	7.376	10.770
1955	-6.225	-1.956	2.313	5.275	6.583	10.853
1956	-4.725	-0.649	3.427	6.254	7.503	11.579
1957	1.826	4.513	7.200	9.063	9.887	12.574
1958	-0.285	2.371	5.027	6.870	7.684	10.340
1959	-1.347	1.610	4.567	6.619	7.525	10.482
1960	3.633	4.719	5.805	6.558	6.891	7.977
1961	10.161	9.397	8.633	8.103	7.869	7.105
1962	7.561	6.464	5.368	4.607	4.272	3.175
1963	7.363	5.223	3.082	1.598	0.942	-1.198
1964	4.750	2.495	0.241	-1.323	-2.013	-4.268
1965	2.071	0.485	-1.100	-2.200	-2.686	-4.272
1966	-0.942	-0.325	0.291	0.719	0.908	1.525
1967	6.084	4.778	3.472	2.567	2.167	0.861
1968	14.446	10.926	7.406	4.954	3.885	0.365
1969	20.859	15.279	9.700	5.830	4.120	-1.460
1970	26.434	19.762	13.090	8.461	6.417	-0.255
1971	27.193	19.540	11.887	6.579	4.234	-3.419
1972	20.322	14.637	8.951	5.008	3.266	-2.419
1973	20.921	14.758	8.595	4.320	2.432	-3.731
1974	15.608	11.931	8.254	5.703	4.577	0.900
1975	16.833	12.155	7.476	4.231	2.797	-1.881
1976	10.093	7.321	4.550	2.627	1.778	-0.993

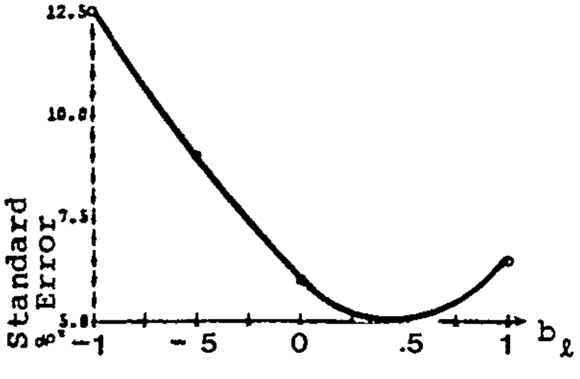


Figure VI - 16 Sensitivity of Projection to Different Values of b_ℓ

b	0.600	0.750	0.811	0.900	0.950	1.100
Avge. Absolute % Error	14.932	7.411	4.600	3.226	4.589	10.354
Standard Percentage Error	15.488	8.164	5.195	3.680	5.390	13.228
Year	Percentage Error	100(Actual Value-Predicted Value)/ Actual Value				
1949	-1.435	-1.872	-2.050	-2.310	-2.456	-2.893
1950	2.525	0.987	0.248	-0.711	-1.251	-2.869
1951	5.830	2.746	1.491	-0.338	-1.366	-4.450
1952	10.975	7.666	6.318	4.356	3.253	-0.857
1953	7.227	4.142	2.886	1.055	0.028	-3.057
1954	11.164	7.733	6.335	4.382	3.158	-0.273
1955	11.196	6.988	5.275	2.780	1.378	-2.830
1956	12.425	8.039	6.254	3.654	2.192	-2.193
1957	15.601	10.955	9.063	6.309	4.760	0.115
1958	13.705	8.848	6.878	3.989	2.370	-2.488
1959	13.472	8.682	6.619	3.731	2.187	-2.753
1960	13.203	8.481	6.558	3.759	2.185	-2.537
1961	14.781	10.036	8.103	5.290	3.708	-1.038
1962	12.744	6.962	4.607	1.179	-0.748	-6.531
1963	10.388	4.141	1.598	-2.106	-4.188	-10.455
1964	8.711	1.380	-1.323	-5.550	-7.927	-15.058
1965	9.743	1.255	-2.200	-7.233	-10.062	-18.550
1966	15.102	-4.881	0.719	-3.341	-8.749	-18.970
1967	18.420	7.153	2.367	-4.113	-7.858	-19.135
1968	22.182	9.946	4.964	-2.290	-6.369	-18.685
1969	23.637	10.982	5.830	-1.674	-5.892	-18.547
1970	26.400	13.852	8.461	0.983	-3.347	-16.095
1971	25.300	11.995	6.579	-1.910	-5.745	-19.049
1972	24.117	10.537	5.008	-3.044	-7.570	-21.151
1973	23.504	9.870	4.320	-3.763	-8.308	-21.942
1974	23.028	10.716	5.703	-1.596	-5.700	-18.012
1975	21.212	9.144	4.231	-2.924	-6.947	-19.015
1976	20.068	7.674	2.627	-4.721	-8.853	-21.248

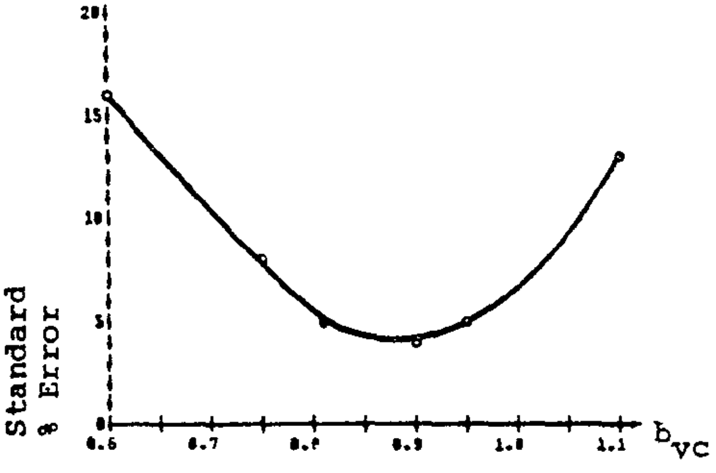


Figure VI - 17 **Sensitivity of Projection to Different Values of b_{vc}**

b	0.400	0.600	0.646	0.700	0.750	0.900
Avge Absolute % Error	13.297	6.858	4.600	3.130	2.790	5.802
Standard Percentage Error	14.446	6.752	5.195	3.774	3.934	7.205
Year	Percentage Error· 100 (Acutal Value-Predicted Value) /Actual Value					
1949	-1.337	-1.917	-2.058	-2.207	-2.352	-2.785
1950	3.253	0.811	0.248	-0.410	-1.021	-2.852
1951	6.274	2.387	1.491	0.443	-0.529	-3.444
1952	10.863	7.169	6.318	5.323	4.399	1.629
1953	8.815	3.846	2.886	1.762	0.728	-2.407
1954	12.304	7.453	6.336	5.828	3.816	0.178
1955	11.729	6.484	5.275	3.851	2.550	-1.384
1956	12.626	7.447	6.254	4.858	3.554	-0.320
1957	15.320	10.235	9.063	7.693	6.421	2.607
1958	12.736	7.968	6.878	5.585	4.393	0.817
1959	12.163	7.657	6.619	5.404	4.278	0.898
1960	11.665	7.515	6.558	5.440	4.402	1.289
1961	13.392	9.094	8.103	6.945	5.878	2.646
1962	10.984	5.802	4.607	3.210	1.915	-1.972
1963	8.195	2.833	1.598	0.153	-1.188	-3.209
1964	6.419	0.127	-1.323	-3.019	-4.592	-5.311
1965	7.044	-0.469	-2.200	-4.226	-6.104	-11.739
1966	12.453	2.916	0.719	-1.852	-4.236	-11.388
1967	15.999	5.082	2.567	-0.376	-3.105	-11.293
1968	19.514	7.689	4.964	1.777	-1.180	-10.848
1969	20.890	8.650	5.830	2.530	-0.530	-9.710
1970	23.010	11.186	8.461	5.274	2.318	-6.551
1971	22.053	9.477	6.579	3.188	0.844	-9.388
1972	20.187	7.851	5.008	1.682	-1.402	-10.654
1973	19.484	7.160	4.320	0.998	-2.083	-11.327
1974	19.858	9.354	5.703	2.602	-0.274	-8.901
1975	17.605	6.735	4.231	1.300	-1.417	-9.569
1976	16.932	5.306	2.627	-0.505	-3.413	-12.132

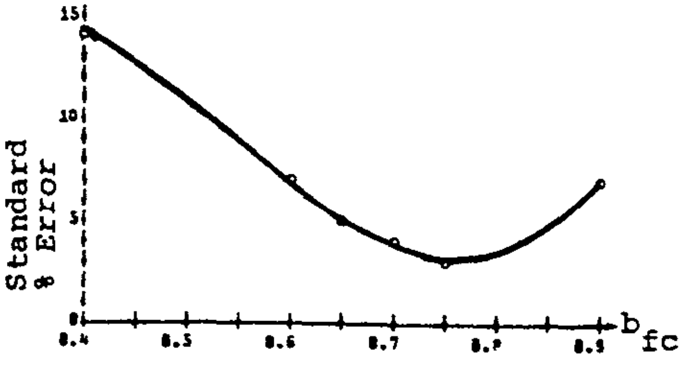


Figure VI - 18 Sensitivity of Projection to Different Values of b_{fc}

Alternatively, if we may assume an elasticity relationship between fare and its determinants, the result of multiple regression on historical data, Table VI-7, is the following:

Independent Variable	a	b_1	R^2	F
	-0.008		0.690	17.813
ℓ		0.218		
vc		0.340		
fc		0.377		

The result is consistent and comparable with the one before. However, in comparing the two there are reasons which encourage the use of constant weight relationships because: 1) in an elastic model, the constant coefficient a has a higher magnitude. 2) R^2 and F both have lower values, and 3) the relative weight for vc is lower than fc, which is in contrast to common understanding that changes in variable costs are more influential on fare than changes of fixed costs.

Fare Model with Current Dollar

To check if a better model can be made using current dollars for fare, variable and fixed costs, the data of Table VI-8 is regressed with the following result:

	a	b_i	R^2	F
	0.001		0.844	43.246
Independent Variable				
ℓ		0.310		
vc		0.824		
fc		0.864		

With initial value of:

Variable	f	ℓ	vc	fc
Initial Value	0.664	0.53	0.19	0.16

Year	Change in Fare (1972 $) Over the Year Before	Change in Load Factor Over the Year Before	Change in DOC Over the Year Before (1972 $)	Change in Indirect Over the Year Before (1972 $)
1949	-0.022	0.032	-0.053	-0.062
1950	-0.123	0.077	-0.126	-0.177
1951	-0.107	0.077	-0.147	-0.125
1952	-0.051	-0.034	-0.008	0.047
1953	0.010	-0.029	0.025	-0.058
1954	-0.060	-0.018	-0.018	-0.047
1955	-0.033	0.020	-0.078	-0.026
1956	-0.017	-0.007	-0.013	0.018
1957	-0.032	-0.038	-0.014	0.029
1958	0.012	0.000	-0.034	0.028
1959	0.007	0.008	-0.005	0.024
1960	0.005	-0.049	0.016	0.034
1961	-0.020	-0.051	0.009	-0.006
1962	-0.037	-0.008	-0.105	-0.069
1963	-0.011	-0.028	-0.055	-0.013
1964	-0.040	-0.001	-0.085	-0.070
1965	-0.070	0.021	-0.115	-0.074
1966	-0.104	0.053	-0.107	-0.110
1967	-0.074	-0.039	-0.033	-0.061
1968	-0.062	-0.041	-0.033	-0.019
1969	-0.030	-0.038	-0.006	-0.005
1970	-0.011	-0.020	0.006	0.053
1971	-0.020	-0.017	-0.041	-0.045
1972	0.006	0.039	-0.052	0.015
1973	-0.003	-0.009	-0.002	0.004
1974	0.046	0.046	0.115	0.027
1975	0.019	-0.021	0.003	0.041
1976	-0.012	0.040	-0.026	-0.057

Table VI - 7 **Historical Change in Fare and Its Determinants Over Their Value in the Year Before** (Figure VI - 14)

