CHARACTERIZATION OF THE FORCE VARIABLE IN SYSTEMS NETWORK APPLICATIONS WITHIN A SOCIO-ECONOMIC ENVIRONMENT

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ABSTRACT

CHARACTERIZATION OF THE FORCE VARIABLE IN SYSTEMS NETWORK THEORY APPLICATIONS WITHIN A SOCIO-ECONOMIC ENVIRONMENT

By

Paul Bankit

Techniques originally developed to model and analyze complex and interacting physical components have recently been adapted for use in analyzing economic systems. These techniques can be applied to any phenomenon which can be identified as a collection of components interacting at clearly defined interfaces, as long as the behavioral characteristics of these terms can be described mathematically in terms of common flow and force variables. The vehicle for analysis is a system model composed of a set of state equations and an output vector.

This research focuses on the derivation of the force variable as used in the economic sense. The application of the element of demand to linear graph applications allows the analyst to model and characterize the system being considered more completely and to provide strategies for control and stability.

This study applies these techniques to the problem of the requirement for a regional airport as a replacement for existing local facilities. The resulting model depicts the

airport system as a combination of interacting flows and forces. Operation of the system is simulated on the computer and the sensitivity of the system to varying service levels is studied. It is concluded that the force or demand factor can be measured for use in systems application and that the technique offers opportunities for socio-economic applications.

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By

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My gratitude is especially directed toward Dr. Frank H. Mossman, committee chairman, for providing me with the basic theoretical framework for implementing this research His inspiration and material help made it possible.

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CHAPTER I

THE APPLICATION OF SYSTEMS NETWORK THEORY TO A SOCIO-ECONOMIC PROBLEM

Introduction

This dissertation represents an attempt to unite two basic methodologies of electrical engineering and business administration into an operational procedure for use in enhancing the decision making ability of the planner and analyst. The two methodologies are systems network theory, based on the theory of electrical circuits, and economic forecasting, a procedure from business administration. This work can then best be categorized as applied research in that it is prescriptive in nature. It will attempt to provide insight into an operational problem.

General Considerations

Modern society is dominated by a complex of networks for the transmission of energy, the transportation of people, the distribution of goods, and the dissemination of information. This complex consists of such diverse systems as the telephone network, gas and oil pipelines, highway networks, and the networks of computers serving as data banks and remote processing units. The cost of the development of these networks demands that they be rationally used and

new ones be intelligently planned and developed.[1]

These networks have as the basis of their structure the elements of branches, along which flows are transmitted, and nodes, points where flows originate, are relayed, or are terminated. These structural elements are combined into mathematical entities called "graphs". The graph consists of the connected branches and vertices.[2,3]

There are network applications such as Program Evaluation Research Technique (PERT) and the Critical Path Method (CPM)[4] in which only flows are stated and the element of "force" or demand is not present. These graphic techniques are not suitable for characterizing the type of networks to be considered in the context of this work. Additionally, dynamic programming offers a solution to some network problems, especially those with time and state sequencing, but here too, the element of demand is not handled or treated.[5]

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[1]See H. Frank and I. Frisch, Communication, Transmission and Transportation Networks (Reading, Mass., Addison-Wesley, 1971), Chapter 1.

[2]See H. Koenig, Y. Tokad, and H. Kesavan, Analysis of Discrete Physical Systems (New York, McGraw-Hill, 1967).

[3]See H. Frank and I. Frisch, Communication, Transmission, and Transportation Networks (Reading, Mass., Addison-Wesley, 1971), Chapter 2.

[4]See R. Miller, Schedule, Cost, and Profit Control With PERT (New York, McGraw-Hill, 1963), Chapter 2 through 4.

[5]See G. Hadley, Dynamic Programming (Reading, Mass., Addison-Wesley, 1964), Chapters 1 through 3.

One network technology does however treat the factor of propensity or "force". Systems Network Theory (SNT) takes the graph of a network, models the characteristics, and states these characteristics in the form of flow and "force" variables so as to determine the interrelationships of the parameters introduced in the modeling process.[1]

The use of Systems Network Theory in the description and development of electrical networks is generally recognized. Electrical networks, telephone networks, power systems, and some traffic flow applications have been completed utilizing the principles of the theory. There has also been some work in the application of the theory in the production and transportation areas.

The problem in previous applications has been the development of suitable "force" variables, consistent with known economic principles and their proper use in network analysis. Systems network problems have been solved using propensity (a term interchangeable with "force", but which does not properly convey or denote the relationship in the economic and business context) variables such as rate of production cost of commodity,[2] marginal cost of movement,[3]

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[1]See H. Koenig, Y. Tokad, and H. Kesavan, Analysis of Discrete Physical Systems (New York, McGraw-Hill, 1967), Chapters 2 and 3.

[2]See F. Mossman and J. Hynes, Systems Network Theory: Applications to Distribution Problems (Braintree, Mass. D. H. Mark, 1968), Chapter 3.

[3]See J. P. Hynes, Motor Carrier Rates in a Normative Spatial Environment (Unpublished Ph.D. Dissertation, Michigan State University, 1971).

mass-energy costs,[1] and others.

These applications have not satisfactorily expressed the demand, push, or "force" which initiates, relays or terminates flows along branches. Because of the difficulty of stating a satisfactory "force" variable, the use of systems network theory has not been widespread and in fact has been limited to academic applications in business. Such techniques as dynamic programming which use only flow variables are more widely used and accepted but lack the ability to state any measure of "force" or demand, and as such are also limited in application.

The next level of programming is the use of simulation techniques, which substitute heuristic or probabilistic techniques in lieu of the determination of usable demand factors. All these techniques are accomodations for lack of ability to characterize and portray the demand factors of the system being examined.

The Problem

The ability to characterize a suitable "force" function is the greatest hurdle in the development and use of systems network theory in the socio-economic discipline. The ability to characterize the "force" variable in the electrical network applications is well defined by a series of laws defining the relationships of flows and forces,

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[1]See H. Koenig, W. Cooper, and J. Falvey, "Engineering for Ecological, Sociological, and Economic Compatibility", <u>IEEE Transactions on Systems, Man, and Cybernetics</u> Vol. SMC-2, July 1972, pp. 319-331.

just as they are in the other physical science applications.[1] The use of systems network theory as an analytical tool in the study of economic processes has therefore not been an area for extensive investigation because of the difficulty of operationalizing the features of the technique, and applying them to actual business and governmental problems.[2]

Review of previous works in the field do not yield evidence of full use of the technique except in very restricted situations, although there have been several excellent efforts describing the technique. The prime reference for the theory is that written by Koenig,[3] which laid the initial base for the work of Mossman and Hynes,[4,5] who

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[1]See T. C. Koopmans and S. Reiter, "A Model of Transportation", in Activity Analysis of Production and Allocation, ed. by T. C. Koopmans (New York: John Wiley & Sons, Inc. 1951), pp. 222-59.

[2]Other linear graph applications within socio-economic systems are described in contemporary literature. For example see H. Koenig and T. Manetsch, Systems Analysis of the Social Sciences (East Lansing, Michigan: College of Engineering, Michigan State University, 1966). (Mimeographed) or M. Beckman, D. Christ, and M. Nerlove, Scientific Papers of Tjallings C. Koopmans (New York, Springer-Verlag, 1970), pp. 184-209.

[3]See H. Koenig, Y. Tokad, and H. Kesavan, Analysis of Discrete Physical Systems (New York, McGraw-Hill, 1967), pp. 343-421.

[4]See F. Mossman and J. Hynes, Systems Network Theory: Applications to Distribution Problems (Braintree, Mass. 1968), pp. 18-37.

[5]See J. Hynes, Motor Carrier Rates in a Normative Spatial Environment (Unpublished Ph.D. dissertation, Michigan State University, 1971).

have applied the theory and established some methodology to the problems of transportation networks.

It appears that applications in the field of transportation offer opportunities for development because of the similarities of flows along transportation links and terminal throughput capabilities to the same applications in electrical circuit theory. The transportation problem is well known in linear programming models and the applications of Mossman and Hynes have utilized linear programming to implement systems network theory. The application of linear programming to the theory limits the problem to static solutions and thus fails to provide adequate temporal sensitivity. Transportation problem solutions as accomplished by the works of Mossman and Hynes focused on the flow aspects of the transportation network. Though considerable work was done attempting to establish a propensity (force) variable suitable for expression of the demands within the system, the studies focused on marginal movement costs which were not entirely satisfactory, especially in the operational sense. Systems network theory has the ability to move from time period to time period in the technique. It is in this area that the research will develop and demonstrate a suitable technique for the derivation of the "force" variable so critical to socio-economic applications. As Baumol points out, "No matter how ingenious the economists circumlocutions that have been employed, there has been no substitute devised

to replace the demand function."[1]

Problem Application

The area of transportation offers a particularly fruitful research medium. Since flows and flow data are available in standardized formats, a problem involving air passenger transportation within the state of Michigan was selected as a candidate for application of systems network theory in an economic context.

An area of current interest is the possibility of construction of an international regional airport facility in the middlewestern states, occasioned by the rise of air traffic volume both in the passenger and air cargo fields and the saturation of present facilities in the area.[2] The various states are, of course, interested in the location of such a facility within their borders. Since the construction of such a facility is an extremely expensive undertaking, the location and siting considerations are of critical importance. To assist in the problem, a smaller scale problem using techniques applicable to scaling could prove to be of assistance in the measurement of future traffic volumes and demand service.

The area of investigation will be a systems network application of the determination of the proper level of

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[1]See W. J. Baumol, Economic Theory and Operations Analysis, 2d, Ed. (Englewood Cliffs, N. J., Prentice-Hall, 1965), pp. 210-230.

[2]See "Facing the Airport Challenge", Avaition Week and Space Technology, November 15, 1971, p. 23.

service for an air terminal facility intended for use as a regional airport in the state of Michigan.[1] The determination of the "force" variable, an economic function intended to depict the demand for services at the facility, will be based on economic factors, and expressed as an index number. This approach differs from other applications of the propensity (force) variable, which have attempted to express this parameter as a finite number, as derived in the accounting sense. Accounting values, such as cost per unit, have not been usable general statements of propensity. Index numbers or ratios are more adaptable to the general case and are freed of some constraints such as magnitude differences, scale problems and quality or time differences.

Systems Network Theory Considerations

The use of systems network theory is based on the ability to model and characterize the behavior of individual entities and their environment and to assemble these behavior traits into systems. A system in our context is defined as, "A coordinated collection of physical elements and conceptual linkages intended to serve a common purpose".[2] While

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[1] Examples of the type of planning criteria applied to airport locations and sizing used in the long range plans are prepared by the Federal government and adjusted to local conditions by local governments. For example see: Federal Aviation Administration, Airport Capacity Criteria Used in Preparation of the National Airport Plan, U. S Government Printing Office, Washington, D. C. 1968, and Federal Avaition Administration, Planning the State Airport System, U. S. Government Printing Office, Washington, D. C., 1968.

[2] See A. M. Lee, Systems Analysis Frameworks (New York, Wiley & Sons, 1970), p. 18.

the physical sciences were first to utilize the systems approach to problems, the social sciences have also developed a considerable experience in the approach. From the definition and recognition of economic systems the procession to use of physical science techniques in certain aspects of economic inquiry such as this dissertation is a natural and evolutionary step. Systems network theory builds on the definition and is particularly suited for those economic applications seeking to maximize benefits gained from the use of scarce resources.[1]

The Axiom and Postulates of Systems Network Theory

Systems network theory, as previously mentioned, is based on work done in the electrical engineering field. This body of knowledge proceeds from the elementary laws of electrical circuits developed by Kirchoff,[2] and specifies that there are two considerations in a circuit, voltage and current, and that these factors are complementary in nature. Flows and flow variables are analogous to electric current and "force" is analogous to voltage and electrical pressure. The electric power system depends on the complementary nature

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[1]The reader is particularly directed to the work of R. Handy and P. Kurtz entitled A Current Appraisal of the Behavioral Sciences (Great Barrington, Mass., 1964, Behavioral Research Council), for an excellent overview of the challenges to application of systems sciences to the behavioral science.

[2]See G. Kirchoff, Uber die Auflosung der Gleichungen, auf welche man bei der Unter-suchungen der Linearn Verteilung Galvanischer Strome gerfuhrt wird (English translation, Transaction of the Institute of Radio Engineers, CT-5), March 1958, pp. 4-7.

of voltage and current just as flows of goods and funds are dependent on demand or "force" in a business firm. Therefore systems network theory is more suitable than other programming techniques for those applications where "force" must be considered.

Limitations in the ability to define the "force" variable are the primary stumbling blocks in the use of the theory, but also provide the key to future applications.

The method of expressing the components of a system as utilized in the systems network theory is the linear graph.[1] With this graph it is possible to model the system, assemble the linkages, derive component equations to mathematically express the linkages, and finally to control the system so as to measure performance and auxiliary effects.[2] It may then be possible to stabilize and redesign the components so as to provide for optimized performance.

The fundamental axiom of systems network theory is that a mathematical model of a closed system characterizes the behavior of the system as an entity and independently of how the component is interconnected with other components to form a system.[3] This axiom is further defined by a series of postulates which characterize the depiction of the system.

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[1]See H. Frank, and I. Frisch, Communication, Transmission, and Transportation Networks (Reading, Mass., Addison-Wesley, 1971), Chapter 2.

[2]See H. Koenig, Y. Tokad, and H. Kesavan, Analysis of Discrete Physical Systems,(New York, McGraw-Hill, 1967), Chapter 1.

[3]See Koenig, etal, op. cit., p. 3

These postulates are:

Postulate I. The pertinent behavior of characteristics of each n-terminal as an identified system structure are completely identified by a set of n-1 equations in n-1 pairs of oriented complementary variables identified by an arbitrarily chosen terminal graph.[1]

Postulate II. The systems graph is defined operationally as the collection of edges and vertices obtained by coalescing the vertices of the component terminal graph in a one to one correspondence with the way in which the terminals of corresponding components are united to form the system.[2]

Postulate III. The algebraic sum of the "force" variables implied by the oriented edges of any circuit in the systems graph is zero.[3]

Postulate IV. The algebraic sum of the flow variables around a vertex and forming a cut-set sum to zero. (A cut-set of a

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[1] *Ibid*, p. 5

[2] *Ibid*, p. 6.

[3] *Ibid*, p. 111.

> connected graph is defined as a set of edges having the property that when these are removed they divide the graph into two unconnected parts and no subset has the first property).[1]

These statements form the foundation of systems network theory and the base for the research to be accomplished in this dissertation.