Year	Change in Fare, Current $	Change in Load Factor	Change in DOC, Current $	Change in Other Costs Current
1949	▼0.015	0.017	▼0.019	▼0.019
1950	▼0.074	0.042	▼0.040	▼0.048
1951	▼0.021	0.045	▼0.023	▼0.013
1952	▼0.017	▼0.021	0.004	0.016
1953	0.010	▼0.018	0.009	▼0.012
1954	▼0.030	▼0.011	▼0.004	▼0.010
1955	▼0.019	0.012	▼0.023	▼0.007
1956	▼0.001	▼0.004	0.000	0.007
1957	0.001	▼0.023	0.006	0.015
1958	0.020	0.000	▼0.002	0.013
1959	0.008	0.005	0.001	0.008
1960	0.011	▼0.028	0.009	0.013
1961	▼0.005	▼0.028	0.005	0.001
1962	▼0.014	▼0.004	▼0.027	▼0.016
1963	0.001	▼0.015	▼0.011	0.000
1964	▼0.015	0.000	▼0.018	▼0.015
1965	▼0.026	0.011	▼0.022	▼0.013
1966	▼0.037	0.027	▼0.016	▼0.019
1967	▼0.021	▼0.021	▼0.001	▼0.007
1968	▼0.009	▼0.021	0.001	0.004
1969	0.009	▼0.019	0.009	0.010
1970	0.020	▼0.010	0.013	0.025
1971	0.010	▼0.008	0.000	▼0.001
1972	0.018	0.018	▼0.004	0.011
1973	0.027	▼0.004	0.012	0.016
1974	0.079	0.022	0.051	0.037
1975	0.064	▼0.011	0.025	0.041
1976	0.029	0.019	0.009	▼0.001

Table VI - 8 Historical Change in Fare and Its Determinants (Figure VI - 14) in Current Dollars

Period	f	ℓ	vc	fc
1949	0.001	0.017	▼0.019	▼0.019
1950		0.042	▼0.040	▼0.048
1951		0.045	▼0.023	▼0.013
1952		▼0.021	0.004	0.016
1953		▼0.018	0.009	▼0.012
1954		▼0.011	▼0.004	▼0.010
1955		0.012	▼0.023	▼0.007
1956		▼0.004	0.000	0.017
1957		▼0.023	0.006	0.015
1958		0.000	▼0.002	0.013
1959		0.005	0.001	0.008
1960		▼0.028	0.009	0.013
1961		▼0.028	0.005	0.001
1962		▼0.004	▼0.027	▼0.016
1963		▼0.015	▼0.011	0.000
1964		0.000	▼0.018	▼0.015
1965		0.011	▼0.022	▼0.013
1966		0.027	▼0.016	▼0.019
1967		▼0.021	▼0.001	▼0.007
1968		▼0.021	0.001	0.004
1969		▼0.019	0.009	0.010
1970		▼0.010	0.013	0.025
1971		▼0.008	0.000	▼0.001
1972		0.018	▼0.004	0.011
1973		▼0.004	0.012	0.016
1974		0.022	0.051	0.037
1975		▼0.011	0.025	0.041
1976		0.019	0.009	▼0.001

Table VI - 9 Exogenous Pulse to Fare (Figure VI - 14)
Using Current Dollars

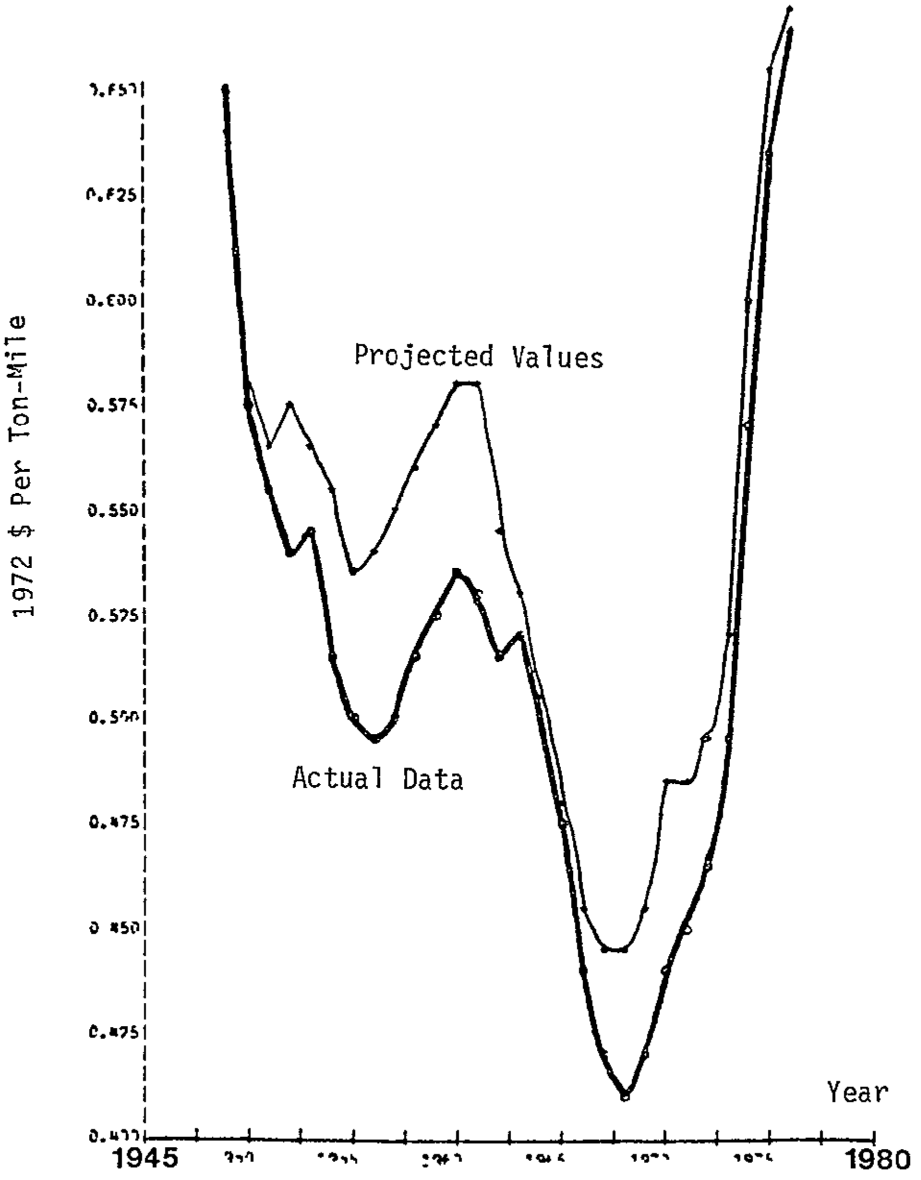


Figure VI - 19 Actual and Predicted Values of Average Revenue per Ton-Mile and an exogenous pulse as Table VI-9, the simulation run results in Figure VI-19, which in terms of accuracy of prediction is less attractive than Figure VI-15 where we used constant (1972) dollars.

In addition, dealing with constant dollars eliminates the difficulty of predicting inflation. Therefore, we prefer to use constant dollars throughout the model.

Formulating the Investment Model

Isolating the nodes representing investment and its determinants from the rest of the model (Figure VI-1), and adding the proper number of time lag nodes, produces a subdigraph representing the investment model, Figure VI-20.

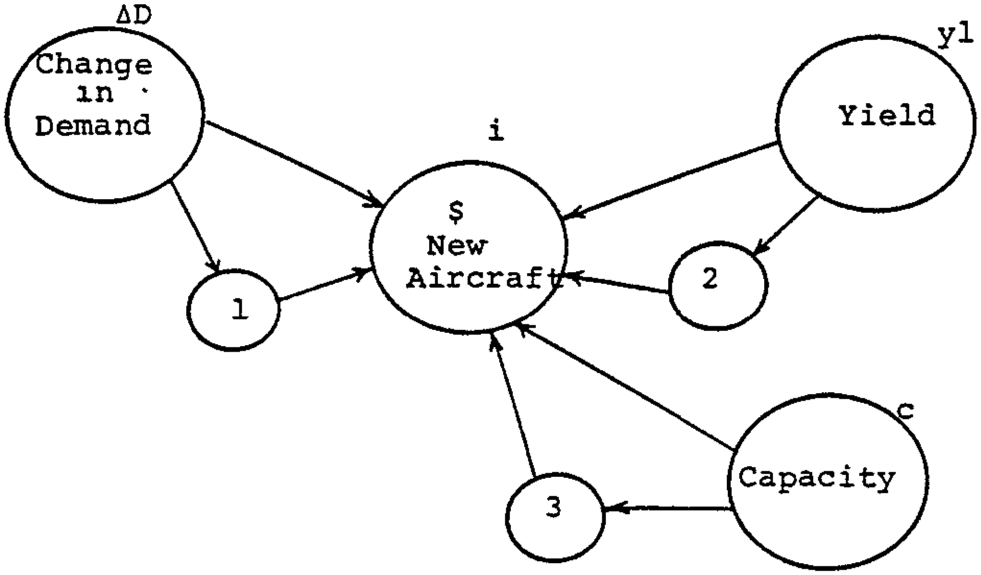


Figure VI-20 New Investment and Its Determinants

Historical data from different sources, regarding dollar value of U.S. airline purchase of flying equipment, is not totally consistent. This is especially true for data before 1960. (See Figure IV-51). Data reported by Boeing Commercial Aircraft Company seem more reliable and therefore has been used for multiple regression analysis (Table VI-10). The results are as follows:

Year	Investment in in Flying Equipment 1972 $ MM	Change in Demand Ton-Miles MM	Industry's Earning 1972 $ M M	Total Capacity Ton-Mile
1958	52.11	81.00	44.87	7589.10
1959	583.72	649.00	45.91	8555.10
1960	853.02	388.00	-26.83	9795.70
1961	795.74	364.00	-121.67	11022.80
1962	561.68	925.00	120.36	12914.50
1963	358.20	590.00	245.09	14473.00
1964	805.12	1199.00	489.02	16884.00
1965	1100.43	2008.00	721.24	20471.00
1966	1542.79	2836.00	860.08	24721.00
1967	2177.94	3439.00	775.69	32373.00
1968	3209.62	2723.00	508.87	39240.00
1969	2545.78	2137.00	307.09	45258.00
1970	1903.21	32.00	-109.92	45273.00
1971	1006.77	1159.00	143.53	49585.00
1972	1417.00	1502.00	405.00	50874.00
1973	1916.75	1243.90	375.06	53967.00
1974	1266.79	-157.70	153.78	51297.00
1975	1034.22	-582.50	102.72	51216.00
1976	704.69	2144.30	517.85	53522.00

Table VI - 10 Historical Data on Investment in Flying Equipment and its Determinants

	a	b_1	R^2	F
	305.8		.918	51.9
Independent Variable				
ΔD		0.487		
yl		0.671		
c		0.010		

With these parameters, b_1's and assumed time lags as in Figure IV-21, (A = 1 B = 1 E = 1), the result of the simulation run is depicted in Figure VI-21. Although there is deviation between the predicted and actual values, the consistent pattern of fluctuation of data gives confidence in the model. Moreover, in predicting the level of investment, analysts are more interested in cumulative values of investment in the years ahead rather than year by year value, for the reason that many factors may affect the timing of the purchase. Cumulative value of the predicted and actual data of Figure VI-21 is depicted in Figure VI-22, in which predicted data are quite close to actual data.

To see how sensitive is the result of predicted data to different values of each parameter, simulation runs were repeated, changing one parameter at a time while keeping the rest at their original values. The results as they are shown in Figure VI-23, VI-24 and VI-25 hint as to which direction we may change the parameter to obtain a closer projection with historical data. Figure VI-26, the improved cumulative level of investment, is obtained by using

$a = 305$

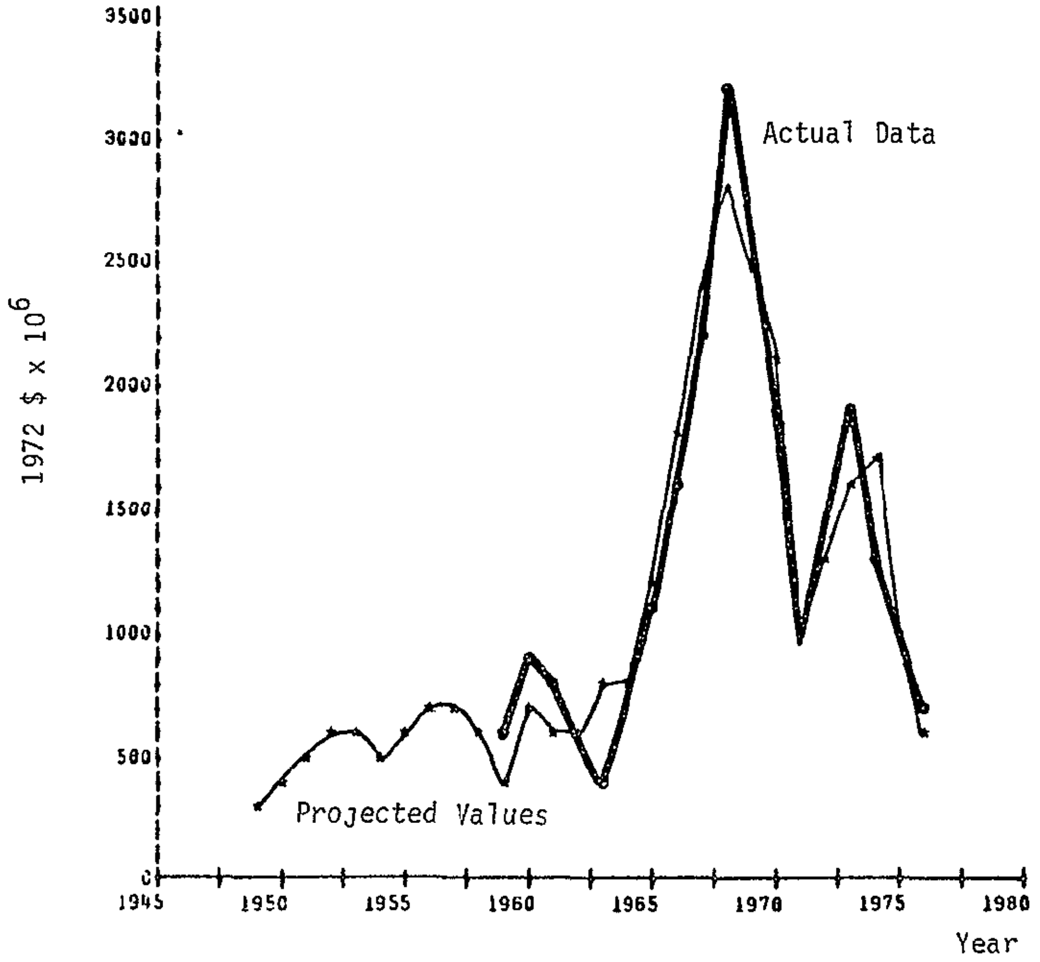
$b_{\Delta D} = .5$

$b_{yl} = .55$

$b_c = 0.009$

Testing the Model in its Totality

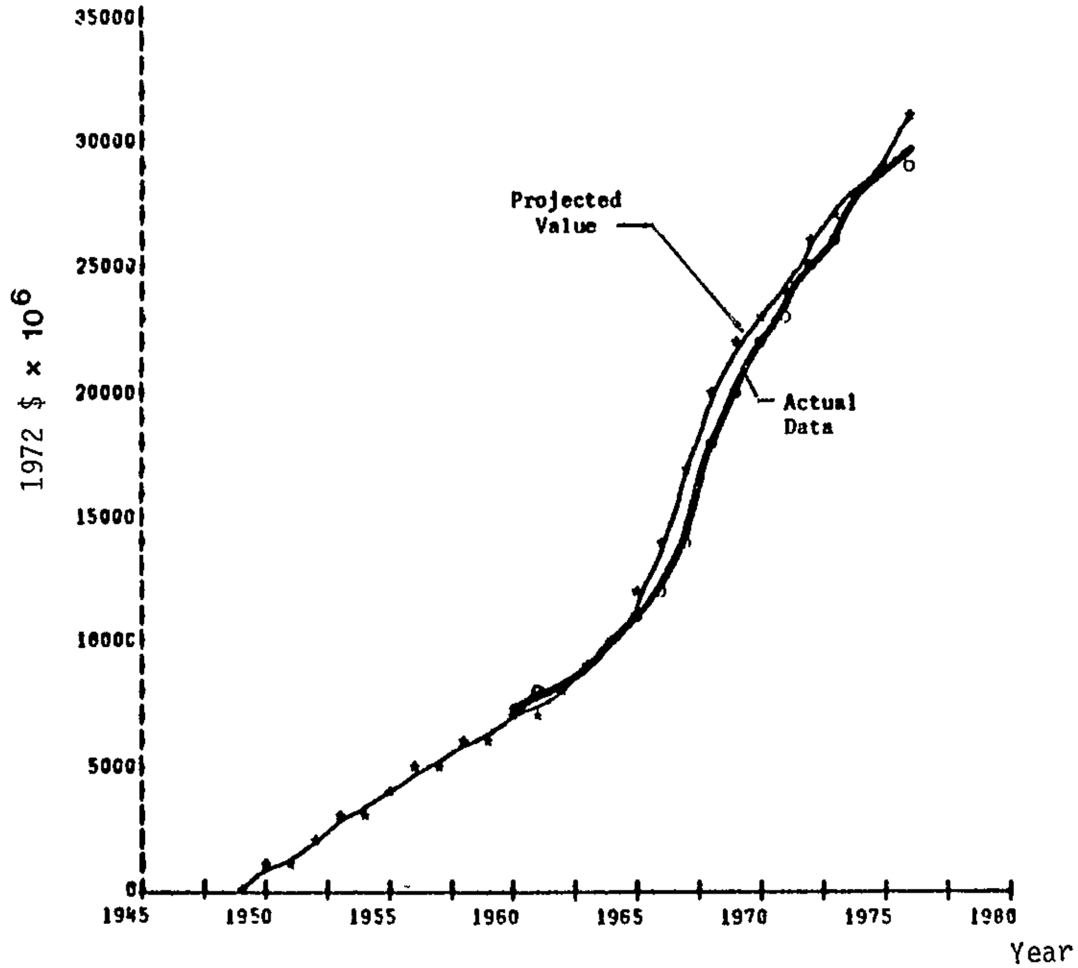
The relationship between the variables produced so far was tested when we considered each submodel in isolation. During



Deviation from Actual Data

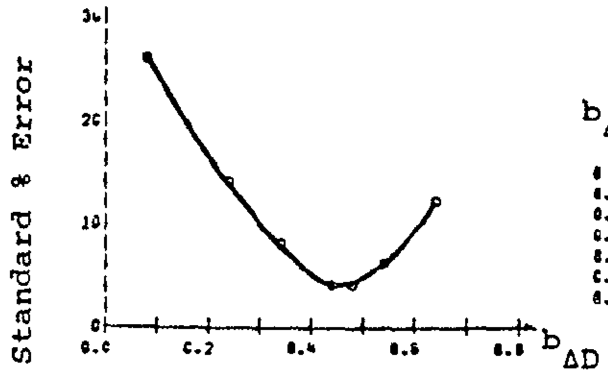
Year	Percent
1959	▼30.028
1960	▼14.654
1961	▼23.547
1962	0.289
1963	119.302
1964	▼0.184
1965	9.094
1966	8.476
1967	9.163
1968	▼12.532
1969	▼2.619
1970	9.494
1971	▼2.322
1972	▼10.846
1973	▼14.758
1974	33.914
1975	▼0.948
1976	▼8.896

Figure VI - 21 Projected and Actual Value of Annual Investment in Flying Equipment



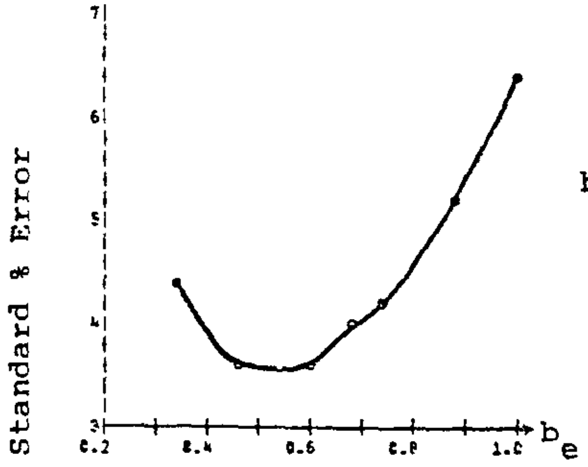
Year	Deviation from Historical Data, %
1959	2.237
1960	-1.512
1961	-4.326
1962	-1.369
1963	3.777
1964	7.596
1965	13.207
1966	17.417
1967	19.145
1968	11.540
1959	7.805
1970	2.979
1971	3.958
1972	4.613
1973	3.447
1974	2.416
1975	0.965
1976	5.119

Figure VI - 22 **Projected and Actual Investment in Flying Equipment (Cumulative Values)**



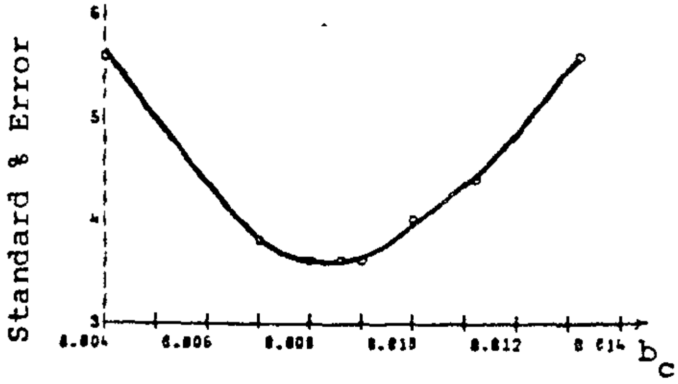
$b_{\Delta D}$	Stand. % Error
0.244	14.097
0.341	7.955
0.439	3.454
0.487	3.902
0.536	6.046
0.634	11.464
0.073	25.812

Figure VI - 23· Sensitivity of Projection to Different Values for $b_{\Delta D}$



b_e	Stand. % Error
0.335	4.394
0.465	3.694
0.505	3.672
0.571	3.902
0.738	4.262
0.872	5.244
1.006	6.405

Figure VI - 24 Sensitivity of Projection to Different Values for b_e



b_c	Stand. % Error
0.0040	5.5957
0.0071	3.8779
0.0081	3.6604
0.0086	3.5677
0.0091	3.6019
0.0101	3.9516
0.0111	4.3702
0.0131	5.6847