Graph Methodology

The development of the research entailed the organization of a closed system encompassing the study cities, all located in the state of Michigan. These cities are Lansing (LAN), Flint (FNT), and Tri-Cities (Midland, Bay City and Saginaw (SGN)), which form the regional boundaries for the proposed location of the new air terminal facility (MID), and Detroit (DET) which serves as the hub city for air traffic in the state. The three cities form the second largest concentration of population and industry in the state of Michigan, second only to Detroit, and generate considerable amounts of air traffic. The city areas are organized into a network graph. This graph will be the mathematical equivalent of the actual relationships of the air traffic flowing between the cities and will represent the air terminal facilities presently operating, in addition a proposed air terminal facility will be entered into the graph. The

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[1] _Ibid_, p. 113.

location of the proposed regional air terminal facility was determined by constructing three center-of-gravity location models. The first was an unweighted geographical centroid location. The second model consisted of weighted locations based on population and population changes from 1970 to the year 2000. The third model located the facility on the weighted basis of personal income for the three cities for the years 1970 through 2000.[1] Sensitivity of demand for air travel at short distances requires careful consideration of location for air terminal facilities.

The different locations are plotted and if the study is utilized at a later time may be used in the determination of the actual location of the terminal if desired. The locations and geographical coordinates are shown at Figure 1, and Table 1. It should be noted that the different economic and demographic growth rates for the three cities cause the location to shift toward east northeast of the geographical center.

The graphic representation of this scheme, shown as directed graph with the appropriate flow directions is shown at Figure 2. The flows as shown which provide the basis for the directed state are the actual numbers of airline passengers who use the air terminal facility in Detroit as a point to assemble for further travel to other destinations.

Some features of the directed graph are uni-directional

[1]Appendix A contains a complete description of the location models used for the regional facility.

FIGURE I

Geographic Location of Proposed MID Facility

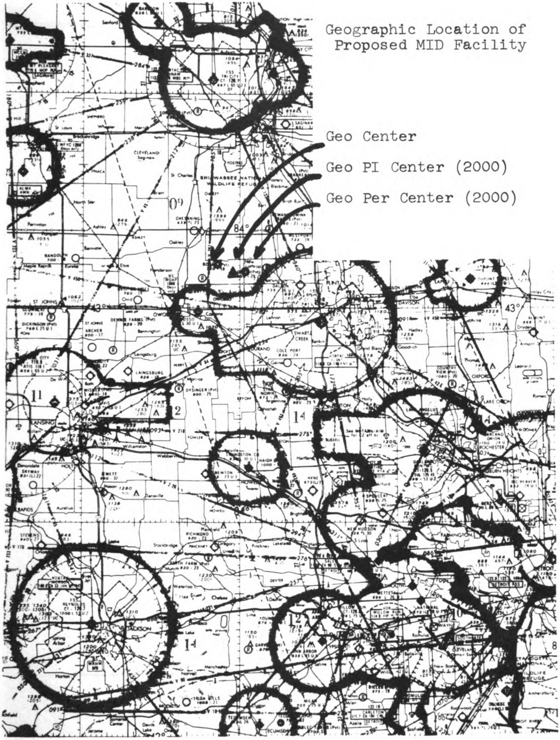


TABLE I

Geographic Coordinates and Locations of Proposed MID Facility

Geographic Center Coordinates

North Latitude. . 43° 05' 59"
West Longitude. . 84° 04' 49"

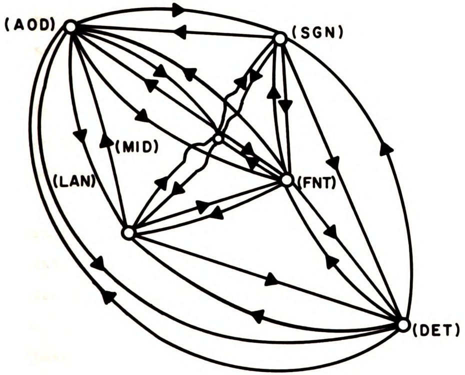
GeoPerCenter Coordinates

Year	North	West
1968	43° 03' 14"	84° 01' 15"
1970	43° 05' 51"	84° 01' 57"
1980	43° 05' 31"	84° 01' 50"
1990	43° 05' 17"	84° 01' 41"
2000	43° 04' 59"	84° 01' 30"

GeoPICenter Coordinates

Year	North	West
1968	43° 04' 15"	84° 00' 44"
1970	43° 04' 12"	84° 00' 43"
1980	43° 04' 08"	84° 00' 40"
1990	43° 04' 28"	83° 58' 16"
2000	43° 05' 28"	83° 58' 16"

FIGURE 2



Directed Graph for Research Cities

flows along the edges (the air routes between the city pairs). In graph theory this type of graph, as opposed to an undirected graph (one in which there exists bi-directional flows along the edges), consists of a set of elements called vertices and a set of ordered pairs of vertices called directed edges. The set of vertices is denoted by the symbol V and the set of directed edges by the symbol B. The graph is finite if both V and B are finite sets, as they are in this case. It must be noted that there can at most be one edge from any vertex (airport terminal facility) v_i to any other vertex v_j.

The "force" variable applicable to each vertex (airport terminal facility) is developed so as to reflect the relative demand of each city pair. This variable is described below with its development methodology. The importance of the "force" variable in characterizing the total graph is of primary importance at this point. One of the properties of a graph, Postulate 3, is that all "force" variables sum to zero around a circuit. A circuit is defined as a selected set of connected branches or edges that form a unique closed path in a systems graph; in other words a circuit is a set of selected edges that form one and only one closed circular path. The criticality of the term "directed graph" now is paramount since the orientation of the edges around a circuit provides the positive or negative value associated with each "force" value.

Of the salient points of systems theory, the requirement that in a closed system all the "force" or demand values sum to zero around a circuit is very important. In the case of the systems graph utilized in this study an additional vertex was required so as to retain the properties of a closed system. This is required since some travelers originating and terminating at the research cities do not move through the Detroit air terminal. The additional vertex (AOD) serves as the origin and destination for all travelers moving to and from the four cities to points outside the system. Thus the systems graph as shown in Figure 2 describes all airline travelers to and from the base cities of Lansing, Flint, and Bay City-Saginaw. The inclusion of the additional vertex also serves as a device allowing the circuits to meet the systems network criteria specified in the four postulates and the basic axiom.

The Research Objective

The objective of the study is the development of a suitable "force" variable capable of depicting the demand for air passenger transportation originating and terminating at the three base cities, and to portray a suitable method for deriving this function in socio-economic applications in order to exploit the advantages of systems network theory. The "force" variable centers around the service levels of airline passenger seats utilized at the base cities to the Detroit air terminal facility and the availability of alternate surface travel options for the traveler. The development of the "force" variable is considered in the secon

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second chapter of this dissertation.

The third chapter develops the systems network model utilized to test the applicability of the "force" variable to the airport feasibility study. The model is designed to forecast the flows and demand conditions for airline travel developed for the time period 1968 to 2000, and the effect of the operation of a regional air terminal facility on the traffic flows between the new facility, the three base cities and Detroit. It generates the total demand (force) for air travel at the regional facility and provides a methodology for comparison of total demands for airline travel with and without the proposed facility.

The fourth chapter synthesizes the conclusions drawn from the investigation, and describes the implications and limitations of the investigation for planning, and other possible applications.

CHAPTER II

CHARACTERIZATION OF THE "FORCE" VARIABLE

Introduction

This chapter is concerned with the development of the "force" variable function used to characterize the demand for air travel in the base cities used in this study. The three base cities and Detroit form an excellent example of the "hub and spoke" airline transportation system used for domestic air carrier transportation in the United States. Truck line service is provided between high density (hub) airports and is characterized by use of such aircraft as the Boeing 707 and 747, McDonnell-Douglas DC-8 and DC-10, and Lockheed Tri-Star. Feeder service is provided by airlines between hub airports and medium and low density airports. This service is characterized by the use of aircraft such as the Boeing 727, McDonnell-Douglas DC-9 and Convair 440 aircraft. This system is designed to provide air service to cities which could not support full trunk line service to and from major population centers. This is accomplished by providing feeder service to larger population centers, which then perform the assembly function of pooling small groups of passengers from remote locations into groups of sufficient size to support trunk line service to major population centers. The Federal Aviation Administration (FAA) plan, for the period 1971 through 1980, shows development and funding for thirty hub airports and 149 medium density air carrier airports.[1] The three base cities in this study all qualify as medium density airports, and Detroit is classed as a high density hub airport.

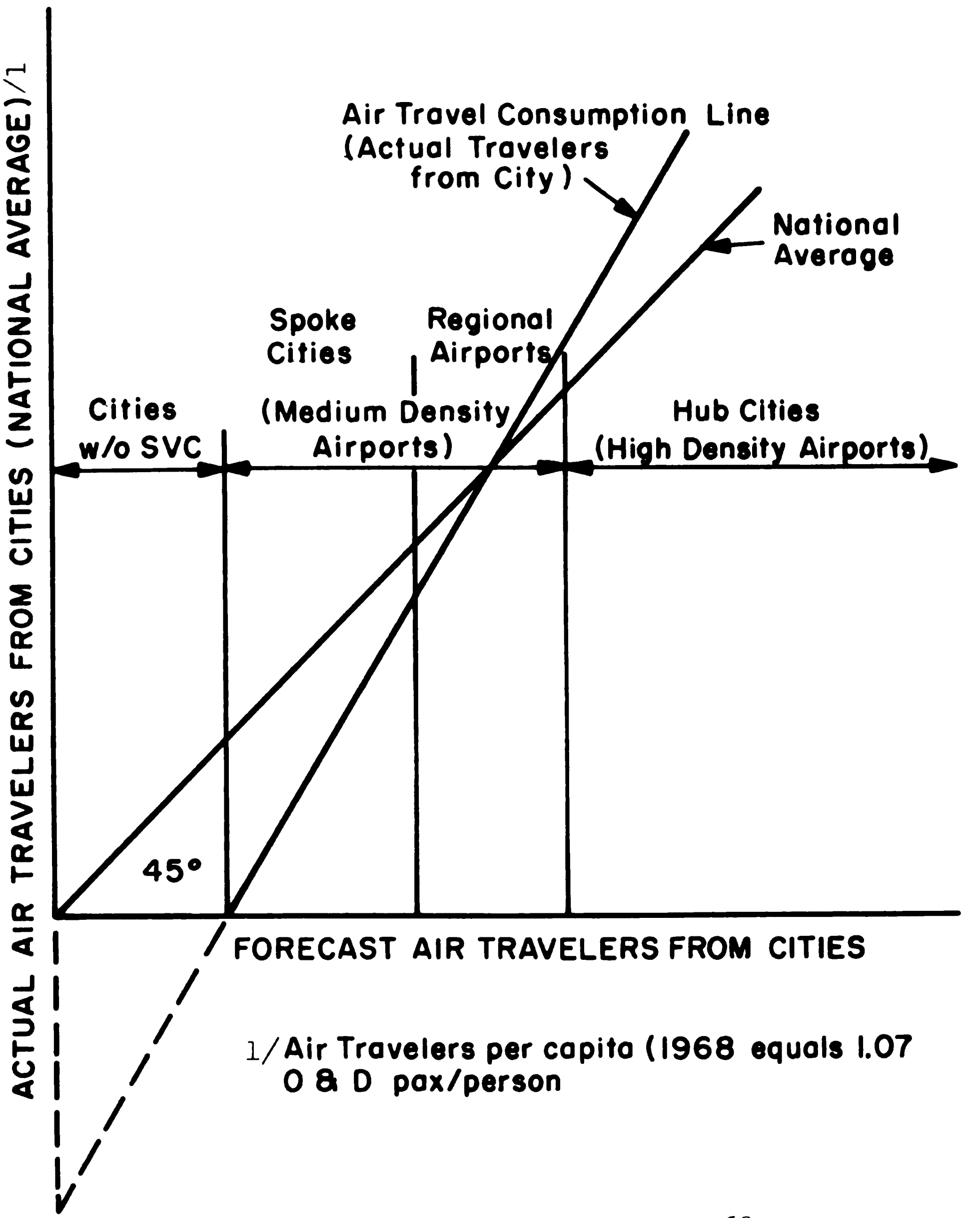
Since the hub airports perform the assembly and disassembly function within the system, the number of origin-destination passengers per capita is higher than that seen at the spoke cities, reflecting the numbers of passengers moving through the hub city for further movement to other destinations.

A graphic display of this arrangement is depicted in Figure 3, which shows that actual origin-destination traffic for large centers of population exceeds the national average while smaller cities show a lower than average of traffic per capita. The diagram (figure 3) is constructed such that the actual amount of air travel per capita originating at cities of various population levels shown on the ordinate and the forecast amount of air travel shown on the horizontal line are drawn at the same scale. Any city which has a level of air passenger traffic equal to the national average forecast would be shown on the 45° line. The 45° line has the

[1]High density (hub) airports are those that enplane over one million passengers annually, while medium density airports are those that will enplane from 50,000 to one million passengers annually. For an excellent description of the planning funding of the national airport system see, The National Aviation System Plan, Ten Year Plan, 1971-1980, Department of Transportation, Federal Aviation Administration (Washington, 1970).

Figure 3

Typical Airline Service Offered at Cities



Source: Civil Aeronautics Board, 1968.

property that the indicated forecast level of air travel, measured by the vertical distance of the point from the horizontal axis is exactly equal to 100 percent of its actual level of air travel on a national basis as measured by the horizontal distance of the point from the vertical axis. For instance in 1968, the Detroit air terminal had a total of 6,823,960 origin-destination passengers move through the facility. During that year the national average of air travelers was 1.07 per capita, the Detroit facility had an average of 1.34 origin-destination passengers per capita.[1] Detroit would be located in the hub city section of Figure 3. Conversely, the Michigan cities which provide transfer passengers to the Detroit air terminal facility had the levels of passengers per capita listed in Table 2 below. This may be due in large part to the travelers within the

TABLE 2

O & D Passenger Over Capita for Selected Michigan Cities

City	Population (000's)	O & D Passengers per capita	O & D Passengers
Jackson	149	.09	14,616
Flint	487	.33	158,954
Lansing	361	.71	254,511
Bay City-Saginaw	372	.75	268,805
Grand Rapids	514	.83	424,255
Detroit	5,015	1.34	6,823,960

Source: Michigan Department of Commerce, State Aeronautics Commission, 1968 Data.

[1]See Origin-Destination Survey of Domestic Airline Passenger Traffic, 1968, Civil Aeronautics Board, Washington, D.C.

system electing to drive to the hub city rather than utilizing the local air service.