Figure VI - 25 Sensitivity of Projection to Different Values for b_c

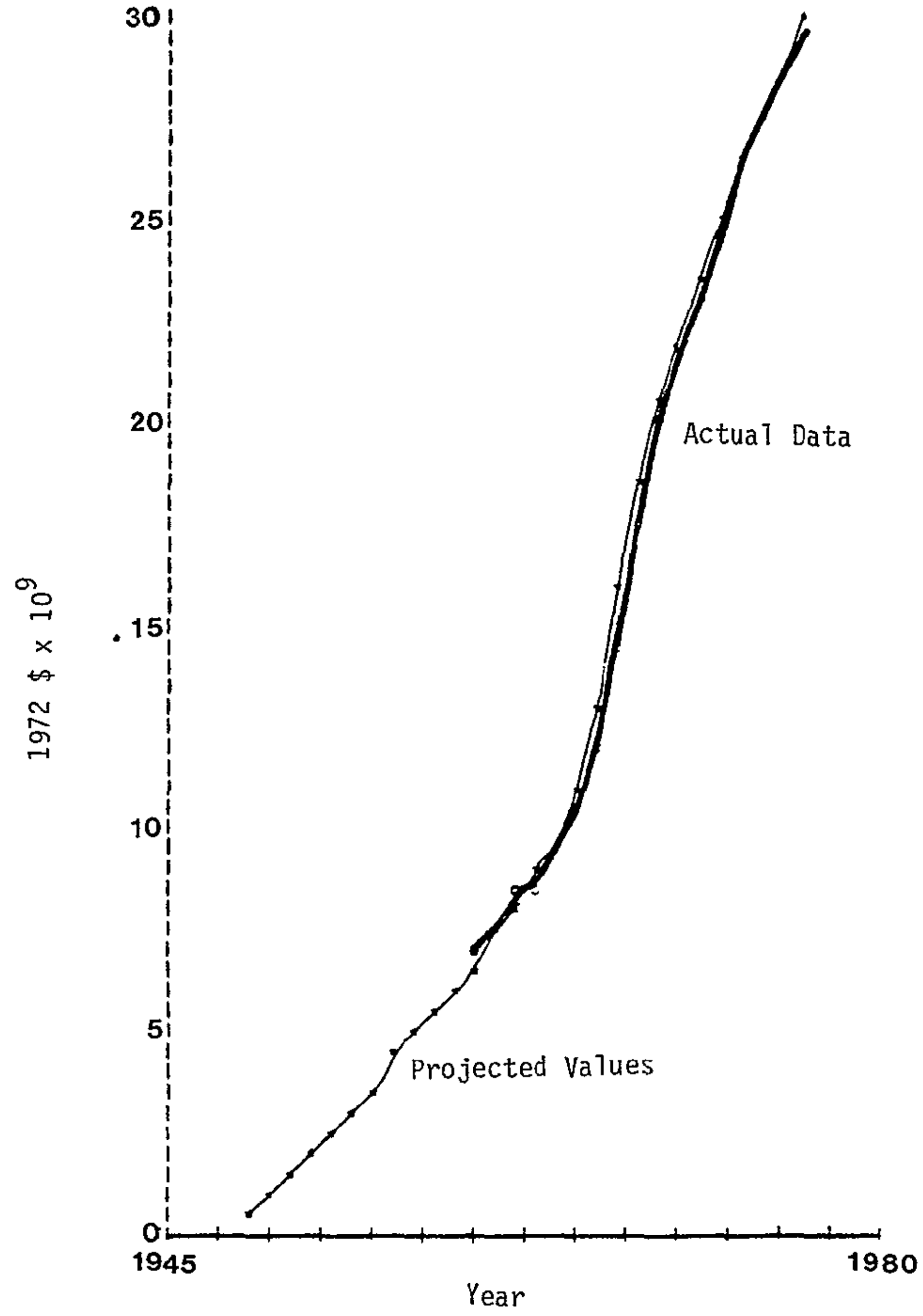


Figure VI - 26 Projected and Actual Data on Investment in Flying Equipment (Cumulative Values) these analyses, some corrections in terms of variable sets and their relationships were found necessary. Pictorial representation of the model (Figure VI-27) include these changes. Five time lag nodes are added to the model on the hypothesis that there might be a gradual time lag between demand and investment, between earning and investment, and finally, between capacity and investment. (See Chapter III for discussion on time lags.)

To examine the validity of the model with the relationships as developed throughout the Chapter, the model should predict the history with reasonable accuracy. We ran the simulation model for the last twenty-nine years (from 1948 to 1976). The initial state of the model is as follows:

Variable	Abbrev.	Node No.	Initial Value (Value for 1948)
Demand	d	1	1077 (MM ton-Mi)
--time lag--		2	
Average Rev. (Fare)	f	3	1.16 (1972 $ per ton-mile)
Load Factor	ℓ	4	0.53 (ratio)
GNP (U.S.)	g	5	448.24 (1972 $ Billion)
--time lag--		6	
Population (U.S.)	p	7	146.6 (MM)
Variable cost	vc	8	0.33 (1972 $/ Ton-Mi.)
Indirect cost	fc	9	0.28 (1972 $/ Ton-Mi.)
--time lag--		10	
Earning	e	11	564 (1972 $ MM)
--time lag--		12	
Capacity	c	13	2320.8 (MM Ton-Mi.)
--time lag--		14	
Investment in flying equipment	i	15	85 $(1972\ \$ \times 10^6)$

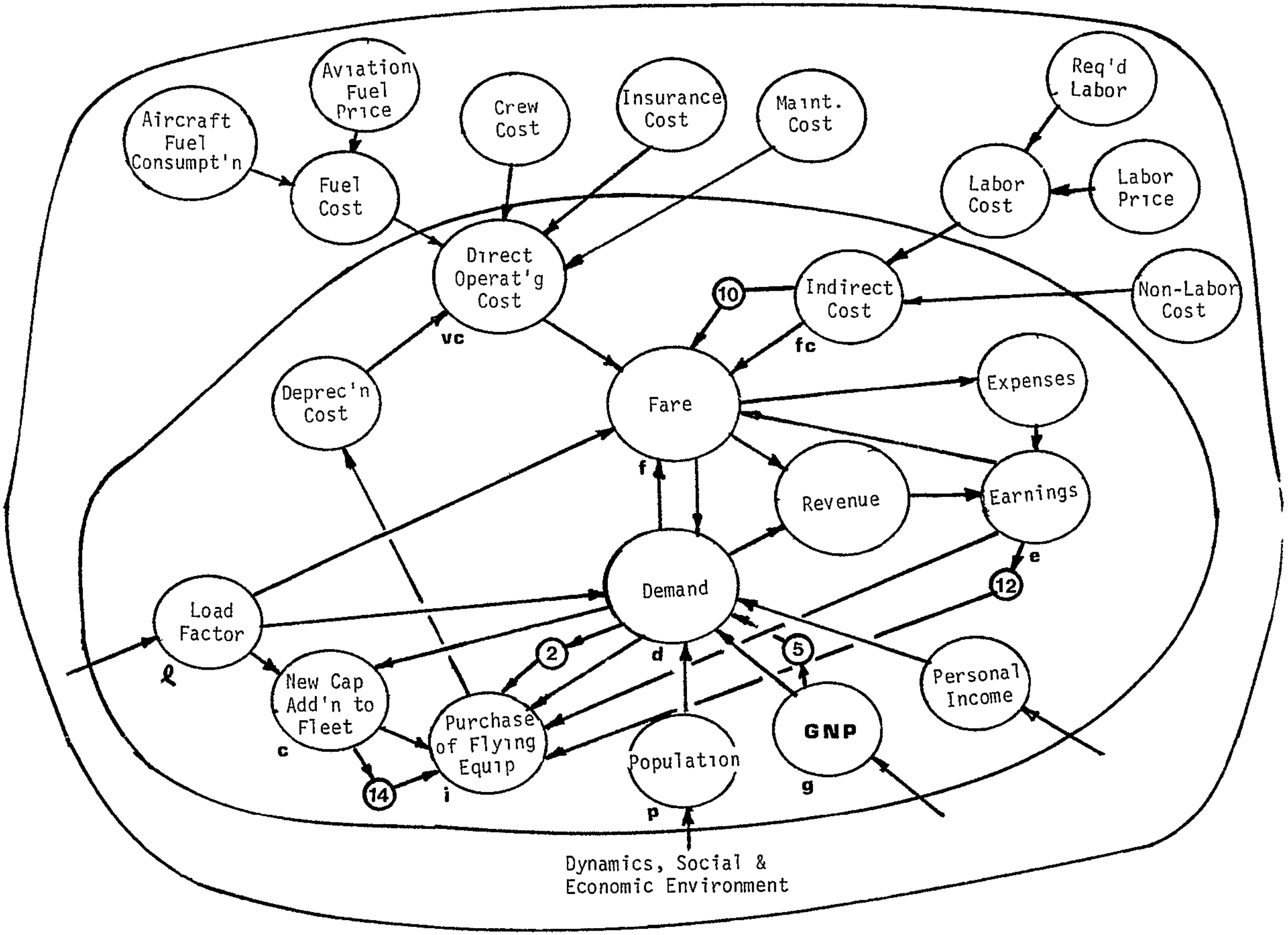


Figure VI - 27 A Conceptual Dynamic Model of Air-Transportation Economics (Revised)

Node / Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1949	$0.006 \times V_{d,t}$	0.004	0	0.02	2.1	0	3.20	*0.03	*0.03	0	0	0	0	0	305
1950				0.04	44.7		2.50	*0.07	*0.09						
1951				0.05	33.8		2.60	*0.08	*0.05						
1952				*0.02	15.8		2.70	0.00	0.02						
1953				*0.02	25.5		2.60	0.01	*0.02						
1954				*0.01	*2.4		2.80	*0.01	*0.02						
1955				0.01	54.2		2.90	*0.03	*0.01						
1956				0.00	23.7		3.00	*0.01	0.01						
1957				*0.02	10.0		3.10	*0.01	0.01						
1958				0.00	*8.2		2.90	*0.01	0.01						
1959				0.00	46.6		2.90	0.00	0.01						
1960				*0.03	17.3		2.90	0.01	0.01						
1961				*0.03	16.6		3.00	0.00	0.00						
1962				0.00	47.2		2.90	*0.04	*0.03						
1963				*0.01	32.2		2.60	*0.02	0.00						
1964				0.00	47.0		2.70	*0.03	*0.02						
1965				0.01	53.8		2.40	*0.03	*0.02						
1966				0.03	58.9		2.30	*0.03	*0.03						
1967				*0.02	27.9		2.10	*0.01	*0.02						
1968				*0.02	44.8		2.00	*0.01	0.00						
1969				*0.02	22.4		2.00	0.00	0.00						
1970				*0.01	*9.0		2.20	0.00	0.01						
1971				*0.01	31.6		2.20	*0.01	*0.01						
1972				0.02	86.5		1.70	*0.01	0.00						
1973				0.00	60.2		1.60	0.00	0.00						
1974				0.02	*30.6		1.50	0.02	0.01						
1975				*0.01	*20.7		1.70	0.00	0.01						
1976				0.02	64.3		1.50	*0.01	*0.02						

Table VI - 11 **Exogenous Pulse to Air Transportation System** (Figure VI - 27)

The vector of exogenous pulse for each period is as Table VI-11.

The cross-impact matrix of the model, corresponding to the digraph of Figure VI-27, is the following in which the weights are as we developed during the analysis.

$$
\begin{array}{cc|ccccccccccccccc}
 & & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 \\
\hline
d & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{d,i} \\
 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{2,i} \\
f & 3 & w_{f,d} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
i & 4 & w_{\ell,d} & 0 & w_{\ell,f} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
g & 5 & w_{g,d} & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
 & 6 & w_{6,d} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
p & 7 & w_{p,d} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
vc & 8 & 0 & 0 & w_{vc,f} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
fc & 9 & 0 & 0_c & w_{fc,f} & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
 & 10 & 0 & 0 & w_{10,f} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
e & 11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & c & w_{e,i} \\
 & 12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{12,i} \\
c & 13 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & w_{c,i} \\
 & 14 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & w_{14,i} \\
i & 15 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}
$$

Where

$$w_{f,d} = {}^{-}1.126 \times \frac{v_{d,t}}{v_{f,t}}$$

$$w_{\ell,d} = {}^{-}0.1 \times \frac{v_{d,t}}{v_{\ell,t}}$$

$$w_{g,d} = G \times 0.92 \times \frac{v_{d,t}}{v_{g,t}}$$

$$w_{6,d} = (1-G) \times 0.92 \times \frac{v_{d,t}}{v_{g,t}}$$

$$w_{p,d} = 3.35 \times \frac{v_{d,t}}{v_{p,t}}$$

$$w_{\ell,f} = 0.33$$

$$w_{vc,f} = 0.82$$

$$w_{fc,f} = C \times 0.72$$

$$w_{10,f} = (1-C) \times 0.72$$

$$w_{d,1} = D \times 0.5$$

$$w_{2,1} = (1-D) \times 0.5$$

$$w_{e,1} = E \times 0.55$$

$$w_{12,1} = (1-E) \times 0.55$$

$$w_{c,1} = A \times 0.01$$

$$w_{14,1} = (1-A) \times 0.01$$

$V_{d,t}$ = Value of Demand, d at period t

$V_{f,t}$ = Value of Fare, f at period t

$V_{\ell,t}$ = Value of Load Factor, ℓ at period t

$V_{g,t}$ = Value of GNP, g at period t

$V_{p,t}$ = Value of Population, P at period t

A, C, D, E and G are the fractions of the weight affecting endogenous variables in the first period.

Figure VI-28 and VI-29 are the results of the simulation run which predict the value of endogenous variables of the system, demand, fare and investment. Each predicted point has used the predicted value of that variable one period ago, namely, $V_{d,t-1}$ and $V_{f,t-1}$ and not the historical data. Moreover, these results show negligible differences from the results of the validation test when each endogenous variable was being considered in isolation (see Figures VI-4; VI-15; and VI-22). This brings more confidence in the model that the errors do not accumulate. The level of error proves to be more insignificant when we consider the fact that in this model we have used aggregated variables, such as having only one conglomerate type of service, a mix of passenger, flight, mail, express, etc.

Projecting the Future with the Model

In Chapter II the approach and purpose of modeling practice in the context of a study such as "Future of Aviation Fuel," was addressed. In summary, first, a model serves as a tool by which the analyst projects his perception of the environment outside the system under study into the system to see how the system will respond. With this practice no one should intend to attempt the impossible task of revealing the future. The practice is solely useful in assessment of a set of "If . . . . then . . ." propositions which shed light into the area of possible influence by the decision-maker control and the extent of those influences. Second, if the structure of the model is understandable for the analyst, he will have the opportunity to change, consciously, one or more of the parameters or time lags and work with a model in which he may have more reliance. For this purpose, straightforwardness and clarity in modeling methodology, model structure and content are of high value.

Simulation with digraph methodology as presented in Chapter III and being applied in this chapter clearly shows its capacity to serve both purposes mentioned above.

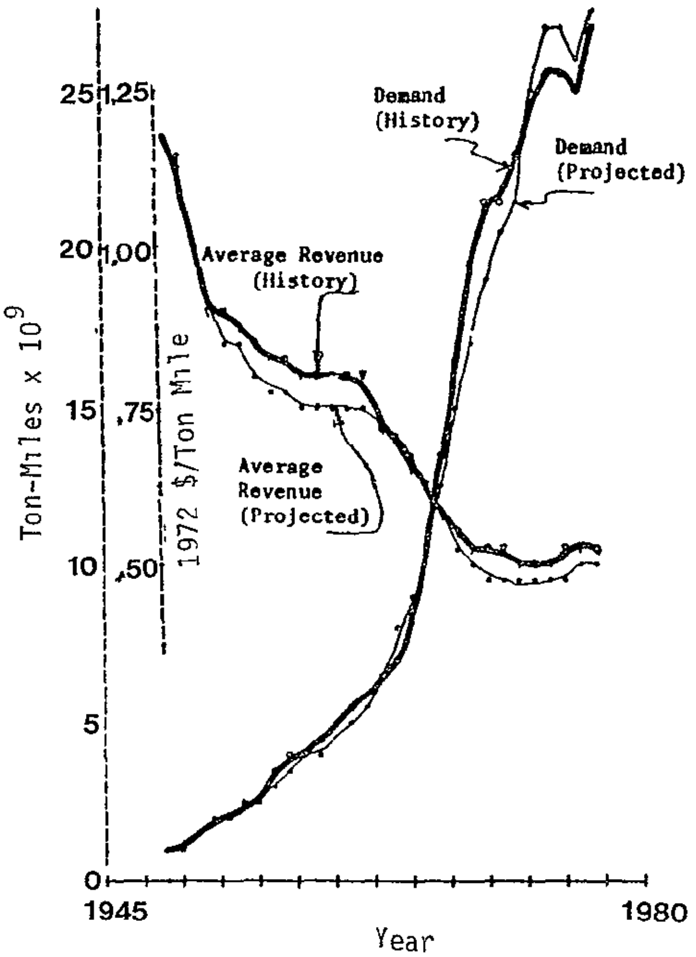
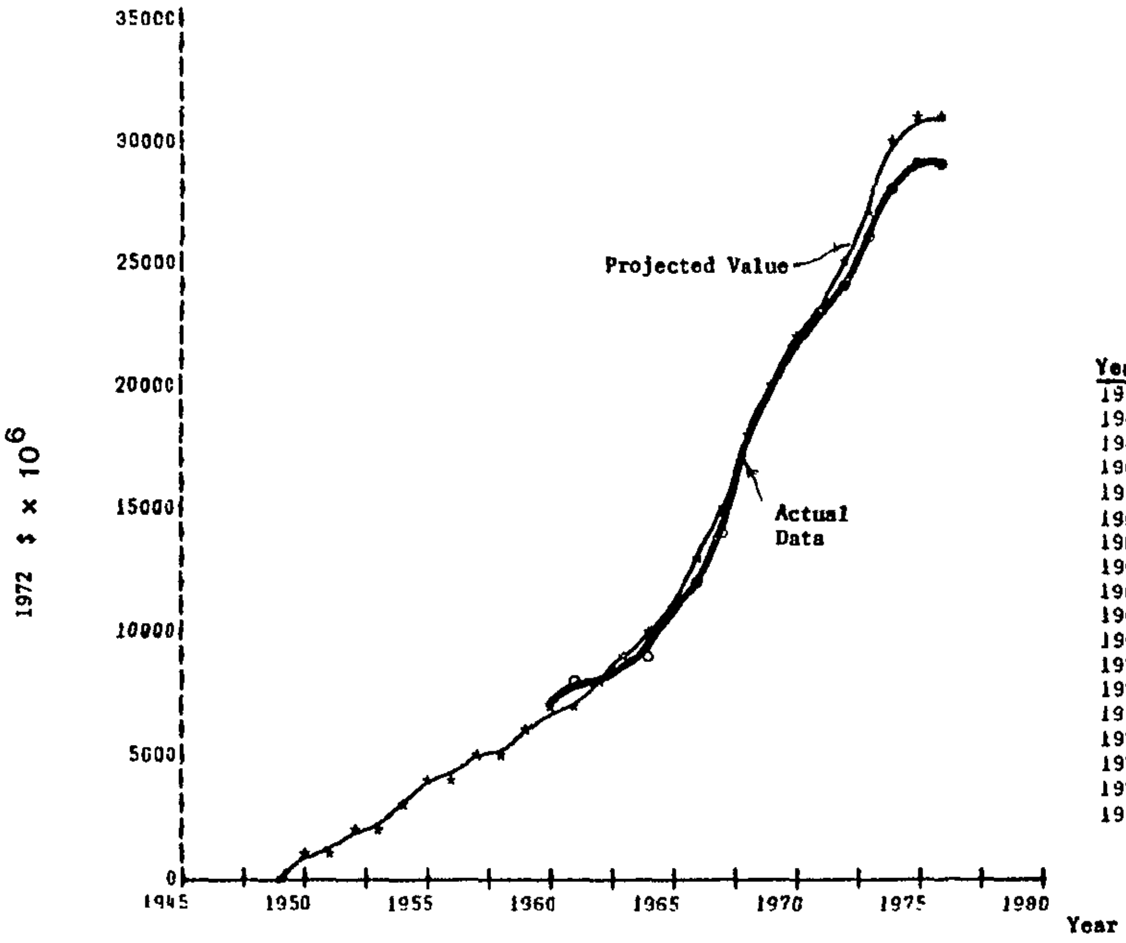


Figure VI - 28 Actual and Projected Values for Air Transportation Demand and Average Revenue per Ton-Mile Available Capacity



Year	Deviation from Historical Data,
1959	-1.050
1960	-2.895
1961	-5.158
1962	-4.728
1963	1.126
1964	5.058
1965	6.859
1966	7.127
1967	6.050
1968	-0.105
1969	-0.952
1970	-0.190
1971	1.533
1972	1.324
1973	4.191
1974	7.156
1975	6.977
1976	4.712

Figure VI - 29 **Projected and Actual Values of Investment in Flying Equipment (Cumulative Value)**

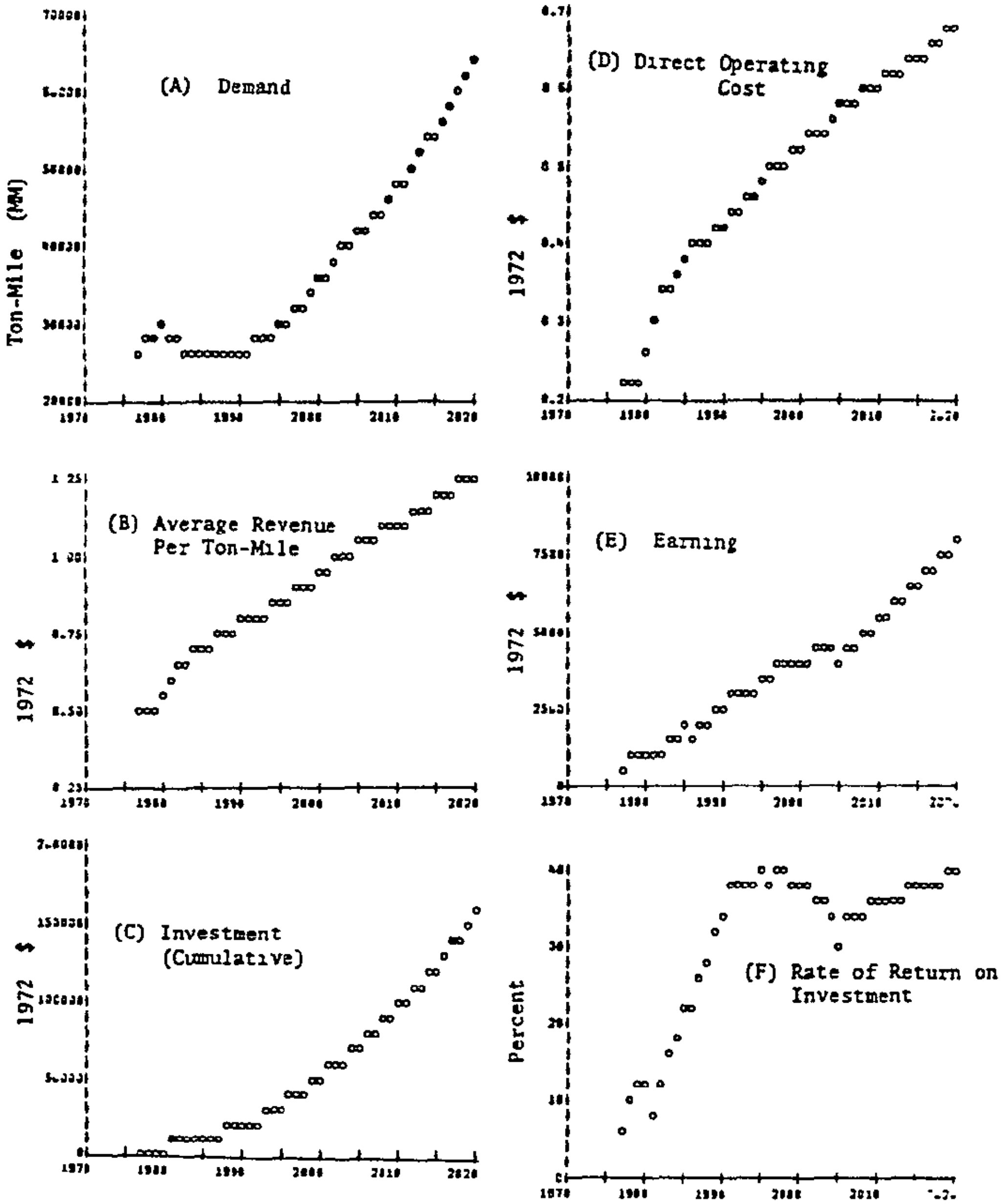


Figure VI - 30 Future Projection Under Interrupted Growth Scenario

To illustrate the practice of projecting the future status of the aviation industry, we run the model with the assumptions under "Interrupted Growth Scenario" developed in Chapter V. The results of this projection as shown in Figure VI-30. No inconsistencies are seen in these results, except the implausible rate of return on investment which shows a growth of 30-40 percent. This obviously is not going to happen. Since all scenario assumptions seem to within reasonable bounds, there must be a mechanism that would not allow the rate of return to go beyond its plausible bound. To supplement the model with such mechanism necessitates a revision of a portion of the model.

Revision in the Fare Model

For the airline industry there are basically a few points of response to outside changes as well as internal forces. Fare and load factor are two more important considerations among these factors. In particular, competitive forces inside the industry put some pressure to reduce fare. This competitive force is, perhaps, proportionate but inversely related to profitability. Therefore, a variable representing a measure of profitability should be added to the set of determinants of fare (Figure VI-14).