It is apparent that the base cities analyzed in this study and shown in Table 2 above have lower than average airline passengers per capita than the national average of 1.07 for 1968. The Table shows that as city size increases the rate of airline travel increases also. This corroborates the information shown in Figure 3. The Figure also shows that there is a range of city size that should have a level of service equal to the national average (regional airports). It would seem then that at this particular city size the economies of service on the part of airlines which provide access to the city are such that a sufficient number of passengers are generated so that trunk line operations to hub cities is feasible. This exact relationship is limited, of course, to the cities depicted in the system being analyzed. The element of distance is also not considered in the graph, but will be shown as a vital element in the relationship of demand for the modes of travel. The intersection of the air travel demanded at the Michigan system cities is an indication of the number of travelers and combined cities sizes that are required at a single facility to ensure a supply of air service equal to the national average, that is the level of service which would enable trunk line service direct to and from major hub cities. The total system demand is balanced by the increased demand at the hub city resulting from the origination of air travel at the hub city by those travelers

who elected to use surface travel for the first leg of their journey rather than utilize local air service.

Demand Factors for Air Travel

Several investigators have attempted to develop the empirical relationships of demand for air travel.[1] One such effort considered and determined the effects of distance as it concerned the attraction between two cities.[2] The authors related three considerations of the distance factor, which they called the primary reason for utilizing air travel, they were:

> 1) The distance between two people may be related to the probability that an occasion for communication between them will arise. As we move out from any point in the economy, the variety of demands that can be satisfied rises as the distance from the point increases; the self-sufficiency of larger areas, other things being equal, is greater than that of smaller areas.
> 2) Distance is related to price and may be taken as proxy for the cost of the trip.
> 3) Distance is related to the competitive position of different modes of travel; in particular, there is likely to be no advantage in traveling by air instead of by some other means of transportation

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[1] Some examples of work accomplished in the area are given below. P. Cherington, "The Domestic Market for Air Transportation", Flight Forum (sponsored by Connecticut General Life Insurance Company), July 1962, pp. 1-10. "Benefits from a National Air Service Guide", an excerpt from testimony by G. Burnard before the U.S. Senate, Committee on Commerce, Review of the Local Air Carrier Industry, Washington, D.C., USGPO, 1966, pp. 335-337. "The Economics of Convenient Airline Service", Tijdschrift voor Vervoerswetenschap, No. 3, 1966, Netherlands Institute of Transport, pp. 217-233 (reprinted in Passenger Transport Michigan State University Business Studies, 1968).

[2] See J. Lansing, J. Liu, and D. Suits, "An Analysis of Interurban Air Travel", Quarterly Journal of Economics, (February 1961), pp. 87-95.

> if the distance is less than some minimum number of miles. Beyond that distance, the time saved by air over the other modes may be expected to be roughly proportional to the number of miles to be covered. There is reason to suppose that the proportion of all travel which is by air will be close to zero for very short distances and tend to increase with distance.[1]

These three factors of distance-mass attraction, distance-cost and distance-modal choice constitute the source of demand for airline travel, in fact for all travel. They also form the basis for the derivation of the "force" variable utilized in this dissertation.

Distance-Mass Attraction

The understanding of the attraction of population masses for retail sales is well known, and is generally so widely accepted as a measure of the power of trading area that it has been granted the cognomen of a "law". First propounded by Reilly over forty years ago, the "law of retail gravitation" expresses the relationships of city size and distance as they pertain to the ability of trading centers to attract patrons.[2] The relationship is a linear one with attraction a direct function of the ratio of population and an inverse relationship of the square of the distance separating the two cities. This relationship is also expressed in the distance-mass attraction statement quoted in the preceding paragraph. Our statement also states that as the

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[1] *op.cit.*, p. 89.

[2] See W. Reilly, *The Law of Retail Gravitation* (New York, William J. Reilly, 1931).

size of the city increases the self-sufficiency increases and that smaller cities are less able to support themselves and provide necessary service. This implies something other than a straight line relationship, possibly some curvilinear increasing function as city size increases. A revision of Reilly's original formulae by Converse substantiated the inability to express a straight line relationship when city size differences exceeded multiples of twenty, the predictive power of the original statement is reduced.[1] There are limits then, which must be observed in the application of the Reilly-Converse formulae, the comparison of retail power must be used only for cities of similar sizes. This would obviate the use of such a model for use in this "force" variable determination, since there is such a large disparity in the sizes of Detroit and the three base cities. We must search further for a suitable determinant.

Distance-Cost

Distance and cost relations are well established in the field of transportation where, as in the statement of the cost and price relationship above, there is a direct correlation. As distance increases the cost of moving that distance increases directly, though there are instances where there are discounts, called rate tapering, for trips of extended

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[1]See P. Converse, A Study of Retail Trade Areas in East Central Illinois, Business Studies Number 2 (Urbana, Illinois., The Univeristy of Illinois 1943).

lengths.[1] While in the traditional depiction of demand price is the determinant of quantity, the demand for travel must contend with competitive modes, time, convenience, service, accessibility, safety, and price. For these reasons the factor of price or cost does not lead us nearer to a suitable measure of "force" without considerable adjustment for the aforementioned factors and for the heterogeneity of the individual traveler and his utility-preference values. In addition, because of the prevailing differences in average fares per mile for different city-pairs, principally because of the availability of lower priced coach service on some routes, there are other possible abattoirs which trap the investigator using price alone as a measure of demand for air travel. The difference in city-pair markets, population, income, and tastes in these markets also mitigate against the use of price alone.[2] In addition, where different types of carriers (trunk, local, or third level) operate on the same route segment or within the system being analyzed the apparent differences of equipment, times and connections along with price may very well consist of the full aspects of what could be called the cost-price aspect of the "force"

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[1]See D. Pergrum, Transportation· Economics and Public Policy, (Homewood, Ill., Richard D. Irwin Inc., 1968).

[2]For an example of a study of the elasticity of air fares and demand for air travel on a national basis see S. Brown, and W. Watkins, "The Demand for Air Travel: A Regression Study of Time-Series and Cross-Sectional Data in the U.S. Domestic Market", Paper -- 47th Annual Meeting, Highway Research Council, Washington, D. C., January 16, 1968.

variable. For this reason (the incalculability of the price aspect) this phase of the typical demand function was not selected for use directly in the "force" variable construction.

Distance-Modal Choice

While the factor of price is not directly utilized in the analysis for the derivation of the elements of the demand function, the factor of modal-choice certainly contains as one of its elements the factor of price or cost. The traveler, in making his choice of mode, takes into account the elements of time, cost, and distance when making the decision prior to initiating travel. An important element appears to be travel time differences and the traveler attaches a value to this time, just as he measures the value of accessibility to the terminal for each mode, the schedule convenience, vehicle delay at the terminal, and average station wait. This time-value concept then forms the basis for measuring the total cost of the block-times for each mode of transportation utilized in reaching his destination. A comparison, planned or unconscious, is made by the traveler and the decision made as to the choice of mode to be utilized in traveling. It would seem that travelers are willing to accept certain penalty costs in order to save time and that when these penalty costs exceed a certain level, the less expensive mode is selected. One study on the time-value coverage principle states that most air travelers are willing to accept a $2 to $3 penalty cost just to save one hour traveling by air, over and above a slower but cheaper means

on the surface.[1]

Modal Choice in the Research Cities

The aspects of modal choice decisions in the research cities for air travel required to move through the Detroit facility from the base cities was clearly demonstrated in a study of land use in the Detroit metropolitan area accomplished in 1968. This study, which measured the anticipated land requirements for various industrial needs, services, highways, and population, estimated the composition of air travelers moving through the Detroit air terminal facility. This was accomplished through the use of a passenger survey conducted by all the airlines serving the city.[2] This sub-study of the Detroit Regional Transportation and Land Use Study (TALUS) provided much valuable input for the data used in this study.[3] Passenger information taken from respondents originating at the three base cities substantiated the modal choice factor previously stated.

The travelers from these cities and their choice of modes used to move to the Detroit facility was in general agreement with the statement that there was some minimum

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[1]See R. Rice, "Time and Cost in Carrier Competition." Passenger Transportation., Edited by S. C. Hollander, East Lansing, Michigan., MSU Business Studies, 1968, pp. 114-117.

[2]See Travel Patterns & Characteristics of Airline Passengers, Detroit Metropolitan Airport, 1968, Wayne County Road Commission (Detroit, Michigan, 1969).

[3]See Detroit Regional Transportation and Land Use Study, Southeast Michigan Council of Governments (Detroit, Mich., 1969). The survey referenced in 2 above was accomplished by a joint effort of the two agencies listed and was not included in the TALUS publication.

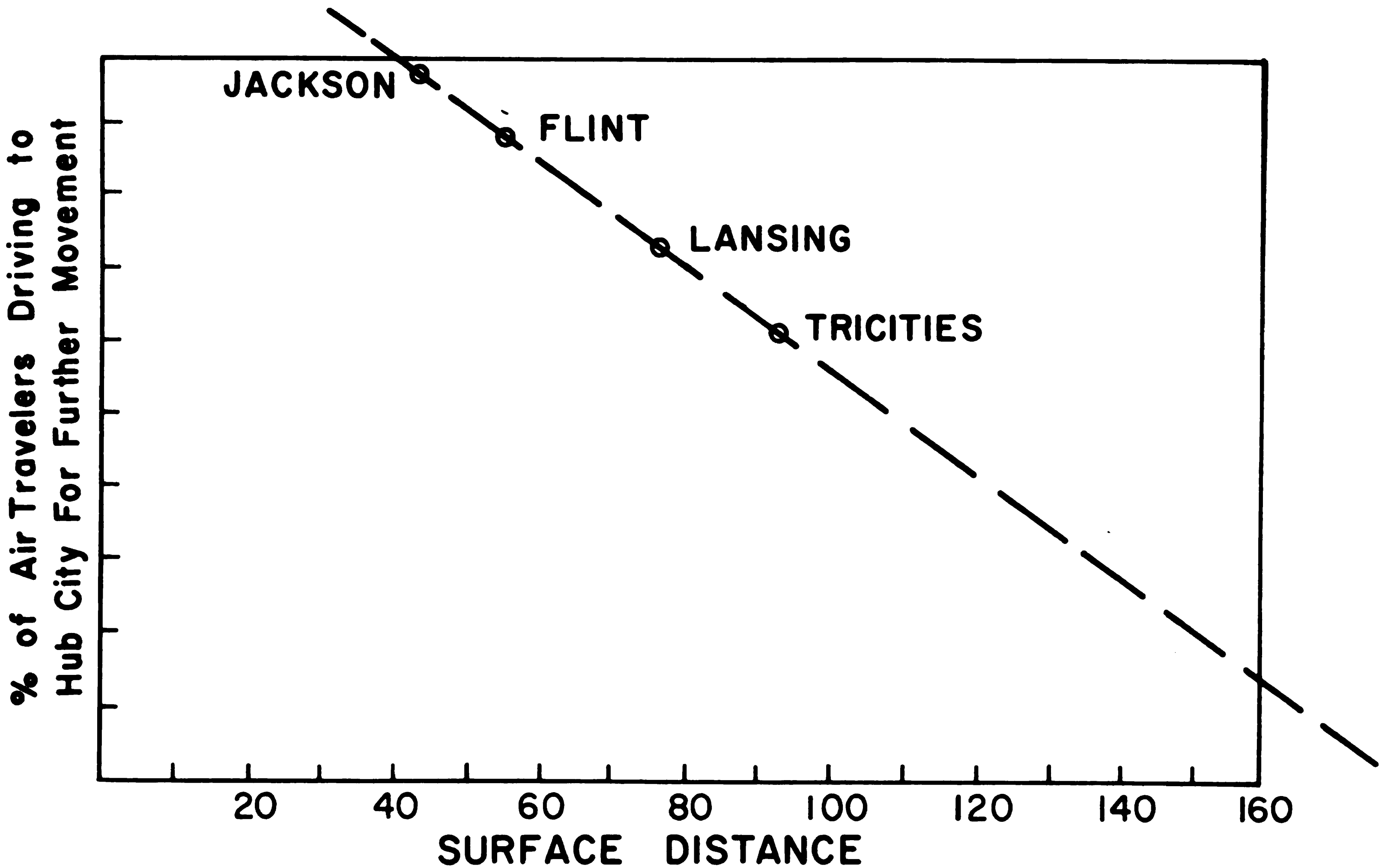
distance at which almost no demand for air travel could be generated for local air terminal. A graphical portrayal of this distance effect on modal choice is shown at Figure 4. The graph shows that at a distance of forty miles almost all travelers elected to utilize surface transport rather than using the available airline service connecting the city of Jackson and the Detroit air terminal facility. The effect of distance at greater ranges is also shown by the proportion of travelees choosing to fly from Grand Rapids rather than drive to the Detroit airport. From this display of information, one can infer that the distance of forty miles constitutes the indifference point at which the time-value of air service is overcome by the less expensive means of driving to the hub air terminal facility. There is, of course, the long distance end of the spectrum which shows that almost no one would choose to drive to the hub air terminal facility when the distance exceeds 180 miles. This modal choice on the part of the traveler constitutes an important factor in the demand for air travel.

From Figure 4 one may also infer that there is some fixed waiting time (the distance of forty miles) associated with air travel which the traveler can save by using surface means to get to the hub facility. This waiting time, when equated to a driving speed of sixty miles per hour by auto, is approximately equal to the time to park an auto, be ticketed, and wait the thirty minutes asked by airlines of passengers.

If this is the case the traveler then makes a decision as to the savings afforded by air travel and as the distance to the hub airport increases a greater proportion then elect to travel by air. Not all the travelers attach the same value to time, but the relationship in our example in Figure 4 is linear, that is, the same proportion elect to change modes per mile of distance. This is not surprising since it reflects the changing elasticity of demand for airline travel as distance increases. The demand for air travel becomes inelastic since the largest proportion of travelers have already been switched over to the airline mode thus it takes a larger time savings to cause the last numbers to move into the air travel mode.

This time ratio (surface driving time over air travel time) is critically important to the demand for air travel because of the higher cost of air travel compared to the perceived cost of driving an owned auto. Since the traveler already possesses the means to move by surface, the additional cost of air travel over and above the cost of surface movement must be accompanied by a real time savings. As the time ratio in favor of air travel increases the number of travelers choosing the air travel mode increases after the forty mile distance and out to the 180 mile distance. This travel time ratio rather than the utilization of either cost, time, or convenience alone shows the demand for air travel, since it embodies all the elements as perceived by the traveler. It also depicts the relationship shown in the

FIGURE 4



Proportions of Surface Travelers between Detroit and Selected Mich. Cities as a function of Distance

SOURCE: Wayne County Road Commission, 1968 third distance factor (distance-modal choice) described earlier. The distance-modal choice factor as stated above also affects the first two distance factors of mass and cost as described through the proportionality of travel assigned to each mode by the fixed time and speed difference of air to surface travel. In the city combinations being investigated in this dissertation the travel time ratio, surface travel time divided by air travel time, ranges from a factor of 2.40 to a factor of 3.31. This ratio is derived from highway travel times from the center of the spoke city to the Detroit airport for the surface mode and equated to a speed of sixty miles per hour, and from the actual flight time from the spoke city airport to the Detroit airport as published in the airline schedules. The surface travel time becomes the numerator of the ratio and the flight time the denominator. Thus the ratio is able to express changes in technology in either of the two modes. Improved highways which would lower surface travel times would adversely affect the demand for air travel, while improvement in flight times sould increase the demand for air travel. In the relatively short distance included in this system, the fixed component of the air travel mode (the forty mile minimum distance) as perceived by the traveler represents the greatest area for improvement since it represents to the traveler the greatest single time factor. As will be shown this factor is depicted in the portrayal of the demand factor selected for this systems problem, and thus is considered automatically when stating the relative demands for the surface and air travel modes, as used in the determination of systems flows and "forces".