Some candidates for such a variable are: yield as a percent of sale, net income before tax as a percentage of sale or as a percentage of investment, and finally, dollar yield per ton-mile available service.

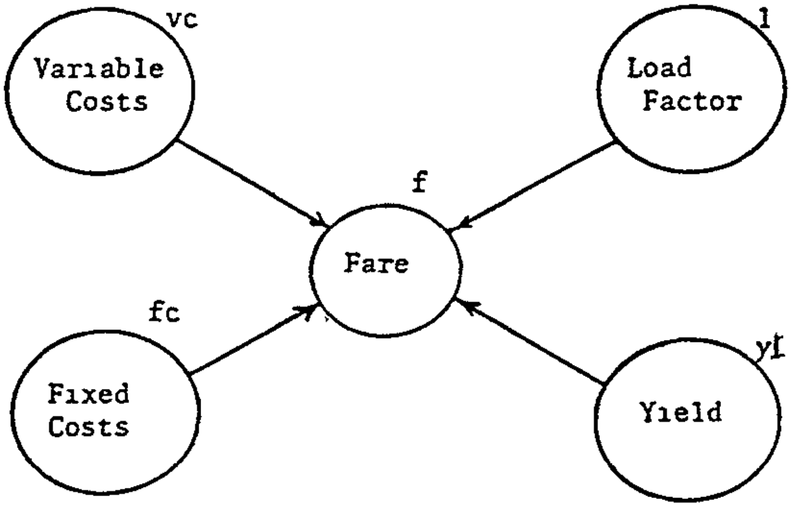


Figure VI-31 Fare and Its Determinants (Revised)

To establish relationships among the variables of Figure VI-31, first, we examine the assumption of linear relationships between fare and its determinants. Among the variables mentioned above as candidates representing profitability, historical data only support the last one, dollar yield per ton-mile. With this variable the result of multiple regression on historical data, Table VI-12, is the following:

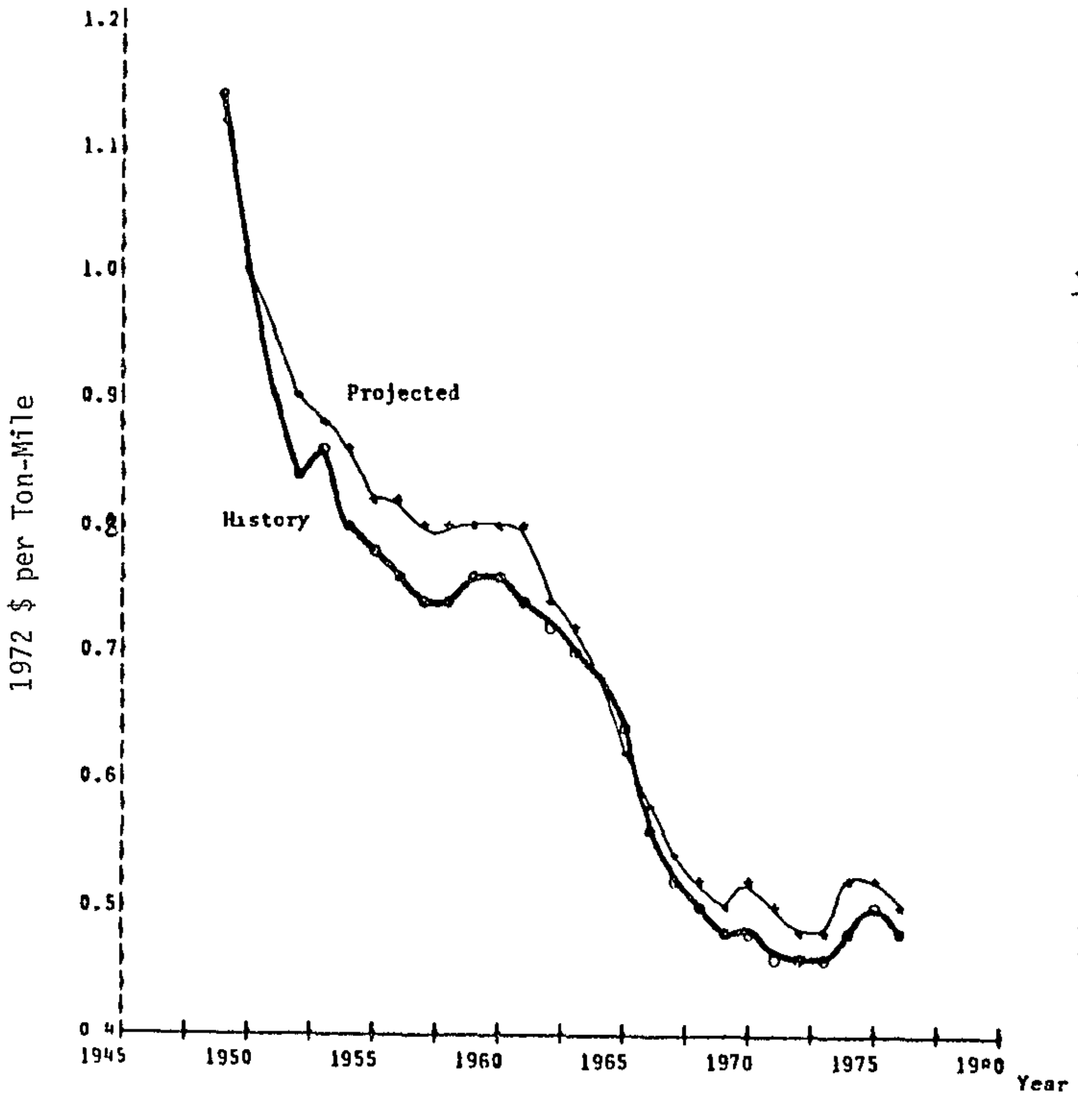
	a	b_i	R^2	F
	0.000		0.764	18.650
Independent Variable				
ℓ		0.346		
vc		0.811		
fc		0.646		
$y\ell$		-0.469		

All b_i's are in plausible range and consistent in sign. To test the validity of the established relationships we run the simulation model of Figure VI-31; the result of the simulation run is shown in Figure VI-32, which is reasonably accurate. With these modifications in fare model, the overall model (Figure VI-27) is tested again and the result is depicted in Figure VI-33 which is, in terms of accuracy of prediction, not much different from what we had before in Figure VI-28.

With the revised version of the model, and under the assumptions of our two scenarios in Chapter V, the future of economics of air transportation is projected as in Figures VI-34 and VI-35. In these projections rate of return on investment as well as other outputs of the model stay within their plausible bounds.

YEAR	Change in Fare 1972 $	Change in Load Factor	Change in DOC 1972	Change in Indirect Cost 1972 $	Earning Per Ton-Mile 1972 $
1949	-0.026	0.017	0.153	-0.033	0.015
1950	-0.140	0.042	0.147	-0.089	0.024
1951	-0.107	0.045	0.149	-0.052	0.036
1952	-0.045	-0.021	0.144	0.017	0.013
1953	0.008	-0.018	0.142	-0.022	0.020
1954	-0.052	-0.011	0.136	-0.017	0.009
1955	-0.027	0.012	0.131	-0.009	0.016
1956	-0.013	-0.004	0.132	0.005	0.010
1957	-0.025	-0.023	0.125	0.010	-0.001
1958	0.009	0.000	0.125	0.010	0.004
1959	0.005	0.005	0.125	0.009	0.004
1960	0.004	-0.028	0.122	0.012	-0.002
1961	-0.015	-0.028	0.112	-0.002	-0.008
1962	-0.027	-0.004	0.103	-0.025	0.007
1963	-0.008	-0.015	0.096	-0.004	0.012
1964	-0.028	0.000	0.092	-0.024	0.021
1965	-0.047	0.011	0.085	-0.024	0.027
1966	-0.066	0.027	0.082	-0.033	0.027
1967	-0.042	-0.021	0.078	-0.016	0.019
1968	-0.032	-0.021	0.075	-0.005	0.011
1969	-0.015	-0.019	0.075	-0.001	0.005
1970	-0.005	-0.010	0.079	0.013	-0.002
1971	-0.010	-0.008	0.078	-0.012	0.003
1972	0.003	0.018	0.080	0.004	0.008
1973	-0.001	-0.004	0.085	0.001	0.007
1974	0.021	0.022	0.113	0.007	0.004
1975	0.009	-0.011	0.122	0.010	0.003
1976	-0.006	0.019	0.133	-0.015	0.013

Table VI - 12 **Annual Change in Fare and its Determinants.**



Year	Deviations from Historical Data, %
1949	-2.050
1950	0.248
1951	1.491
1952	6.318
1953	2.886
1954	6.336
1955	5.275
1956	6.254
1957	9.063
1958	6.870
1959	6.619
1960	6.558
1961	8.103
1962	4.607
1963	1.598
1964	-1.323
1965	-2.200
1966	0.719
1967	2.567
1968	4.954
1969	5.830
1970	8.451
1971	6.579
1972	5.009
1973	4.320
1974	5.703
1975	4.231
1976	2.627

Figure VI - 32 Projected and Actual Values of Average Revenue Per Ton-Mile (Revised Model of Figure VI - 31)

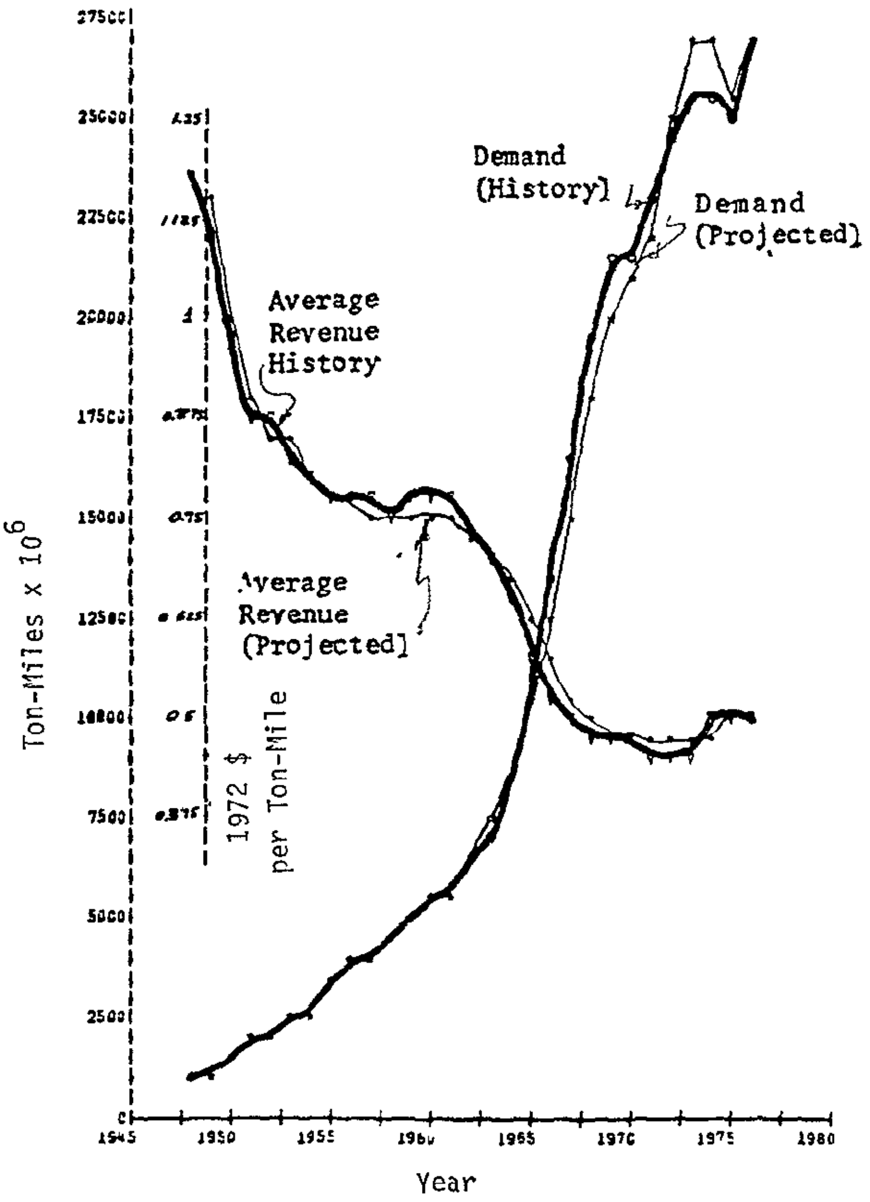


Figure VI - 33 Actual and Projected Values for Air Transportation Demand and Average Revenue per Ton-Mile Available Capacity (Revised)

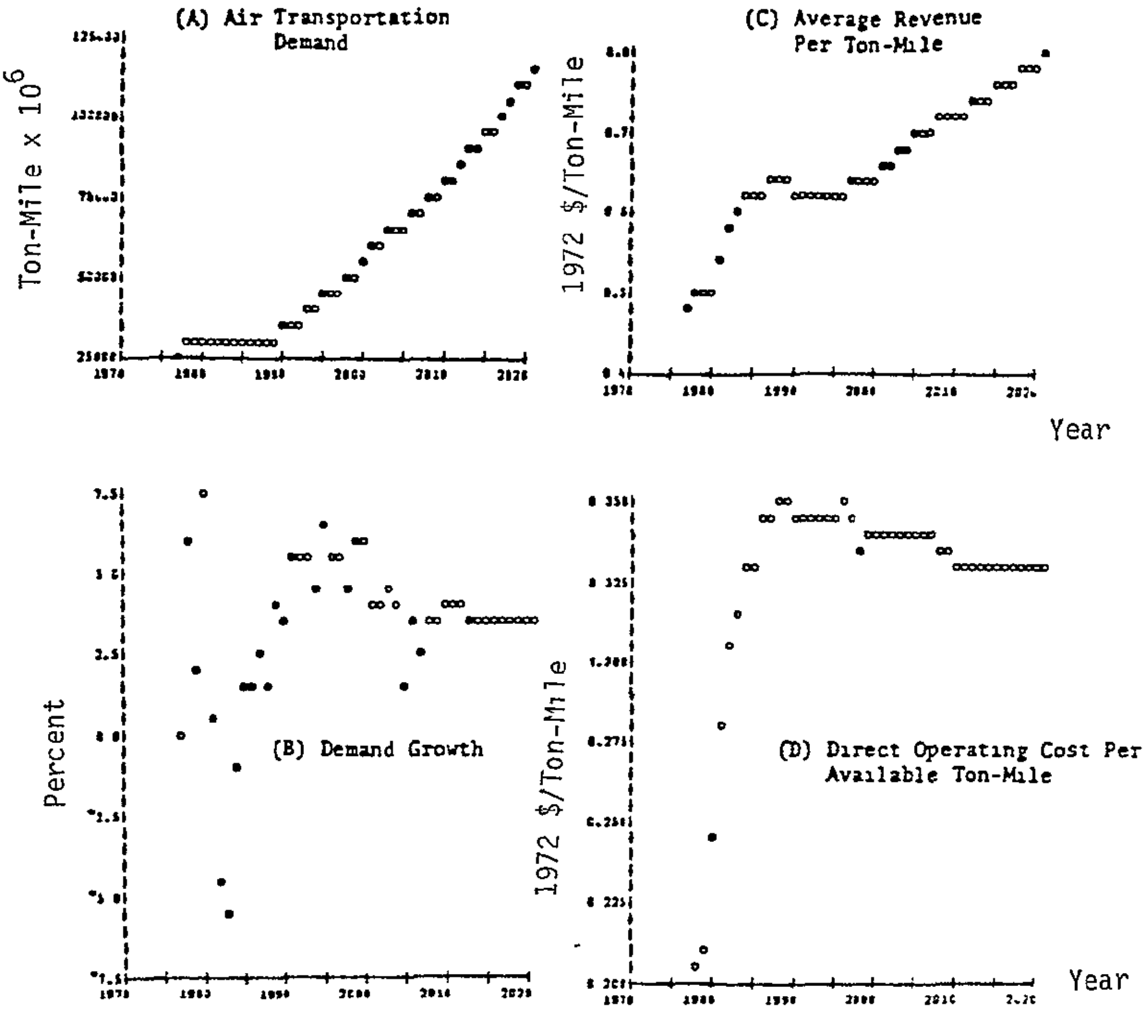


Figure VI - 34 Future Projection Under Interrupted Growth Scenario (Revised)

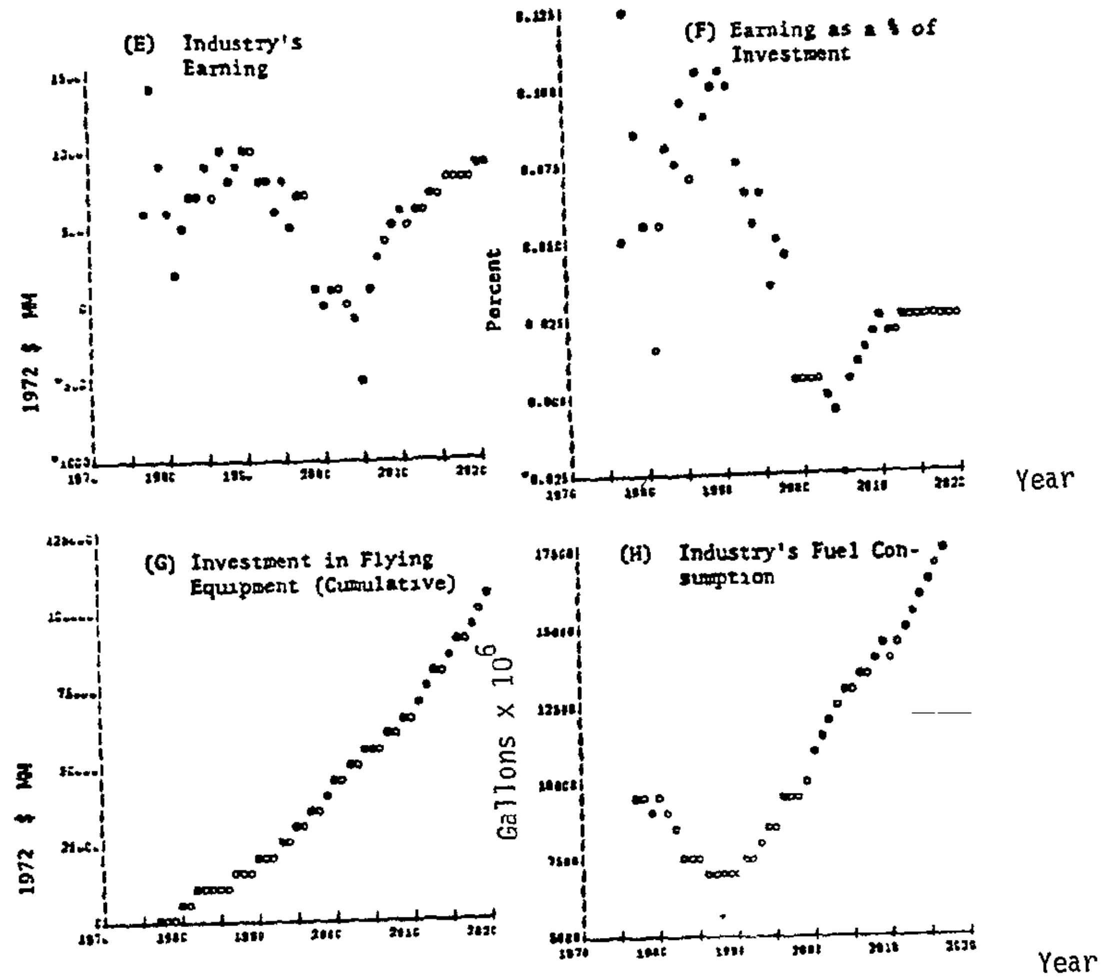


Figure VI - 34 (Continued)