The Service Level Ratio Effect

The actual service levels at the spoke cities reflects the relative demand between the several cities and with the national system airline. Service level is stated as the number of origin-destination passengers per capita, a standard Civil Aeronautics Board (CAB) term. An origin-destination passenger is defined as a single boarding and disembarkation with no immediate stops enumerated. As distance increases the demand for airline service increases because of the time-value savings accrued by the traveler when using air transport. This is manifested by a greater demand per capita at greater distances and a lower demand at short travel distances, due to the higher proportion of travelers electing to fly rather than drive at the longer distances. This effect is reflected in the service level offered at the local spoke city air terminal facility, not in the number of aircraft arrivals and departures, but in the actual passenger boardings which in the long run depict the actual service level. The total system demand is balanced in this case by increased demand at the hub city resulting from the origination of air travel at the hub city by those travelers who elected to use surface travel for the first leg of their journey rather than utilize local air service. This shows the individual preference and time-value associated with the distance between the originating spoke city and the hub city. In order to establish a reference point the national average for the year being considered is utilized as a base value and the service levels at the air terminal facilities being studied is computed as a percentage of that value, in the case of Detroit in 1968 the value assigned to the service is equal to 1.34, while that associated with Lansing is .71. From these two values, a service level ratio has been constructed using the hub city (Detroit) value as a denominator and the spoke city (in this case, Lansing) value in the numerator. The resulting service level ratio is a number less than one for all Detroit/spoke city combinations i.e., Lansing-Detroit within the "hub and spoke" system of Detroit and its spoke cities. An additional constraint on this value is that it be less than 1.00/1.34, that is that the city being considered has an associated service level equal to the national average, which would indicate that it is capable of being independent of the air terminal facility located in Detroit, having no need of the assembly function accomplished by the Detroit facility for its' spoke cities. This service level ratio as stated comprises the second element of the "force" function utilized in the system study. It relates the "force" function that is equal to the demand for air travel at the base cities being considered in this dissertation to the travel time ratio as perceived by the traveler.

The "Force" Function

The two elements of travel time ratio and service level ratio comprise the "force" function as developed for use in this application of systems network theory. Together they express the relationships of demand or "force" between the system base cities and Detroit. The "force" function is graphically shown at Figure 5. It depicts that the service level required at a spoke airport in the system is related to the travel time ratio by the following relationship.

$$F = a + b + CT^2$$

F = Service Level Ratio (Spoke city/ Detroit) (Force Value)

T = Travel Time Ratio (Surface Driving Time/Air Flight Time).

In this form the "force" equation is:

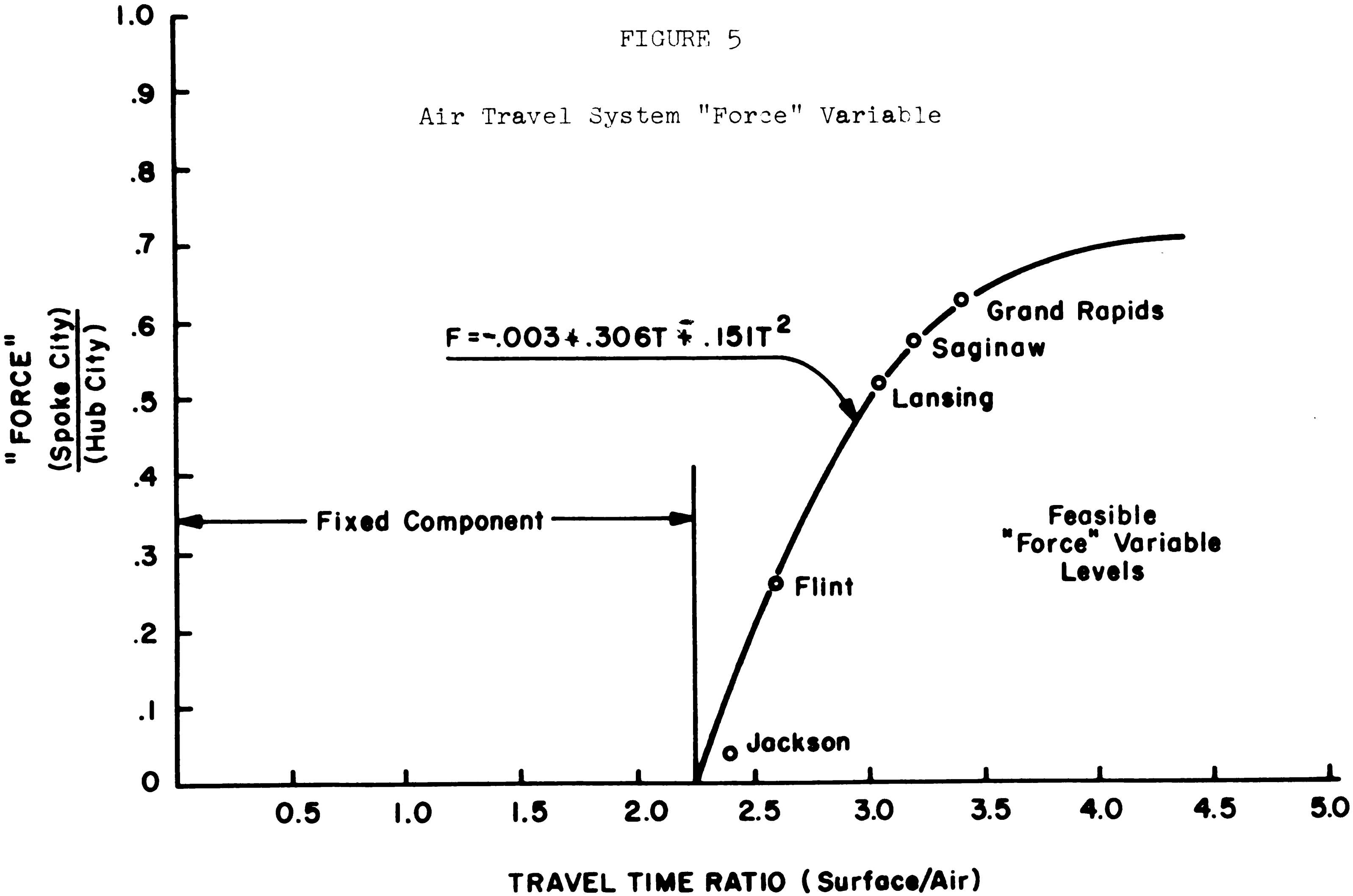
$$F = .003 - .306T + .151T^2$$

This form of the equation depicts the fact that demand for air travel is equal to zero at travel times ratios less than 2.0, increasing rapidly then increasing at a decreasing rate as the service level ratio approaches .75 (the ratio of 1.00/1.34). This is, of course, the ratio of independence from use of the Detroit air terminal facility.

From the graph one can ascertain that the area to the right and below the "force" curve contains the feasible area for service at spoke airports. This is a level lower than that offered presently but within the modal choice possibility constrained by the travel time ratio which fixes the limit of traveler decisions.

FIGURE 5

Air Travel System "Force" Variable



Changes in the travel time ratio will cause the "force" curve to shift either to the left or right. Improvements in air service through reduced travel times causes a shift to the left reducing the fixed component (minimum distance at which the traveler first begins to choose air travel) of the air travel demand. Likewise, improvements in surface transportation enabling the traveler to reach the air terminal facility in less time will cause the "force" curve to move to the right, thus reducing demand for air travel at the affected spoke city.

For the purposes of this dissertation, it is assumed that there will be no improvements in the travel time ratio (that is to say that there will be no high magnitude changes in the other mode). This allows only a vertical shift in the "force" curve due to changes in the relative growth rates at the various spoke cities over the period being considered. Rather the changes in technology that are foreseen will be incremental improvements in both the surface and air travel modes, resulting in only slight travel time changes and little or no ratio value changes.

Projecting the "Force" Function

The "force" or demand function values in the "hub and spoke" system as constituted in this study are based on the relative values of the local demand for air travel and compared to the national average per capita. In the closed system design used in the systems network technique each edge possesses unique "force" and flow variable values. The "force" variable is directionally oriented on the basis of passenger flow, in order to fulfill one of the postulates of systems network theory (Postulate IV) requiring flows around circuits to sum to zero.

The "force" function that drives the systems model is the air travel demand generated at each city in the system. This "force" value is based on the forecast growth in population and personal income during the period being considered (1968 to 2000). These factors are the same ones used by the CAB for estimating the number of passenger-miles per capita on a national basis.[1] Adapting the general formulation to the local system, the forecast measures the passengers per capita growth rate as a function of time, based on the changes in personal income and population. In addition, the formulation provides for growth in acceptance of air travel. The formula thus developed is:

$$PPC_i = PPC_{i-1} + .0725(1.3Per_i + 1.1\ PI_i + .3AR)$$

PPC_i = Passengers per capita

Per_i = Population Growth Rates per annum

PI_i = Personal Income Growth Rate per annum

Ar = Growth in acceptance of air travel (equals .3 per annum)

i = Forecast year

The factors in this formulation were applied to the research cities in this analysis and a forecast of air

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[1]See footnote 1 on page 28 (Brown and Watkins)., The authors develop the rationale for this formulation for passenger-miles on a national basis using regression analysis.

traveler rates was constructed for the years 1970, 1980, 1990, and 2000. These forecasts are used in establishing the particular "force" value for each city in the systems model, and are shown in Table 3 below.

TABLE 3

Passengers Per Capita Forecast
for Selected Michigan Cities

City	1970	1980	1990	2000
Flint	1.09	1.36	1.41	1.46
Lansing	1.06	1.31	1.36	1.40
Tri-Cities	1.06	1.28	1.35	1.39
Detroit	1.37	1.46	1.53	1.57

CHAPTER III

APPLICATION OF SYSTEMS NETWORK METHODOLOGY

Introduction

This chapter is concerned with the systems model of the traffic flows and system "forces" in the airport system formed by the research cities. The model provides a view of the air travel system and establishes the interrelationship of the flows and forces within the system and for all origins and destinations outside the four city system being analyzed.

Structure of the System

The system is conceived as having two sectors: (1) the presently operating airline system, and (2) the proposed regional airport system. The present system is composed of the local airports and the air and highway links with the Detroit facility. The proposed regional airport system is composed of the highway links between the research cities and the regional airport and the air link with the Detroit terminal facility. Each of the systems had its interfaces with the national airport system.

The base cities are considered to generate a "force" or demand for air travel, stated and measured in passengers per capita, and through this demand a flow of air passengers from the city is produced. This flow of passengers is measured in passengers per year. The model differentiates between the travelers driving from the local city to the hub airport at Detroit and those utilizing the local air service. This differentiation is shown in the model by one path (edge) for surface travel and one path (edge) for air travel between the spoke city and the hub city (e.g. Flint and Detroit).

Each of the airports in the system has an interface with the national airport system. This is evidenced in the actual system by the airline connections with other destinations than the hub city of Detroit.

The proposed regional airport is included in the system and is joined to the three base cities and Detroit by a similar set of edges linking the base cities. The "force" or demand for this vertex (airport) is considered to be a function of the three base cities.

The demand generated at the base cities is transferred from the local air terminal facilities to the new regional airport, thus leaving the local airport without airline service. This transfer is affected when the relative demand for airline service at the three base cities reaches a critical level.

The systems model, as designed, operates on an iterative basis being a state sequential mixed-parameter type. This type of model is characterized by its ability to provide successive time period information based on prior system states. Mixed-parameter refers to the fact that the model utilizes a hybrid state equation to describe the actions of the system. In this type of model the state equation uses both "force" and flow information in the description of the action of the model. The state equation in this study is a discrete-time type in that the variables in the state equation are linear functions of time dependent functions and current systems variables.

The state equations for this model take the form:

$$S(n+1) = P \cdot S(n) + Q \cdot E(n)$$

where

n is an integer representing discrete points in time.

S(n) is a vector of system variables at time n.

P & Q are constant matrices containing system values.

E (n) is a vector of variables dependent on time.

The model is observed at discrete points in time, in our case on a yearly basis. The output as the state vector at time n becomes a portion of the inputs to the system for ensuing time period. This recursive cycling is dependent also on the "force" and flow of the present time period. In this way the model represents the actual system in operation, where forecast system states in one time period depend to some degree on the conditions prevailing in the previous time period.

The systems model also incorporates an output equation

system which contains the system outputs at time n in order to more closely observe the interactions and changing conditions within the model structure. This output vector takes the form:

$$R(n) = M \cdot S(n) + N \cdot E(n)$$

where

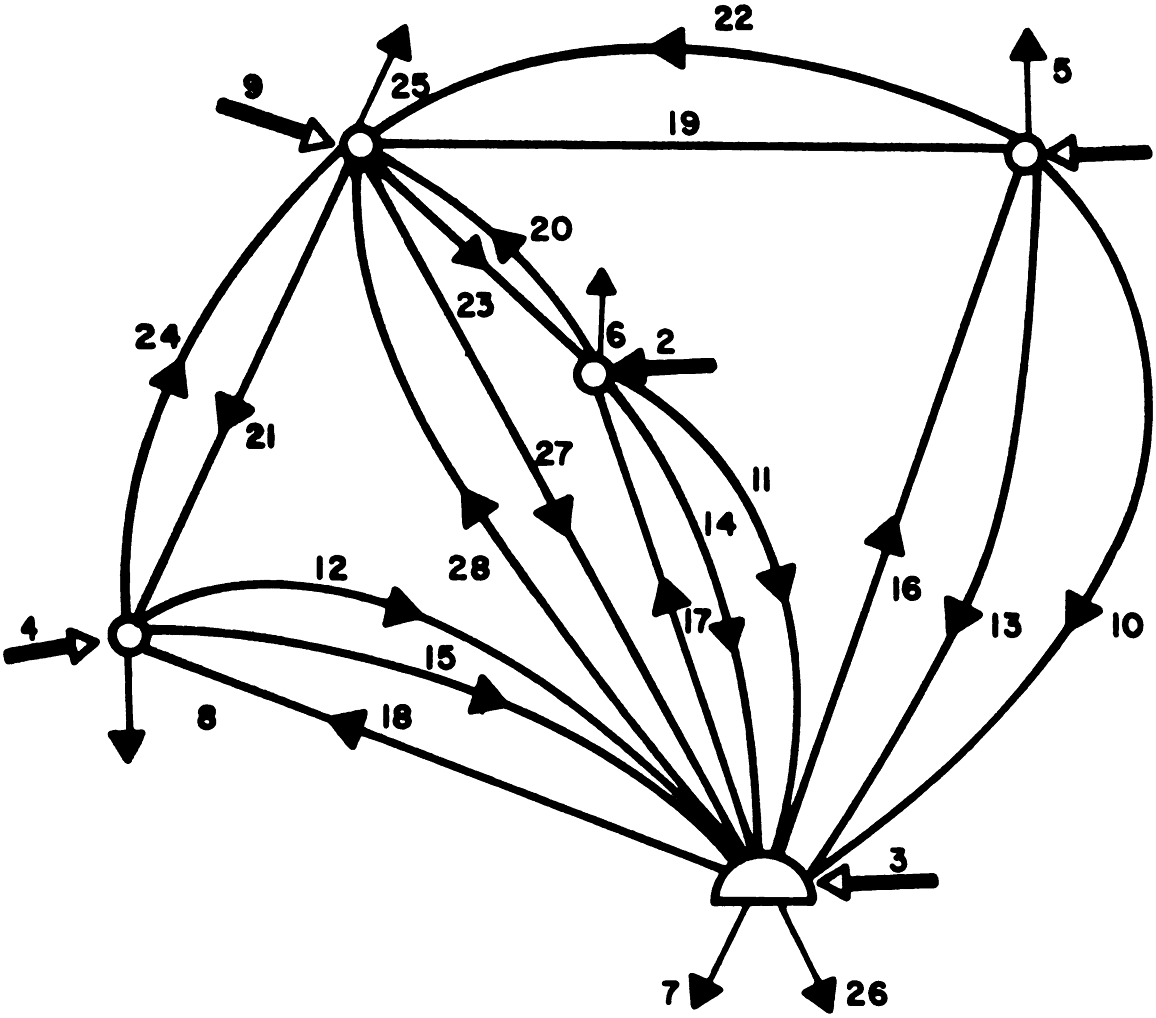
R(n) is the output vector containing variables of interest in the systems model at time n.

M & N are constant matrices containing system values.

Both the state equation section of the model and the output vector section of the model utilize identical inputs. This provision allows the lateration of a minimum set of input variables in order to change internal conditions within the model and to simplify the simulation of changing economic conditions external to the system being analyzed.

The equations for both the state and output sections of the systems model are derived from the characteristics of the linkage between each of the system graph vertices. The systems graph utilized in this study differs slightly from the general systems graph shown in Chapter 1, Figure 2. The systems graph of the airport-city linkages is shown at Figure 6. The model consists of 28 separate edges, each represented by complementary "force" and flow. The state equations provide primary information on the system conditions. The model developed in this study utilizes all system outputs in the response equations for ease of inspection and determination of the intrasystem relationships.

FIGURE 6



System Graph For Component Model

The Mathematical Relationships

Each of the cities being analyzed in this study possesses different "force" and flow characteristics. The complementary relationship between "force" and flow variable allows us to specify one of the variables if the other is known or can be calculated.

The equation in the systems model are of two different types called (1) dissipative components and (2) dynamic components. The equations which are of the dissipative type are considered as passive relationships within the model. That is, they do not provide for changing relationships within the characterization of the description of the edge being modeled. These dissipative equations are of the type:

$$Y(n) = aX(n)$$

where

$Y(n)$ is the flow value at time n.

$X(n)$ is the "force" value at time n.

a is a constant parameter indicating the relationship between Y and X.

The equation for edge 10 in the systems graph is:

$$Y_{10}(n) = 943\ X_{1}(n),$$

where

Y_{10} equals the number of air travelers driving from SGN to Detroit.

X_{1} equals the "force" value for SGN

943 equals the transformation coefficient for the edge.

The equation states that the annual flow of passengers along the edge is equal to 943 times the "force" value developed at SGN in the time period.

The a parameter indicates the linear relationship between the flow and "force" variables describing the edge in the model. It is equal to the slope of the line measuring the characteristics of the flow and "force" variable. This linearity can be considered to be true within a limited range.

Another characteristic of this type of equation is that a change in sign of one variable signals a change in sign of the other variable. In the case of the model in this study, changes in sign of the "force" variable would amount to the change in direction of flow between the cities being analyzed.

The second type of equation used in the system model is the dynamic component. This type of equation is characterized by the time aspect, the flow variable being dependent at subsequent time states on the values of the "force" and flow component values in previous time stages. This type of equation is of the form:

$$Y(n+1) = PY(n) + QX(n)$$

where

Y is the flow variable.

X is the "force" variable.

In the above equation the flow variable takes on the values of the flow and "force" variables of the previous time period, the flow variable of that time period being dependent on the values in preceding periods.

The equation for edge 5 in the systems graph is:

$$Y_5(n+1) = .07\, Y_5(n) + 4913\, X_1(n) + 71.5\, X_3(n),$$

where

Y_5 equals the number of air travelers who depart the SGN airport for destinations other than DET.

X_1 equals the "force" value for SGN.

X_3 equals the "force" value for DET.

.07, 4913, and 71.5 are the transformation coefficients for the edge.

The equation states that the passenger flow in the next time period is equal to .07 times the flow in this period plus 4913 times the "force" value at SGN and 71.5 times the "force" value developed at DET in the present time period.

These two types of component equations form the model of the system being analyzed in this study and it now remains to specify the relationships of these equations in the model.

Component Equations

The component equations for the systems model used in this study can be grouped into three like sets, differing only in the coefficients used in the determination of the relationship of the "force" and flow variables. Each of the three base cities utilizes the same pattern of edges to describe its relationship within the airport system. The equation matrix shown in Figure 7 summarizes the systems graph shown in Figure 6.

Figure 7

Component Equation Matrix

CITY \ EDGE	Passengers driving to Hub	Passengers flying to Hub	Passengers from Hub	Passengers driving to MID	Passengers driving from MID	Passengers leaving system	"Force" for air travel	Passengers transferring to Hub from MID	Passengers transferring from Hub to MID
Flint	10 11	13	16	20	23	6	2	-	-
Lansing	11	15	17	24	21	8	4	-	-
Tri-Cities	12	14	18	22	19	5	1	-	-
Detroit	-	--	--	--	--	7,26[1]	3	28	27

1/ Edge 26 collects and separates those flows which originate in the three base cities.

Edges 1, 2, 3, and 4 prescribe the external "force" values for each of the cities in the system. The complementary flow variable is equal to the number of passengers moving into the system. These edges correspond to the drivers of the system providing energy for system operation. These equations take the form:

$$S_{1,\,2,\,3,\,4}(n) = F(n)$$

These system "force" variables are taken as known functions of time and are derived from economic forecasts of air passenger traffic as developed in the previous chapter.

The edges 5, 6, 7, and 8 are the edges which represent the air travelers leaving the system at the base cities. The equation for these edges take the form:

$$Y_i(n+1) = PY_i(n) + QX_i(n) \text{ where}$$

$$i = 5, 6, 7, \text{ and } 8.$$

These edges form a portion of the state equation system and provide the recursive sector of the model. These equations state that the flow in the subsequent time period is a function of the flow in this time period and the "force" in this time period. In the use of this type of equation in the model, the (differential) demand or "force" is utilized in the equation reflecting changes in growth patterns.

The edges 10, 11, and 12 represent the travelers who choose to drive to the hub city rather than to utilize the available local air service. The proportion of travelers electing to use this mode at any given distance in the system is shown in Figure 4. The edges represent the difference in the "force" function value and the actual demand for air travel originating at the city to which the edge pertains. These edges take the form:

$$Y_i = G \cdot X_j$$

where

i = 10, 11, or 12.

j = 1, 2, or 4, dependent on the city from which the edge originates.

G = constant parameter relating the "force" at city j times the proportion driving to the hub airport. This value may be unique on each edge.

These edges are of the dissipative type and indicate the direct transfer of "force" and flow within a single time period.

Edges 13, 14, and 15 correspond to the travelers flying between the base city and Detroit. The "force" values on these edges are the system "force" values derived in the previous chapter. These edges are of the same type as edges 10, 11, and 12, and have the same mathematical relationships. These edges transmit the "force" developed at the base cities to the Detroit terminal facility for further movement into the national airport system.

Edges 16, 17, and 18 correspond to the return flow of travelers from the Detroit terminal facility to the base cities. These edges combine the travelers driving and flying. It is assumed that the proportions of driving and

flying travelers returning to the base city are the same as those who moved to the Detroit facility. These edges are of the same type as the outbound edges from the base cities (10, 11, 12, 13, 14, and 15), and possess the same property of transmitting the flows without any loss of "force".

The edges 19, 21, and 23 are the edges which correspond to the travelers who will drive from the proposed regional airport to the base cities. These edges are also of the dissipative type directly transmitting the "forces" and flows generated at the base cities and returned through the regional airport.

Edges 20, 22, and 24 are the edges which correspond to the travelers driving to the proposed regional airport, and are of the dissipative type as are edges 19, 21, and 23. These edges directly transmit the flows of passengers from the base cities. When the regional airport (MID) is activated these edges will accomplish the same activities as the combination of the edges which radiate from the base cities during the time the local air service is in action. For example, at the FNT facility edges 11, 14, and 6 account for the outbound flow of travelers from the city while the local airport is in operation; when the regional facility is activated local service will be terminated and all airline service will be offered at the regional facility for the city and edge 20 will perform the function of moving travelers outbound from the Flint area by surface to

the regional facility.

Edges 27 and 28 correspond to the travelers who will utilize the MID facility as a transfer point to and from the Detroit facility. It is assumed in this study that if the level of service offered at the MID facility can be increased to a critical level there will be some trade-off of service between the Detroit facility and the proposed MID terminal and that there may be some transfer of passengers between the facilities for further movement in the national airport system.

Edge 26 in the systems graph is designed to total the travelers moving through the Detroit facility and that originate at the base cities. The equation for this edge is of the dissipative type.

The two remaining edges (9 and 25) in the component model are of primary interest in the system and as such are included in the state equations of the systems model. These edges correspond to the travelers who will enter and leave the three city complex formed by the establishment of a regional airport serving these cities. The equations for these edges are of the dynamic type and are expressed as follows:

$$Y_{25}(n+1) = PY_{25}(n) + QX_1 + QX_2 + QX_3 + QX_4$$

$$X_9(n+1) = PX_9(n) + QX_1 + QX_2 + QX_3 - QX_4$$

where

Q is a constant value relating the flow variables to systems "forces".

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These equations are combined into the systems interface model, the state equation sector and the output vector as functions of the systems input vector, and capable of solution by conventional mathematical methods. The set of component equations are shown in Figure 8.

Characteristics of the Model

The system of equations, depicted in Figure 8 have certain standard characteristics that are of interest for possible applications in the socio-economic environment. The transition matrix (labeled P in the example of the state matrix shown earlier) has the characteristic that, if the connectivity of the system allows, this matrix may be raised to the power of the number of time periods in the iteration to arrive at a solution for the state equation. That is if there are twenty time periods to be considered in the problem solution the transition matrix may be raised to the twentieth power directly by matrix algebra and a solution arrived at immediately.

The model developed in this study does not have that capability since it is an identity matrix having the property that when raised to any power the value of the matrix is still one, or equal to the original value. This characteristic of the model as used herein is due to the fact that there is no feasible air linkage between the three base cities. The "force" function developed for the system shows that at the distances encountered in the system between the base there is no feasible level of air service that can be

Figure 8

Systems Component Equations

State Equation Sector

$$
\begin{matrix} Y5 \\ Y6 \\ Y7 \\ Y8 \\ Y25 \\ X9 \end{matrix}
=
\begin{bmatrix}
.07 & 0 & 0 & 0 & 0 & 0 \\
0 & .07 & 0 & 0 & 0 & 0 \\
0 & 0 & .07 & 0 & 0 & 0 \\
0 & 0 & 0 & .07 & 0 & 0 \\
0 & 0 & 0 & 0 & .07 & 0 \\
0 & 0 & 0 & 0 & 0 & .07
\end{bmatrix}
\begin{bmatrix} Y5 \\ Y6 \\ Y7 \\ Y8 \\ Y25 \\ X9 \end{bmatrix}^{N}
+
\begin{bmatrix}
4913 & 0 & 71.5 & 0 \\
0 & 4873 & 107.2 & 0 \\
0 & 0 & 7619 & 0 \\
0 & 0 & 102.1 & 5557 \\
5269 & 9472 & 281 & 5946 \\
1 & 1 & 1 & 1
\end{bmatrix}
\begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \end{bmatrix}^{N}
$$

Figure 8. - Continued.

Response Equation Sector

$$
\begin{bmatrix} Y10 \\ Y11 \\ Y12 \\ Y13 \\ Y14 \\ Y15 \\ Y16 \\ Y17 \\ Y18 \\ Y19 \\ Y20 \\ Y21 \\ Y22 \\ Y23 \\ Y24 \\ Y26 \\ Y27 \\ Y28 \end{bmatrix}
=
\begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 588 \\
0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\begin{bmatrix} Y5 \\ Y6 \\ Y7 \\ Y8 \\ Y25 \\ X9 \end{bmatrix}_N
+
\begin{bmatrix}
943 & 0 & 0 & 0 \\
0 & 3716 & 0 & 0 \\
0 & 0 & 0 & 1738 \\
941 & 0 & 0 & 0 \\
0 & 580 & 0 & 0 \\
0 & 0 & 0 & 538 \\
1140 & 0 & 71.5 & 0 \\
0 & 3960 & 107.2 & 0 \\
0 & 0 & 102 & 1985 \\
372 & 0 & 0 & 0 \\
0 & 487 & 0 & 0 \\
0 & 0 & 0 & 361 \\
372 & 0 & 0 & 0 \\
0 & 487 & 0 & 0 \\
0 & 0 & 0 & 361 \\
1140 & 3960 & 281 & 1905 \\
0 & 0 & 0 & 0 \\
0 & 0 & 421 & 0
\end{bmatrix}
\begin{bmatrix} X1 \\ X2 \\ X3 \\ X4 \end{bmatrix}_N
$$

developed to overcome the time ratios for surface and air travel. However, this characteristic of the transition matrix is an important feature, despite the fact that there was no usable way to utilize this feature in the present model.