MM = million

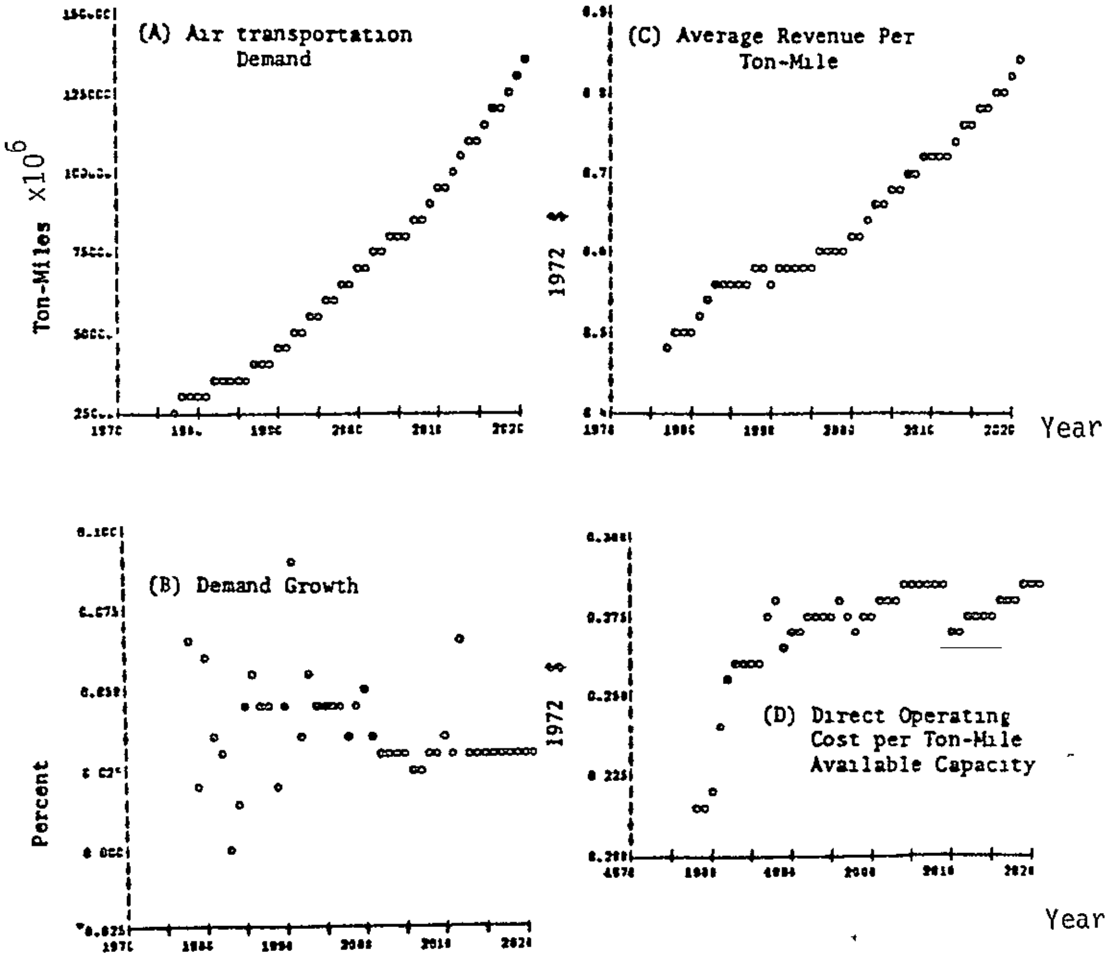


Figure VI - 35 **Future Projection Under Uninterrupted Growth Scenario**

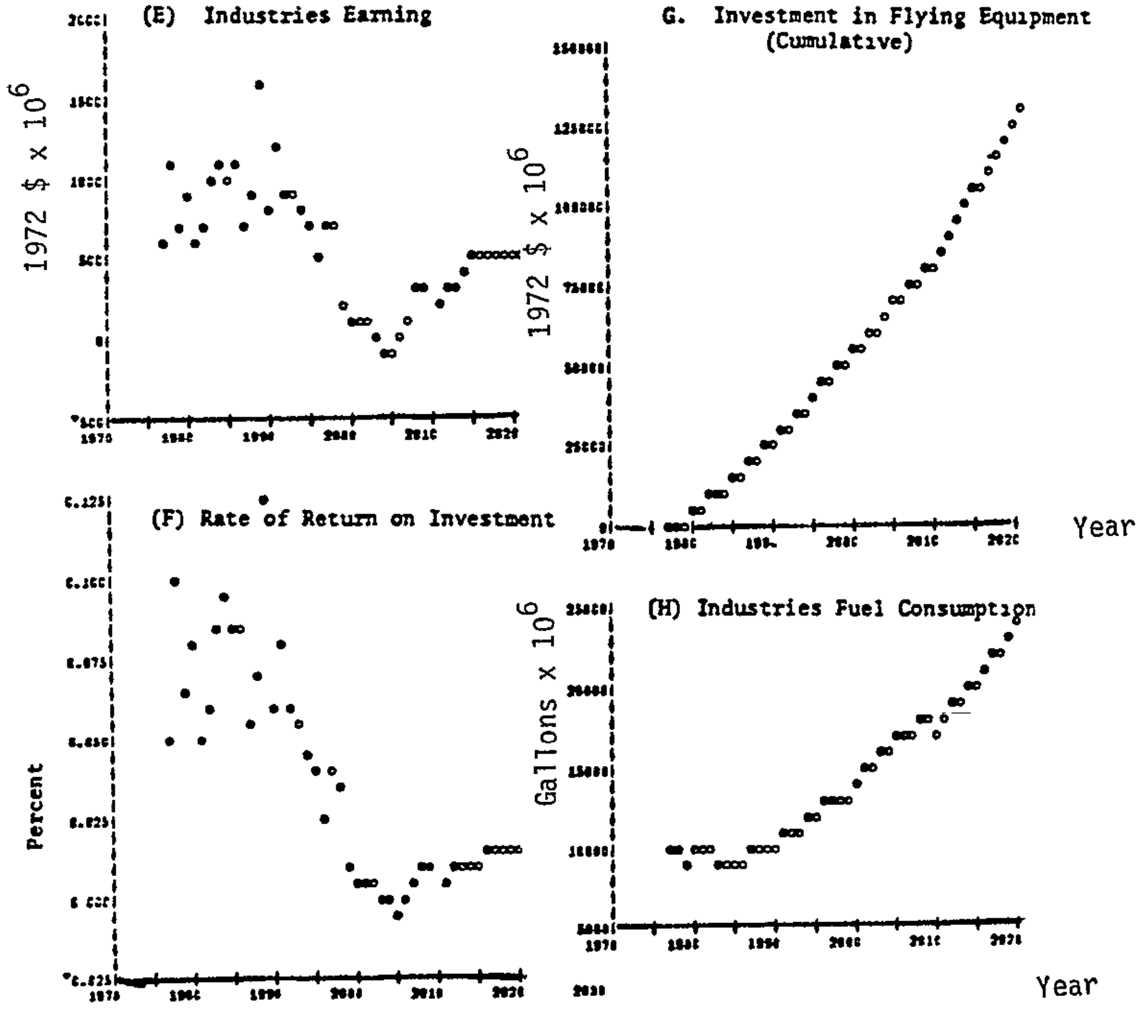


Figure VI - 35 (Continued)

CHAPTER VII

FUTURE RESEARCH IN THE ECONOMICS OF AIR TRANSPORTATION

Suggestions with regard to frontiers for future research fall into two categories. First, the model (and the methodology) may be used for other than the purpose of this report; Second, improvement and expansion of the present model are indicated.

1) Short vs. Long-term projections:

The model developed in Chapter VI is aimed to be used in connection with long-term projections. Since the parameters obtained in the course of the research are based on a long-term history of twenty-nine years, the period covers the history of the industry from infancy to near maturity. Moreover, the historical values used in the analysis are average annual data which eliminate the short run seasonal effects. Furthermore, the future of exogenous variables of the system is projected with the scenario approach which again emphasizes the long-term change in the environment.

However, there is no reason that the methodology cannot be used for short-term models provided that short-run historical data (weekly, monthly, or seasonal) be used for parameter identification.

Questions have been raised about the stability of the parameters. In other words, it may be argued that the parameters such as demand elasticity with respect to price, income, etc., may be changing over time (Eriksen, 1978). In particular, are the elasticities the same for expanding and contracting economic conditions? Although there is some validity in the argument, there are serious problems in evaluating the nature and direction of change in parameters. First, it must be recognized that a parameter relates to the behavior of the system--in the air transportation model mutual response of the industry and its customs. These behaviors are of a more permanent nature. Second, a much longer historical data base is required for assessment of such changes. Third, acceptance of change in parameters introduces another dimension of uncertainty into the model. With a set of constant parameters, such as developed in Chapter VI, which has passed the validity test, Figure VI-29, the user need to concentrate only on his scenario for the exogenous variables. While with the assumption of changing parameters, he also faces more uncertainty with his model.

2) There are a number of suggestions which may improve or expand the presented model:

a) Search for more related variables. For example, price of alternatives to air transportation is a probable relevant variable in the set of independent variables of demand. The alternative for some segment of air transportation are bus, railroad, communication services, etc. Another important variable which influences fare is an index of the quality of service. Development of such an index requires more research. In the model developed in Chapter VI we have used the inverse load factor as a proxy for the index. This may not be adequate.

b) Desegregating the components of air transportation such as business, tourist, cargo, etc. may produce a representative model. Such a model modification may be more interesting for different users with different objectives.

c) Development of a similar model for military air transportation, which uses a considerable amount of aviation fuel, is necessary to enhance understanding of the overall aviation fuel question.

3) As it was pointed out in Chapter I, one of the control points in operations of airlines is load factor. The industry's choice of load factor vs. utilization of aircraft is one of the most intricate problems in modeling the industry. So far, no attempt to model load factor vs. utilization has appeared in the literature. For the projection purposes in Chapter VI, future trends in load factor postulations were based on scenarios of Chapter V. There are theoretical foundations for development of a model for the choice of load factor vs. utilization, but further work on this model is left to future studies.

APPENDIX A

GENERAL METHOD OF MULTIPLE REGRESSION ANALYSIS

This Appendix is to serve as a quick reference to general solutions of multiple regression analysis and therefore, no proof is presented. To save notations the solution is illustrated using three independent variables. Generalization for more independent variables will be obvious.

Assume:

$$y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 \qquad (1)$$

$$x_i = X_i - X_i \qquad (2)$$

where

x_i = deviation from mean $\bar{X}_i$

in matrix notation

$$\sum x_i x_j = \begin{bmatrix} \sum x_1^2 & \sum x_1 x_2 & \sum x_2 x_3 \\ \sum x_2 x_1 & \sum x_2^2 & \sum x_2 x_3 \\ \sum x_3 x_1 & \sum x_3 x_2 & \sum x_3^2 \end{bmatrix} \qquad (3)$$

From the above matrix, the correlation matrix, **R** is:

$$\mathbf{R} = R_j = r_{x_i x_j} = \frac{\sum x_i x_j}{\sqrt{\sum x_i^2 \sum x_j^2}} \qquad (4)$$

On the other hand, correlation between the independent variables and the dependent variables, r_{yj}, are:

$$\beta_1 + r_{12}\beta_2 + r_{13}\beta_3 = r_{y1}$$

$$r_{21}\beta_1 + \beta_2 + r_{23}\beta = r_{y2} \qquad (5)$$

$$r_{31}\beta_1 + r_{32}\beta_2 + \beta_3 = r_{y3}$$

Where β_j, the beta weights, are the direct effect of variable j on y. In matrix notation (5) can be written as

$$\begin{pmatrix} r_{11} & r_{12} & r_{12} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{pmatrix} = \begin{pmatrix} r_{y1} \\ r_{y2} \\ r_{y3} \end{pmatrix} \qquad (6)$$

or

$$R_{ij} \quad x \quad \beta_j \; = R_{yj} \qquad (7)$$

$$\beta_j = \left[R_{ij} \right]^{-1} \quad x \quad R_{yj} \qquad (8)$$

The relation between coefficient of correlation b_j and β_j is

$$b_j = \beta_j \frac{s_y}{s_j}$$

Where s_y = Standard deviation of y and

s_j = Standard deviation of x_j

And finally,

$$a = \bar{y} - b_1 \bar{X}_1 - b_2\bar{X}_2 - b_3\bar{X}_3$$

Where $\bar{y}$ and $\bar{X}_j$'s are mean values.

EXAMPLE

```
      MR
 WHAT IS YOUR DEPENDENT VARIABLE?
⎕:
      ΔD
 HOW MANY ARE YOUR INDEPENDENT VARIBLES?
⎕:
      4
 INPUT YOUR INDEPENDENT VARIBLES IN ONE VECTOR
⎕:
      ΔF,ΔLF,ΔGNP,ΔP

  1.000    ¯0.499    ¯0.250    ¯0.201    ¯0.166    ¯0.302   2006.182 ¯8476.001      0.560       7.319
 ¯0.499     1.000     0.300    ¯0.168    ¯0.008    ¯0.405            ¯20014.968
 ¯0.250     0.300     1.000    ¯0.143     0.605     0.593                21.356
 ¯0.201    ¯0.168    ¯0.143     1.000    ¯0.363    ¯0.407              ¯782.678
```

X_iX_j R_{yj} β A b_i R^2 F

```
    ∇ MR;Y;XX:I;SX:SY:RIJ;RYJ;BTA;A;R;F;J;M
[1]  ⍝ APL PROGRAM FOR MULTIPLE REGRESSION  ANALYSIS
[2]   J←0
[3]  L2:J←J+1
[4]   ' WHAT IS YOUR DEPENDENT VARIABLE?'
[5]   DY←⎕
[6]   NN←M←ρDY
[7]   Y←DY-(+/DY÷M)
[8]   ' HOW MANY ARE YOUR INDEPENDENT VARIBLES?'
[9]   N←⎕
[10]  ' INPUT YOUR INDEPENDENT VARIBLES IN ONE VECTOR'
[11]  X←⎕
[12]  (M≠(ρX)÷N)/'ERROR1'
[13]  XD←(N,M)ρX
[14]  X←(N,M)ρ0
[15]  I←0
[16] L:I←I+1
[17]  X[I;]←XD[I;]-(+/XD[I;]÷M)
[18]  →(I<N)/L
[19]  Y←Y[(J-1)+⍳NN]
[20]  X←X[;(J-1)+⍳NN]
[21]  XX←(N,N,0)ρ⍳0
[22]  I←0
[23] L1:I←I+1
[24]  XX←XX,X[;I]∘.×X[:I]
[25]  →(I<ρY)/L1
[26]  XX←+/XX
[27]  SX←+/X*2
[28]  SY←+/Y*2
[29]  RIJ←XX-((SX∘.×SX)*0.5)
[30]  RYJ←(Y+.×⍉X)÷(SX×SY)*0.5
[31]  BTA←RYJ+.×(⌹RIJ)
[32]  SX←(SX÷N-1)*0.5
[33]  SY←(SY÷N-1)*0.5
[34]  BI←BTA×(SY÷SX)
[35]  A←((+/DY[(J-1)+⍳NN])÷ρY)-+/BI×((+/XD[;(J-1)+⍳NN])÷ρY)
[36]  YDC←A+(BI+.×XD[;(J-1)+⍳NN])
[37]  YC←YDC-(+/YDC÷ρY)
[38]  R←(Y+.×YC)÷((+/Y*2)×(+/YC*2))*0.5
[39]  F←(R*2)×((ρY)-N+1)÷(N×(1-R*2))
[40]  'F10.3' ΔFMT(RIJ;RYJ;BTA;A:BI:(R*2):F)
[41]  →(J<M-NN)/L2
    ∇
```

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16 Abstract

A conceptual model of the commercial air transportation industry is developed which can be used to predict trends in economics, demand, and fuel consumption The methodology is based on digraph theory, which considers the interaction of variables and propagation of changes Air transportation economics are treated by examination of major variables, their relationships, historic trends, and calculation of regression coefficients The report includes a description of the modeling technique and a compilation of historic airline industry statistics used to determine interaction coefficients Results of model validations show negligible difference between actual and projected values over the twenty-eight year period of 1959 to 1976 A limited application of the method presents forecasts of air transportation industry demand, growth, revenue, costs, and fuel consumption to 2020 for two scenarios of future economic growth and energy consumption

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