Additionally only one edge in the output vector is stated in terms of the state variables. This edge (27) provides the energy for increasing the transfer of travelers to and from the MID facility based on the changing "force" levels of the system when the MID facility is activated.

Activation of the MID facility was of concern in the study; the switching of the system from the hub and spoke mode to the regional mode was accomplished through the use of an external constraint equation. Switching of the system was accomplished to the regional mode occurs when the combined "force" values of the three base cities equalled the "force" generated at the Detroit terminal.

This external decision equation accomplishes the switching of the systems state and output equations and is of the "on or off" type. The decision equation is written in the following manner:

If $X_3 \geq X_1 + X_2 + X_4$ then Y_{20}, Y_{22}, and Y_{24} equal 0,

but if $X_3 < X_1 + X_2 + X_4$ then Y_{10}, Y_{13}, Y_{11}, Y_{14}, Y_{12}, and Y_{15} equal 0.

The switching of the system to the regional mode is accomplished by transferring the flows on the edges which correspond to the travelers leaving the system (5, 6, and 8) and those which correspond to the travelers driving to the regional facility (20, 22, and 24).

The use of the external switching constraint allows freedom in the analysis of the system as far as determining the time for activation of the regional facility. After activation, the analyst is able to observe the flow patterns within the system and is free to provide different "force" inputs to the system so as to produce desired system changes. The lack of a suitable transition matrix to achieve and produce response is a distinct limitation, but this phenomenon is in keeping with the actual system and its operation.

Operation of the Model

The system model is operated in an iterative simulation of the actual three city and Detroit air travel model. The model operates on an annual cycle providing "force" and flow information for the interrelated links within the system.

Utilizing the projected "force" function as input information, the state equations within the model translate the maximum "force" inputs into passenger flows for the coming period, while the response sector provides current period intra-modal flow and "force" information. An automated solution problem is developed for the solution of the state and response equation sectors and is shown at Appendix B.

The state sector of the model provides the iterative portion of the model depicting information to be utilized for the next time period. The components selected for this provision are the system values corresponding to the flows of passengers out of the local system into the national airport system. These values were selected in the event the model is used as a module within the national airport system. These output values can be considered and incorporated into a larger scale systems model for evaluation, planning, and control. The capability of modular application is a vital characteristic of the type of model constructed using the techniques of systems network theory.

The response sector of the model provides information for the control and evaluation of flow and "force" patterns within the system. The characterization of the flow patterns occurring when switching is implemented for operation of the regional airport is observable in the outputs both in the response sector and in the state sector of the model. The utilization of an external control equation allows the selection of the "force" level combination desired to effect switching (establishment of the regional airport). Because of the use of an external constraint equation, the response sector of the model only provides information of interest in the characterization of the internal flows in the model. This was accomplished in order to demonstrate the modularity of the model. Any of the vertices corresponding to the three base cities can be removed from the system or additional cities can be incorporated into the model.

The model operation as written in the program shown in Appendix B, is strictly accomplished on an annual basis. The computations halt at the end of each period in order to observe the action of the flows in the system. Thus an individual output of the solution of the systems model equations is obtained for each year. The sample outputs shown in the Appendix depict the flow and "force" results in the model at the times indicated and with the "force" constraints imposed on the model during simulation.

The systems model as derived shows the application of the "force" function into the systems network theory linear graph technique. The compatibility of the technique and a socio-economic problem demonstrate that there may be profitable use for this analytical tool in other applications.

Sensitivity of the Systems Model to Service Level Changes

The "force" function derived in Chapter II provides information on the maximum feasible service level ratios obtainable by the three research cities. This value is determined by the travel time ratio. Consistent with the "force" function, then is the assumption that given no changes in the technology (that is, no changes in the travel time ratio) the only way to obtain changes in the "force" values is to alter the elements of the service level ratio. This ratio can be modified by changing either of the elements. Because of the topography of the system, that is the shape of the "force" curve, service at the base cities must conform to the proportions of the travelers driving and flying to Detroit. This limits changes in the system to modifying the service level offered at Detroit. When this ratio is changed, the relative number of travlers leaving the system at the base city compared to the number of travelers moving through the Detroit facility is changed. Lowering the service level at Detroit in comparison to the service level available at the base city increases the number of travelers moving into the national system at the base city. Referring to Figure 5, the area below and to the right of the "force" function curve corresponds to the feasible service level combinations available to the three base cities within the hub and spoke concept. The systems model sensitivity within this feasible region was tested by a series of simulations at various Detroit service levels through the 1970 to 2000 period.

The range of service levels offered at Detroit during the simulations ranged from 1.000 to 1.340.[1] The lower value corresponds to the national average for air passenger traffic or a service level equal to that of providing no assembly or disassembly traffic for the spoke cities. The upper value corresponds to the service level that is offered at Detroit while performing the assembly and

---

[1]The Ratio 1.000 corresponds to the number of passengers per capita, while the Ratio 1.340 corresponds to a value 1.340 times the number of passengers per capita.

disassembly function for the spoke cities in the system. The sensitivity of the system to service level ratio changes is shown in the following table.

TABLE 4

System Service Level Sensitivity and Flows

Detroit Service Level	MID Facility Activation Year	Passenger Flow in Year of MID Activation	
		Detroit (000's)	MID (000's)
1.000	MID Facility already required		
1.100	1974	6,332.2	5,511.9
1.150	1978	6,789.3	5,973.8
1.175	1979	6,933.5	5,970.9
1.200	1992	7,534.8	6,555.5
1.340	No requirement for MID		

The table shows that the system is sensitive to changing service levels at the Detroit terminal facility. If the service level at Detroit is lowered to the national average, there is an immediate requirement for the MID facility. As the service level at Detroit is increased the activation date for the MID is postponed further into the thirty year period. When the service level at Detroit is increased to the present level there is no requirement for a regional facility. The service level at Detroit corresponding to 1.340 times the national average represents the maximum value in the "force" function as derived in this study and also represents the point at which the system will not switch over to the regional mode.

The lower service level ratios are representative of the proportion of the Detroit traffic volume that is due to the assembly and disassembly function being performed by the facility. In 1968, the Detroit facility had 16.2 percent of its traffic devoted to the assembly and disassembly function. Reducing the Detroit service level by an amount equal to this percentage (1.340 times 83.3 percent) reduces the Detroit service level ratio to 1.175. The model depicts that if this proportion of the Detroit service level was transferred to a regional facility, the combined demands for air traffic at the three base cities would be greater than the total demand for air service at Detroit and there would be a requirement for the MID regional facility in the year 1979.

Varying the service levels in the model produces significant changes in the activation date and requirement for the MID facility. The analyst utilizing a model such as this then may be able to translate these activation dates into usable planning tools if cost and revenue data are applied.

The systems sensitivity operations which determine the activation dates under certain service level ratios depend on forecast data developed on the basis of economic information. This information may be subject to error. Possible variations could result in deviations from the "force" projections used in the iterations of the model. The sensitivity of the system to these errors may cause deviations from the projected activation dates as shown above. A lower than forecast "force" projection results in later activation dates for the MID facility, if the deviation occurs at the three base cities. If a lower than forecast "force" projection occurs at the DET facility, the activation dates for the MID facility are advanced. These deviations from the "force" projections cause the following MID activation time changes; for ten percent forecast errors at the three base cities:

Flint	1 year
Lansing	3 years
Tri-Cities	3 years

For each five percent error in forecast "force" levels at Detroit, the MID activation date is either advanced or delayed three years. The activation time changes listed above are contingent on being independent variations, if deviation from forecast "force" values present in all four of the system cities then there would be little effect on activation time. Corresponding and matching deviations from forecasts at all the system cities would provide little change in the predicted activation dates.

An example of the effect of changes in demand or forecast errors on the activation date for the MID terminal facility is shown below: (Data are excerpted from the sample of systems model operations in Appendix B, and may be consulted for verification.)

1974 System State	1976 System State	1978 System State
X1 = .3192	X1 = .3304	X1 = .3416
X2 = .1489	X2 = .1567	X2 = .1635
X3 = .8085	X3 = .8177	X3 = .8292
X4 = .3067	X4 = .3200	X4 = .3333

1980 System State
X1 = .3528
X2 = .1703
X3 = .8395
X4 = .3467

In the four system states shown above, the "force" at DET is first less than the total "force" for the three research cities indicating that the activation requirements for the MID facility have not been met (total demand for air travel at the three cities is less than the "force" at DET). In the 1978 system state the opposite is true, "force" at the three base cities is greater than the "force" at DET. By applying a five percent lower "force" at DET in 1974, the condition is reversed and the total "force" at the three base cities becomes greater than the "force" at DET, indicating that the MID facility should be activated in 1974. If the forecast for Flint facility is ten percent lower for 1978, the activation date for the MID facility will be delayed to 1980. The ten percent forecast error for Flint is determined as follows:

.654 originating air travelers ($\frac{1}{2}$ x 1.308 O & D passengers) at Flint forecast for 1968.

.25 "force" variable for Flint.

.90 x .654 x .25 = .1473

The .1473 revised forecast for 1978 is substituted for the original forecast value of .1635. The resulting value for combined "force" at the three base cities is less than the "force" at DET and the activation of the MID facility is not required until 1980, when the combined values for the three base cities is greater than the value obtained for DET.

CHAPTER IV

EVALUATIONS AND CONCLUSIONS

General

The primary objectives of this study as stated in Chapter I are:

1. Develop a suitable "force" function variable to depict the demand for air transportation at the three base cities.
2. Portray a suitable method for deriving this function for use in systems network theory applications in a socio-economic environment.

The development of the "force" function and the construction of the systems model using systems network theory concepts demonstrates that the techniques used in systems network theory can be applied, albeit in this instance simply, to socio-economic problems. The utilization of a "force" function enhances the linear graph applications by incorporating the aspects of demand and propensity so vital to socio-economic applications.

The model, although unrefined, is a vehicle for analysis of the airport system, and provides explicit knowledge of flow values for use in planning and decision. A more detailed level of analysis can be approached if the system components are sufficiently magnified and refined.

Increased detail in the component models, achieved by a lower scale of aggregation or increased resolution will increase the detail of the resulting analysis. Since the city vertices can be modeled independently, each can be removed from the system and studied separately. The same property can be utilized to connect the system as modeled or in increased detail in to a larger scale system. This property of systems network methodology should lead to considerable refinement in the component models.

Techniques for analysis are well developed and highly articulate in the physical sciences, and are directly applicable to business systems. The control concept, briefly touched on earlier, and not displayed in this model has special appeal to the decision maker. Because of the low level of connectivity in this model this aspect of systems theory could not be deomonstrated, but provides considerable interest for planning.

Simulating the system operation provides a valuable experimental device for large scale systems where there is no possibility of incorporating test changes without total disruption. If the sensitivity of the system to changes can be developed and modeled the simulation offers a powerful analytical tool.

Significance of the Model

The applications of systems network theory techniques to socio-economic problems can be of vital importance. The technique embraces the demand function necessary to characterize the total system in business and government applications. Any business entity having flows of goods, information, funds, or people can be modeled using this technique. The application presented here can be extended into a complete model of the national airport system, with the capability of assembling and disconnecting portions or modules of the system, adding new sectors, revising traffic patterns, and evaluating the effects of such actions. Inter-modal applications are also possible, this model already contains the modal split for air travel and surface travel for the purposes of further air travel.

The use of a modal-split analysis is extended through this technique. The application here shows that modal-split can be extended temporally, a use not previously demonstrated. This obviously means that systems network theory can be utilized in inter-modal studies, and models incorporated hybrid transportation and distribution systems are possible. The use of appropriate control response strategy within the response vectors of the model can characterize changing technology and then apply suitable controls for minimum disruption of systems states. The ability to structure the dynamic aspects of changing modal technology or individual tastes and preferences is present in the applications of the technique demonstrated here.

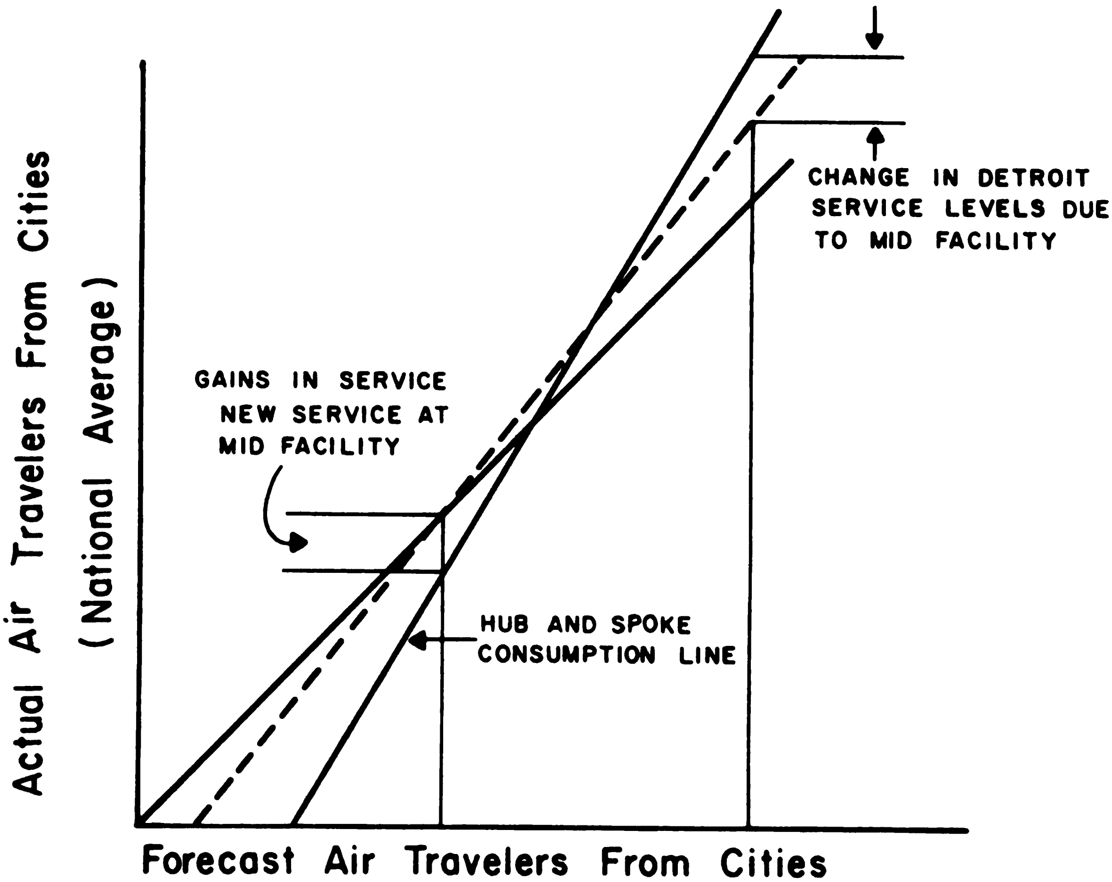
Control and response strategy incorporated into a syxtems network model also offers the ability to stage and sequence appropriate service levels or new facilities into the systems being analyzed.

The implications of the type of model presented here for the research cities concerned are several. First, the combined cities planning organizations can now visualize the levels of service necessary to maintain a regional facility, and the effects of the combination of the air travel "forces" in the system. Planning for the regional facility can be accomplished using the model presented here. Target service levels can be obtained from the model and facilities based on these levels. The effect of the single regional facility is shown in Figure 9. This graph depicts the change in the air travel consumption line caused by the establishment of the MID regional terminal facility. The rotation of the air travel consumption line is caused by the change in service at the Detroit facility, which no longer is required to perform the assembly and disassembly function for the base cities. The combination of the three cities into a single "force" causes an increase in the total service offered to the combined regional demand source.

Secondly, for the cities concerned, the ability to plan for the time of initiating operations at the MID facility is important. Predicted service levels at certain time periods can be derived from the model and the effects on revenue and funding can be obtained.

An important facet of the utilization of systems network theory for socio-economic applications is the level of connectivity in the system. This factor is the prime

FIGURE 9



Airline Service Offered At MID Facility

Source: Civil Aeronautics Board, 1968

determinant in the resolution of the model. Simple models with low levels of connectivity in the system depict greater independence of sub-systems. This factor is the prime determinant in the resolution of the model. Simple models with low levels of connectivity, that is a minimum number of mathematical characterizations of the interrelationships between vertices, provide aggregated information. More complex models can be utilized to more completely describe the detailed relationships thus providing more or less dependence effects. These effects are of vital importance to the control strategy and responses in the system and the ability to chart minimum cost paths or maximum revenue strategies. The level of connectivity within the system being modeled is reflected in the transformation matrices (P & M) of the state equation and response equation sectors of the model. The transformation matrix of the state sector in the present model shows only values along the main diagonal and zero entries off the diagonal. As the connectivity of the system increases, off diagonal entries are inserted. These additional entries increase the interrelationships of the components of the model and decrease the independence of the components of the model and decrease the independence of the components being modeled. It is from the complexity of the transformation matrices that the level of control and accuracy or response to control strategy proceed. The model developed here shows a high level of independence for the cities in the system.

While the research has demonstrated that systems network theory can be used in the analysis of this type of economic system, it also depicts that the ability to model the system and identify the components in a mathematically tractable form is vital. If business components can be can be classified as neatly and described with the precision of physical components, the value of linear graph theory, exemplified by the techniques of systems network theory, would be significantly advanced.

The first generation model resulting from this research is acknowledged to be crude; it deals only with low resolution first order effects and has assembled highly aggregated system components. The power of the technique of systems network theory is far more powerful than demonstrated here; however this research shows the feasibility and merit of the concept, and the requirement for continuing effort in the development of an operational methodology for socio-economic uses.

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APPENDICES

APPENDIX A

REGIONAL AIRPORT LOCATION MODELS

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REGIONAL AIRPORT LOCATION MODELS

Introduction

As an ancillary portion of this study, a location for the proposed regional airport facility (MID) had to be selected. On primary reason for the criticality of the location was that the facility had to be located at a distance from each of the three base cities such that there would be requirement to establish air line service to the facility from any of the cities. The critical minimum distance was estimated to be forty miles. This value is the point at which the "force" function developed for this study was equal to zero indicating that there would be no suitable service level ratio that could support air service and that travelers would choose to drive to the terminal facility. The forty mile distance is based on a sixty mile per hour surface speed between the city center and the facility.

There were three center of gravity models constructed to place the MID facility. One was an unweighted model based on geographic coordinates of the city centers. The second and third models were weighted on the basis of personal income for each city, and for population growth for each of the cities. These models had different coordinate locations plotted for each ten year period through the year 2000. The information for both weighting factors was obtained from the State of Michigan Department of Commerce. The map locations for the final locations for each of the three models is shown at Figure 1.

Geographic Center Model

This model provides the least distance from the three base cities to a point based on geographic coordinates. The algebraic formula for determining the Geographic center is:

$$X = \frac{\sum_{i=1}^{n} x_i}{n} \quad \text{and} \quad Y = \frac{\sum_{i=1}^{n} y_i}{n}$$

where

X = West Longitude of Center point.

n = Number of locations being considered.

This model furnishes the analyst with a centroid of the moments of geographic coordinate values. If there is reason to believe that the economic or demographic qualities of the area being analyzed give cause to weight the location on the basis of these factors then the second and third models described below can be utilized.

Geographic-Personal Income and Geographic-Population Models

These models furnished a series of locations for the proposed regional terminal facility (MID). The geographic-personal income (GEOPI) model was developed using U. S.

Department of Commerce forecasts for personal income for the years through 2000. This model showed slight shifts to the east toward the Flint area, in consonance with the greater growth forecast for the Flint area.

The geographic-population (GEOPER) model also produced shifts from the centroil location producte by the unweighted coordinate model. In addition, the model also shifted to the east-northeast of the centroid location.

The model for computing the weighted center-of-gravity location for the proposed MID facility location were determined by the following formulation:

$$X = \frac{\sum_{i=1}^{n} w_i x_i}{n \sum_{i=1}^{n} w_i}$$

$$Y = \frac{\sum_{i=1}^{n} w_i y_i}{n \sum_{i=1}^{n} w_i}$$

X = North Latitude of Center point.

Y = West Longitude of Center point.

W = Personal Income of location (for Population).

n = Number of locations being considered.

The models thus constructed provide the necessary information for determining the possible locations for the

MID terminal facility. This information was required to emplace the facility in the system such that there would be no exaggeration of any pertinent factors in the systems model.

APPENDIX B

PROGRAM SIMEQ

APPENDIX B

PROGRAM SIMEQ

The computer program used in this research, written in FORTRAN 6500 language, is listed in this appendix. It is not a general program, but is specifically designed to meet the requirements of the research described in this dissertation.

The program utilized is primarily an algebraic solution to the set of component equations which constitute the systems model. Since all the equations in the model are written explicitly in the known functions of time, the solution process consists primarily of supplying the proper coefficient and matching it to the known input. In an application where the connectivity of the model is more complex, the information matrix used to contain system values, which in the case of this model equals 28 times 100, would contain a larger number of non-zero entries than the present model, a possible restructuring of the information matrix might result in a more compact requirement for memory space. The program, SIMEQ, is presented in the next pages of this appendix.

A sample listing of a series of simulation iterations is also presented in this appendix. This series of iterations is for the service level ratio at Detroit equaling 1.175. This is the middle value in the range of service level sensitivity iterations performed in this study and is representative of the other operations performed in the study of the airport system being portrayed by the model. The information is portrayed on a biennial basis for the period 1970 to 2000. It should be noted that the system switches to the regional mode in the year 1979. Caution should be exercised in the interpretation of some entries such as the ones for the Y-25 and X-9 values. These values are equal to zero in the hub and spoke mode, but are printed out as shadow values for use in the analysis of the model. The values for actual use in plotting flow and "force" values for these entries are to be used only when the systems model is operating in the regional mode. The order for the switching of the system is the statement: X_3 is less than $X_1 + X_2 + X_4$. The values for Y-25 and X-9 in the iteration in which this order is stated then are equal to the actual flow and "force" values predicted for the MID facility when activated.

```
PROGRAM     SIMEQ                              CDC 6400 FTN V3.0-L292 OPT=1  10/31/72 .12.09.18.       PAGE      1

          PROGRAM  SIMEQ(INPUT,OUTPUT)
    C
    C          PROGRAM  TO SOLVE  SIM  EQUATIONS  OF THE FORM
    C              Q(N+1)   =  P   Q(N)   #  Q1 E(N)
    C              R(N)     =  M   Q(N)   #  Q2 E(N)
    C
    C
    C
    C
          DIMENSION     Y (28,100)
          N=1
          PRINT 2009
     2009 FORMAT (/ * TYPE IN THE VALUE FOR CONSTRAINT ON THE X.*)
          READ 1003, NREST
     1003 FORMAT (I2)
          PRINT  2000
     2000 FORMAT  (/* TYPE IN  INITAL VALUES FOR Y5,Y6,Y7,Y8,Y25,X9*/)
          READ   1000,(Y(M,1),M=5,8),Y(25,1),Y(9,1)
     1000 FORMAT  (1X,6(F5.3,1X) )
       10 PRINT  2001, (N,K=1,4)
     2001 FORMAT(/* TYPE IN VALUES FOR X1(*I3*),X2(*I3*),X3(*I3*),X4(*I3*)
         1OR S*/)
          READ   1001,I,Y(1,N), Y(2,N) , Y(3,N), Y(4,N)
     1001 FORMAT  ( A1, 4( F5.3,1X))
          IF( I.EQ.1HS) GO TO 900
    C
    C          CHECK  X  VALUES AGAINST RESTRAINTS
    C
          CHECK = Y(3,N) / NREST
          CHECK2 = Y(1,N) + Y(2,N) + Y(4,N)
          IF(CHECK .LT.CHECK2) GO TO  30
          ICHECK = 1
          GO TO 40
       30 ICHECK = 2
       40 Y(5,N+1) = .07*Y(5,N) + 4913*Y(1,N) + 71.5*Y(3,N)
          Y(6,N+1) = .07*Y(6,N) + 4873*Y(2,N) + 107.2*Y(3,N)
          Y(7,N+1) = .07*Y(7,N) + 7619*Y(3,N)
          Y(8,N+1) = .07*Y(8,N) + 5557*Y(4,N) + 102.1*Y(3,N)
          Y(25,N+1) = .07*Y(25,N) + 5269*Y(1,N) + 9472*Y(2,N) + 281*Y(3,N)
         1                                                 + 5946*Y(4,N)
          Y(9,N+1) = .07*Y(9,N) + Y(1,N) + Y(2,N) + Y(3,N) + Y(4,N)
          Y(10,N) = 943 * Y (1,N)
          Y(11,N) = 3716 * Y(2,N)
          Y(12,N) = 1738 * Y(4,N)
          Y(13,N) = 941 * Y(1,N)
          Y(14,N) = 580 * Y(2,N)
          Y(15,N) = 538 * Y(4,N)
          Y(16,N) = 1140*Y(1,N) + 71.5*Y(3,N)
          Y(17,N) = 3960*Y(2,N) + 107.2 * Y(3,N)
          Y(18,N) = 1905*Y(4,N) + 102*Y(3,N)
          Y(19,N) = 372 * Y(1,N)
          Y(20,N) = 478 *Y(2,N)
          Y(21,N) = 361 * Y(4,N)
          Y(22,N) = 372*Y(1,N)
          Y(23,N) = 487 *Y(2,N)
          Y(24,N) = 361 * Y(4,N)
```

```
PROGRAM     SIMEQ                              CDC 6400 FTN V3.0-L292 OPT=1  10/31/72 .12.09.18.       PAGE      2

          Y(26,N) = 1140 * Y(1,N) + 3960 * Y(2,N) + 281 * Y(3,N)
         1                                          + 1905 * Y(4,N)
          Y(27,N) = 588 * Y(9,N)
          Y(28,N) = 421 * Y(3,N)
          IF (ICHECK.NE. 2 ) GO TO 50
          PRINT 2004, NREST
     2004 FORMAT(* X3/*,I2,* IS LESS THAN X1 + X2 + X4 .*/)
          Y(5,N+1)=Y(6,N+1)=Y(8,N+1)=Y(26,N) = 0.0
          DO 55 II = 10,18
       55 Y(II,N) = 0.0
          PRINT 2012
     2012 FORMAT (* Y10 THRU Y18, AND Y26 SHOULD BE ZERO.*/* NEW VALUES FOR
         1Y5, Y6, Y8, WERE SET TO ZERO.*/)
          GO TO 60
       50 PRINT 2005, NREST
     2005 FORMAT (* X3/*,I2*  IS GREATER THAN OR EQUAL TO X1 + X2 + X4 .*/)
          PRINT 2011
          Y(19,N) = Y(20,N) = Y(21,N) = 0
     2011 FORMAT (/* Y19, Y20, Y21 SHOULD BE ZERO.*/)
       60 DO 85 I = 1,4
       85 PRINT  2006,  I,  Y(I,N)
     2006 FORMAT (*  X*,I1,* = *, F15.5 )
          DO 100 I = 5,28
          IF (I.EQ.9) GO TO 90
          PRINT  2007,  I,  Y(I,N)
     2007 FORMAT (*  Y*,I2, * = *, F15.5)
          GO TO 100
       90 PRINT 2015, I, Y(I,N)
     2015 FORMAT (*  X*,I2, * = *, F15.5)
      100 CONTINUE
          PRINT 2008,(Y(NN,N+1),NN=5,8),Y(25,N+1), Y(9,N+1)
     2008 FORMAT (/*  NEW VALUES AT N+1*/* Y 5 = *,F15.5,
         1                               /  * Y 6 = *,F15.5,
         2                               /  * Y 7 = *,F15.5,
         3                               /  * Y 8 = *,F15.5,
         4                               /  * Y25 = *,F15.5,
         5                               /  * X 9 = *,F15.5)
          N = N + 1
          GO  TO  10
      900 PRINT  2010
     2010 FORMAT  (*  PROGRAM TERMINATION.*)
          END
MORE MEMORY WOULD HAVE RESULTED IN BETTER OPTIMIZATION
```

1970 System Response

X1 =	.29680	Y11 =	506.49080	Y20 =	0.00000
X2 =	.13630	Y12 =	488.37800	Y21 =	0.00000
X3 =	.78700	Y13 =	279.28880	Y22 =	110.40960
X4 =	.28100	Y14 =	79.05400	Y23 =	66.37810
Y5 =	122.50000	Y15 =	151.17800	Y24 =	101.44100
Y6 =	75.14000	Y16 =	394.67970	Y25 =	-0.00000
Y7 =	3272.00000	Y17 =	624.20016	Y26 =	1634.77680
Y8 =	114.60000	Y18 =	615.66060	Y27 =	0.00000
X9 =	-0.00000	Y19 =	0.00000	Y28 =	331.66380
Y10 =	279.88240				

Ne
New Values at N + 1

Y5 = 1523.08110
Y6 = 753.90186
Y7 = 6231.28820
Y8 = 1649.97338
Y25 = 4747.07060

1972 System Response

X1 =	.30800	Y11 =	531.75960	Y20 =	0.00000
X2 =	.14310	Y12 =	511.49340	Y21 =	0.00000
X3 =	.79810	Y13 =	289.82800	Y22 =	114.57600
X4 =	.29430	Y14 =	82.99800	Y23 =	69.68970
Y5 =	1523.08110	Y15 =	158.33340	Y24 =	106.24230
Y6 =	753.90186	Y16 =	408.18415	Y25 =	4747.07060
Y7 =	6231.28820	Y17 =	652.23232	Y26 =	1702.70360
Y8 =	1649.97338	Y18 =	642.04770	Y27 =	883.11720
X9 =	1.50190	Y19 =	0.00000	Y28	336.00010
Y10 =	290.44400				

New Values at N + 1

Y5 = 1676.88383
Y6 = 835.65575
Y7 = 6516.91407
Y8 = 1832.40925
Y25 = 5284.76404
X9 = 1.64863

1974 System Response

X1 =	.31920	Y11 =	553.31240	Y20 =	0.00000
X2 =	.14890	Y12 =	553.04460	Y21 =	0.00000
X3 =	.80850	Y13 =	300.36720	Y22 =	118.74240
X4 =	.30670	Y14 =	86.36200	Y23 =	72.51430
Y5 =	1676.88383	Y15 =	165.00460	Y24 =	110.71870
Y6 =	835.65575	Y16 =	421.69575	Y25 =	5284.76404
Y7 =	6516.91407	Y17 =	676.31520	Y26 =	1764.98400
Y8 =	1832.40925	Y18 =	666.73050	Y27 =	969.39620
X9 =	1.64863	Y19 =	0.00000	Y28 =	340.37850
Y10 =	301.00560				

New Values at N + 1

Y5 =	1743.41922
Y6 =	870.75680
Y7 =	6616.14549
Y8 =	1915.14840
Y25 =	5513.00578
X9 =	1.69870

1976 System Response

X1 =	.33040	Y11 =	582.29720	Y20 =	0.00000
X2 =	.15670	Y12 =	556.16000	Y21 =	0.00000
X3 =	.81770	Y13 =	310.90640	Y22 =	122.90880
X4 =	.32000	Y14 =	90.88600	Y23 =	76.31290
Y5 =	1743.41922	Y15 =	172.16000	Y24 =	115.52000
Y6 =	870.75680	Y16 =	435.12155	Y25 =	5513.00578
Y7 =	6616.14594	Y17 =	708.18944	Y26 =	1836.56170
Y8 =	1915.14840	Y18 =	693.00540	Y27 =	998.83813
X9 =	1.69870	Y19 =	0.00000	Y28 =	344.25170
Y10 =	311.56720				

New Values at N + 1

Y5 =	1803.76010
Y6 =	912.20952
Y7 =	6693.18648
Y8 =	1995.78756
Y25 =	5743.54410
X9 =	1.74371

1977 System Response

X1 = .33600	Y11 = 594.93160	Y20 = 0.00000
X2 = .16010	Y12 = 567.80460	Y21 = 0.00000
X3 = .82280	Y13 = 316.17600	Y22 = 124.99200
X4 = .32670	Y14 = 92.85800	Y23 = 77.96870
Y5 = 1803.76010	Y15 = 175.76460	Y24 = 117.93870
Y6 = 912.20952	Y16 = 441.87020	Y25 = 5743.54410
Y7 = 6693.18648	Y17 = 722.20016	Y26 = 1870.60630
Y8 = 1995.78756	Y18 = 706.28910	Y27 = 1025.30107
X9 = 1.74371	Y19 = 0.00000	Y28 = 346.39880
Y10 = 316.84800		

New Values at N + 1

Y5 = 1835.86141
Y6 = 932.22613
Y7 = 6737.43625
Y8 = 2039.18491
Y25 = 5862.66429
X9 = 1.76766

1978 System Response

X1 = .34160	Y11 = 0.00000	Y20 = 78.15300
X2 = .16350	Y12 = 0.00000	Y21 = 120.32130
X3 = .82920	Y13 = 0.00000	Y22 = 127.07520
X4 = .33330	Y14 = 0.00000	Y23 = 79.62450
Y5 = 1835.86141	Y15 = 0.00000	Y24 = 120.32130
Y6 = 932.22613	Y16 = 0.00000	Y25 = 5862.66429
Y7 = 6737.43625	Y17 = 0.00000	Y26 = 0.00000
Y8 = 2039.18491	Y18 = 0.00000	Y27 = 1039.38387
X9 = 1.76766	Y19 = 127.07520	Y28 = 349.09320
Y10 = 0.00000		

New Values at N + 1

Y5 = 0.00000
Y6 = 0.00000
Y7 = 6789.29543
Y8 = 0.00000
Y25 = 5973.75590
X9 = 1.79134

1980 System Response

X1 = .35280	Y11 = 0.00000	Y20 = 81.40340
X2 = .17030	Y12 = 0.00000	Y21 = 125.15870
X3 = .83950	Y13 = 0.00000	Y22 = 131.24160
X4 = .34670	Y14 = 0.00000	Y23 = 82.93610
Y5 = 0.00000	Y15 = 0.00000	Y24 = 125.15870
Y6 = 0.00000	Y16 = 0.00000	Y25 = 5973.75590
Y7 = 6789.29534	Y17 = 0.00000	Y26 = 0.00000
Y8 = 0.00000	Y18 = 0.00000	Y27 = 1053.30567
X9 = 1.79134	Y19 = 131.24160	Y28 = 353.42950
Y10 = 0.00000		

New Values at N + 1

Y5 = 0.00000
Y6 = 0.00000
Y7 = 6871.40117
Y8 = 0.00000
Y25 = 6187.52541
X9 = 1.83469

1982 System Response

X1 = .36060	Y11 = 0.00000	Y20 = 81.97700
X2 = .17150	Y12 = 0.00000	Y21 = 126.16950
X3 = .84760	Y13 = 0.00000	Y22 = 134.14320
X4 = .34950	Y14 = 0.00000	Y23 = 83.52050
Y5 = 0.00000	Y15 = 0.00000	Y24 = 126.16950
Y6 = 0.00000	Y16 = 0.00000	Y25 = 6187.52541
Y7 = 6871.40117	Y17 = 0.00000	Y26 = 0.00000
Y8 = 0.00000	Y18 = 0.00000	Y27 = 1078.79980
X9 = 1.83469	Y19 = 134.14320	Y28 = 356.83960
Y10 = 0.00000		

New Values at N + 1

Y5 = 0.00000
Y6 = 0.00000
Y7 = 6938.86248
Y8 = 0.00000
Y25 = 6273.87878
X9 = 1.85763

1984 System Response

X1 =	.36500	Y11 =	0.00000	Y20 =	82.55060
X2 =	.17270	Y12 =	0.00000	Y21 =	127.21640
X3 =	.85560	Y13 =	0.00000	Y22 =	135.78000
X4 =	.35240	Y14 =	0.00000	Y23 =	84.10490
Y5 =	0.00000	Y15 =	0.00000	Y24 =	127.21640
Y6 =	0.00000	Y16 =	0.00000	Y25 =	6273.87878
Y7 =	6938.86248	Y17 =	0.00000	Y26 =	0.00000
Y8 =	0.00000	Y18 =	0.00000	Y27 =	1092.28559
X9 =	1.85763	Y19 =	135.78000	Y28 =	360.20760
Y10 =	0.00000				

New Values at N + 1

Y5 =	0.00000
Y6 =	0.00000
Y7 =	7004.53677
Y8 =	0.00000
Y25 =	6333.96491
X9 =	1.87573

1986 System Response

X1 =	.36940	Y11 =	0.00000	Y20 =	83.12420
X2 =	.17390	Y12 =	0.00000	Y21 =	128.22720
X3 =	.86370	Y13 =	0.00000	Y22 =	137.41680
X4 =	.35520	Y14 =	0.00000	Y23 =	84.68930
Y5 =	0.00000	Y15 =	0.00000	Y24 =	128.22720
Y6 =	0.00000	Y16 =	0.00000	Y25 =	6333.96491
Y7 =	7004.53677	Y17 =	0.00000	Y26 =	0.00000
Y8 =	0.00000	Y18 =	0.00000	Y27 =	1102.93159
X9 =	1.87573	Y19 =	137.41680	Y28 =	363.61770
Y10 =	0.00000				

New Values at N + 1

Y5 =	0.00000
Y6 =	0.00000
Y7 =	7070.84787
Y8 =	0.00000
Y25 =	6391.64584
X9	1.89350

1988 System Response

X1 =	.37380	Y11 =	0.00000	Y20 =	83.67980
X2 =	.17510	Y12 =	0.00000	Y21 =	129.23800
X3 =	.81717	Y13 =	0.00000	Y22 =	139.23800
X4 =	.35800	Y14 =	0.00000	Y23 =	85.27370
Y5 =	0.00000	Y15 =	0.00000	Y24 =	129.23800
Y6 =	0.00000	Y16 =	0.00000	Y25 =	6391.64584
Y7 =	7070.84787	Y17 =	0.00000	Y26 =	0.00000
Y8 =	0.00000	Y18 =	0.00000	Y27 =	1113.37881
X9 =	1.89350	Y19 =	139.05360	Y28 =	366.98570
Y10 =	0.00000				

New Values at N + 1

Y5 =	0.00000
Y6 =	0.00000
Y7 =	7136.44165
Y8 =	0.00000
Y25 =	6449.13031
X9 =	1.91115

1990 System Response

X1 =	.37800	Y11 =	0.00000	Y20 =	85.85810
X2 =	.17630	Y12 =	0.00000	Y21 =	130.35710
X3 =	.87980	Y13 =	0.00000	Y22 =	140.61600
X4 =	.36110	Y14 =	0.00000	Y23 =	85.85810
Y5 =	0.00000	Y15 =	0.00000	Y24 =	130.35710
Y6 =	0.00000	Y16 =	0.00000	Y25 =	6449.13031
Y7 =	7136.44165	Y17 =	0.00000	Y26 =	0.00000
Y8 =	0.00000	Y18 =	0.00000	Y27 =	1123.75332
X9 =	1.91115	Y19 =	140.61600	Y28 =	370.39580
Y10 =	0.00000				

New Values at N + 1

Y5 =	0.00000
Y6 =	0.00000
Y7 =	7202.74712
Y8 =	0.00000
Y25 =	6507.35912
X9 =	1.92898

1992 System Response

X1	=	.37910	Y11	=	0.00000	Y20	=	84.84500
X2	=	.17750	Y12	=	0.00000	Y21	=	131.25960
X3	=	.88160	Y13	=	0.00000	Y22	=	141.02520
X4	=	.36360	Y14	=	0.00000	Y23	=	86.44250
Y5	=	0.00000	Y15	=	0.00000	Y24	=	131.25960
Y6	=	0.00000	Y16	=	0.00000	Y25	=	6507.35912
Y7	=	7202.74712	Y17	=	0.00000	Y26	=	0.00000
Y8	=	0.00000	Y18	=	0.00000	Y27	=	1134.24033
X9	=	1.92898	Y19	=	141.02520	Y28	=	371.15360
Y10	=	0.00000						

New Values at N + 1

Y5	=	0.00000
Y6	=	0.00000
Y7	=	7221.10270
Y8	=	0.00000
Y25	=	6543.96824
X9	=	1.93683

1994 System Response

X1	=	.38020	Y11	=	0.00000	Y20	=	85.41860
X2	=	.17870	Y12	=	0.00000	Y21	=	131.90940
X3	=	.88340	Y13	=	0.00000	Y22	=	141.43440
X4	=	.36540	Y14	=	0.00000	Y23	=	87.02690
Y5	=	0.00000	Y15	=	0.00000	Y24	=	131.90940
Y6	=	0.00000	Y16	=	0.00000	Y25	=	6543.96824
Y7	=	7221.10270	Y17	=	0.00000	Y26	=	0.00000
Y8	=	0.00000	Y18	=	0.00000	Y27	=	1138.85522
X9	=	1.93683	Y19	=		Y28	=	371.91140
Y10	=	0.00000						

New Values at N + 1

Y5	=	0.00000
Y6	=	0.00000
Y7	=	7236.10179
Y8	=	0.00000
Y25	=	6574.90178
X9	=	1.94328

1996 System Response

X1 =	.38130	Y11 =	0.00000	Y20 =	85.99220
X2 =	.17990	Y12 =	0.00000	Y21 =	132.55920
X3 =	.88530	Y13 =	0.00000	Y22 =	141.84360
X4 =	.36720	Y14 =	0.00000	Y23 =	87.61130
Y5 =	0.00000	Y15 =	0.00000	Y24 =	132.55920
Y6 =	0.00000	Y16 =	0.00000	Y25 =	6574.90178
Y7 =	7236.10179	Y17 =	0.00000	Y26 =	0.00000
Y8 =	0.00000	Y18 =	0.00000	Y27 =	1142.64747
X9 =	1.94328	Y19 =	141.84360	Y28 =	372.71130
Y10 =	0.00000				

New Values at N + 1

Y5 =	0.00000
Y6 =	0.00000
Y7 =	7251.62783
Y8 =	0.00000
Y25 =	6605.46612
X9 =	1.94973

1998 System Response

X1 =	.38240	Y11 =	0.00000	Y20 =	86.56580
X2 =	.18110	Y12 =	0.00000	Y21 =	133.20900
X3 =	.88730	Y13 =	0.00000	Y22 =	142.25280
X4 =	.36900	Y14 =	0.00000	Y23 =	88.19570
Y5 =	0.00000	Y15 =	0.00000	Y24 =	133.20900
Y6 =	0.00000	Y16 =	0.00000	Y25 =	6605.46612
Y7 =	7251.62783	Y17 =	0.00000	Y26 =	0.00000
Y8 =	0.00000	Y18 =	0.00000	Y27 =	1146.44092
X9 =	1.94973	Y19 =	142.25280	Y28 =	373.55330
Y10 =	0.00000				

New Values at N + 1

Y5 =	0.00000
Y6 =	0.00000
Y7 =	7267.95265
Y8 =	0.00000
Y25 =	6636.03273
X9 =	1.95628

2000 System Response

X1	=	.38360	Y11	=	0.00000	Y20	=	87.23500
X2	=	.18250	Y12	=	0.00000	Y21	=	133.93100
X3	=	.88900	Y13	=	0.00000	Y22	=	142.69920
X4	=	.37100	Y14	=	0.00000	Y23	=	88.87750
Y5	=	0.00000	Y15	=	0.00000	Y24	=	133.93100
Y6	=	0.00000	Y16	=	0.00000	Y25	=	6636.03273
Y7	=	7267.95265	Y17	=	0.00000	Y26	=	0.00000
Y8	=	0.00000	Y18	=	0.00000	Y27	=	1150.29326
X9	=	1.95628	Y19	=	142.69920	Y28	=	374.26900
Y10	=	0.00000						

New Values at N + 1

Y5	=	0.00000
Y6	=	0.00000
Y7	=	7282.04769
Y8	=	0.00000
Y25	=	6670.12569
X9	=	1.96304